THE EVOLUTION AND MATURATION OF TEAMS IN ORGANIZATIONS: THEORIES, METHODOLOGIES, DISCOVERIES & INTERVENTIONS,

2nd Edition

EDITED BY: Eduardo Salas, Marissa Shuffler and Michael Rosen

PUBLISHED IN: Frontiers in Psychology and Frontiers in Communication

frontiers Research Topics

Frontiers eBook Copyright Statement

The copyright in the text of individual articles in this eBook is the property of their respective authors or their respective institutions or funders. The copyright in graphics and images within each article may be subject to copyright of other parties. In both cases this is subject to a license granted to Frontiers.

The compilation of articles constituting this eBook is the property of Frontiers.

Each article within this eBook, and the eBook itself, are published under the most recent version of the Creative Commons CC-BY licence. The version current at the date of publication of this eBook is CC-BY 4.0. If the CC-BY licence is updated, the licence granted by Frontiers is automatically updated to the new version.

When exercising any right under the CC-BY licence, Frontiers must be attributed as the original publisher of the article or eBook, as applicable.

Authors have the responsibility of ensuring that any graphics or other materials which are the property of others may be included in the CC-BY licence, but this should be checked before relying on the CC-BY licence to reproduce those materials. Any copyright notices relating to those materials must be complied with.

Copyright and source acknowledgement notices may not be removed and must be displayed in any copy, derivative work or partial copy which includes the elements in question.

All copyright, and all rights therein, are protected by national and international copyright laws. The above represents a summary only. For further information please read Frontiers' Conditions for Website Use and Copyright Statement, and the applicable CC-BY licence.

ISSN 1664-8714
ISBN 978-2-88966-237-1
DOI 10.3389/978-2-88966-237-1

About Frontiers

Frontiers is more than just an open-access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers Journal Series

The Frontiers Journal Series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the Frontiers Journal Series operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to Quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews.
Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the Frontiers Journals Series: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area! Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers Editorial Office: researchtopics@frontiersin.org

THE EVOLUTION AND MATURATION OF TEAMS IN ORGANIZATIONS: THEORIES, METHODOLOGIES, DISCOVERIES & INTERVENTIONS,
2nd Edition

Topic Editors:
Eduardo Salas, Rice University, United States
Marissa Shuffler, Clemson University, United States
Michael Rosen, Johns Hopkins Medicine, United States

Publisher's note: In this 2nd edition, the following article has been added: Shuffler ML, Salas E and Rosen MA (2020) The Evolution and Maturation of Teams in Organizations: Convergent Trends in the New Dynamic Science of Teams. *Front. Psychol.* 11:2128. doi: 10.3389/fpsyg.2020.02128

Citation: Salas, E., Shuffler, M., Rosen, M., eds. (2020). The Evolution and Maturation of Teams in Organizations: Theories, Methodologies, Discoveries & Interventions, 2nd Edition. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-88966-237-1

Table of Contents

05 ***Visualized Automatic Feedback in Virtual Teams***
Ella Glikson, Anita W. Woolley, Pranav Gupta and Young Ji Kim

16 ***Organizational Meeting Orientation: Setting the Stage for Team Success or Failure Over Time***
Joseph E. Mroz, Nicole Landowski, Joseph Andrew Allen and Cheryl Fernandez

28 ***There is Light and There is Darkness: On the Temporal Dynamics of Cohesion, Coordination, and Performance in Business Teams***
Pedro Marques-Quinteiro, Ramón Rico, Ana M. Passos and Luís Curral

45 ***Using State Space Grids for Modeling Temporal Team Dynamics***
Annika L. Meinecke, Clara S. Hemshorn de Sanchez, Nale Lehmann-Willenbrock and Claudia Buengeler

61 ***The Emergence of Group Potency and its Implications for Team Effectiveness***
Hayden J. R. Woodley, Matthew J. W. McLarnon and Thomas A. O'Neill

74 ***Teams in a New Era: Some Considerations and Implications***
Lauren E. Benishek and Elizabeth H. Lazzara

89 ***What We Know About Team Dynamics for Long-Distance Space Missions: A Systematic Review of Analog Research***
Suzanne T. Bell, Shanique G. Brown and Tyree Mitchell

110 ***A Bottom Up Perspective to Understanding the Dynamics of Team Roles in Mission Critical Teams***
C. Shawn Burke, Eleni Georganta and Shannon Marlow

126 ***Advancing Teams Research: What, When, and How to Measure Team Dynamics Over Time***
Fabrice Delice, Moira Rousseau and Jennifer Feitosa

146 ***Understanding Team Learning Dynamics Over Time***
Christopher W. Wiese and C. Shawn Burke

160 ***A Team Training Field Research Study: Extending a Theory of Team Development***
Joan H. Johnston, Henry L. Phillips, Laura M. Milham, Dawn L. Riddle, Lisa N. Townsend, Arwen H. DeCostanza, Debra J. Patton, Katherine R. Cox and Sean M. Fitzhugh

173 ***Laborious but Elaborate: The Benefits of Really Studying Team Dynamics***
Michaela Kolbe and Margarete Boos

189 ***Beyond Separate Emergence: A Systems View of Team Learning Climate***
Jean-François Harvey, Pierre-Marc Leblanc and Matthew A. Cronin

201 ***Learning From the Past to Advance the Future: The Adaptation and Resilience of NASA's Spaceflight Multiteam Systems Across Four Eras of Spaceflight***
Jacob G. Pendergraft, Dorothy R. Carter, Sarena Tseng, Lauren B. Landon, Kelley J. Slack and Marissa L. Shuffler

224 ***Advancing Our Understandings of Healthcare Team Dynamics From the Simulation Room to the Operating Room: A Neurodynamic Perspective***
Ronald Stevens, Trysha Galloway and Ann Willemsen-Dunlap

238 ***The Evolution of Human-Autonomy Teams in Remotely Piloted Aircraft Systems Operations***
Mustafa Demir, Nathan J. McNeese and Nancy J. Cooke

250 ***Adaptive Team Performance: The Influence of Membership Fluidity on Shared Team Cognition***
Wendy L. Bedwell

265 ***The Behavioral Biology of Teams: Multidisciplinary Contributions to Social Dynamics in Isolated, Confined, and Extreme Environments***
Lauren Blackwell Landon, Grace L. Douglas, Meghan E. Downs, Maya R. Greene, Alexandra M. Whitmire, Sara R. Zwart and Peter G. Roma

285 ***The Evolution and Maturation of Teams in Organizations: Convergent Trends in the New Dynamic Science of Teams***
Marissa L. Shuffler, Eduardo Salas and Michael A. Rosen

frontiers in Psychology

ORIGINAL RESEARCH
published: 16 April 2019
doi: 10.3389/fpsyg.2019.00814

Visualized Automatic Feedback in Virtual Teams

Ella Glikson[1], Anita W. Woolley[1], Pranav Gupta[1] and Young Ji Kim[2]*

[1] Tepper School of Business, Carnegie Mellon University, Pittsburgh, PA, United States, [2] Department of Communication, University of California, Santa Barbara, Santa Barbara, CA, United States

Management of effort is one of the biggest challenges in any team, and is particularly difficult in distributed teams, where behavior is relatively invisible to teammates. Awareness systems, which provide real-time visual feedback about team members' behavior, may serve as an effective intervention tool for mitigating various sources of process-loss in teams, including team effort. However, most of the research on visualization tools has been focusing on team communication and learning, and their impact on team effort and consequently team performance has been hardly studied. Furthermore, this line of research has rarely addressed the way visualization tool may interact with team composition, while comprehension of this interaction may facilitate a conceptualization of more effective interventions. In this article we review the research on feedback in distributed teams and integrate it with the research on awareness systems. Focusing on team effort, we examine the effect of an effort visualization tool on team performance in 72 geographically distributed virtual project teams. In addition, we test the moderating effect of team composition, specifically team members' conscientiousness, on the effectiveness of the effort visualization tool. Our findings demonstrate that the effort visualization tool increases team effort and improves the performance in teams with a low proportion of highly conscientious members, but not in teams with a high proportion of highly conscientious members. We discuss the theoretical and practical implications of our findings, and suggest the need of future research to address the way technological advances may contribute to management and research of team processes.

Keywords: virtual team, task effort, feedback, team composition, conscientiousness, awareness systems

OPEN ACCESS

Edited by:
Eduardo Salas,
Rice University, United States

Reviewed by:
Jamie Gorman,
Georgia Institute of Technology, United States
Wendy L. Bedwell,
PACE Consulting Solutions, United States

****Correspondence:***
Ella Glikson
ella.glikson@gmail.com

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *30 October 2018*
Accepted: *26 March 2019*
Published: *16 April 2019*

Citation:
Glikson E, Woolley AW, Gupta P and Kim YJ (2019) Visualized Automatic Feedback in Virtual Teams. Front. Psychol. 10:814. doi: 10.3389/fpsyg.2019.00814

INTRODUCTION

Measuring and managing the relative effort of contributors to a shared outcome is among the oldest problems in psychology (Triplett, 1898; Ringelmann, 1913). With the advent of technology and growth in technology-mediated collaboration in teams, the problem gets more complicated. Advances in information and communication technologies and continuing globalization keep

facilitating the growing reliance of organizations on geographically dispersed virtual teams (Marlow et al., 2017). Geographical dispersion suggests dependence on technology for team communication and teamwork, which has dramatically changed team dynamics and processes (Breuer et al., 2016). Despite the significant use of geographically-dispersed virtual teams in organizations for tasks that require diverse expertise, knowledge and resources, the questions regarding how to enhance their performance are still open (Gilson et al., 2014).

One of the biggest challenges that dispersed virtual teams face is the management of team members' effort (Peñarroja et al., 2017). The low visibility of team members' individual contribution suggests a difficulty for social comparison and for monitoring and evaluation of each other's effort. Under these circumstances team members might withhold their contribution to teamwork, resulting in significant process loss, or what is also known as social loafing (Ingham et al., 1974; Harkins and Szymanski, 1989).

Past research has demonstrated that feedback can be useful for increasing team motivation and reducing social loafing within distributed teams (Chidambaram and Tung, 2005). However, most of the current literature on feedback in teams suggests that it is very subjective and is typically given in a relatively complex one-time intervention that requires a focused session of team reflection to be effective (Konradt et al., 2015; Peñarroja et al., 2017). The relatively high cost (in terms of time and effort) and low effectiveness of existing feedback systems suggests a need for alternative ways of increasing team members' motivation and effort.

Awareness tools may meet this need. For instance, the evolving literature on team awareness in collaborative learning suggests that dynamic tools that allow the members of dispersed teams to learn about the timing of each other's activities and contributions may significantly improve team coordination and learning (Leinonen et al., 2005; Bodemer and Dehler, 2011; Buder, 2011). However, in these studies, awareness tools were mostly used for reflecting upon team members' relative contribution to communication (DiMicco et al., 2007; Janssen et al., 2011), and have produced inconsistent findings (Jermann and Dillenbourg, 2008). Following this evolving line of research we suggest that using a shared, automatic, effort visualization tool that reflects member participation may regulate team members' effort, thereby reducing social loafing and contributing to team performance.

Furthermore, we argue that such automatic feedback may not be useful for all teams, and that team composition will moderate its effectiveness. Specifically, we suggest that for teams with higher internal motivation (as a result of team members' high conscientiousness), an effort visualization tool, aimed to increase external motivation, will be less effective than for teams with low internal motivation. To test our hypotheses regarding the effect of an effort visualization tool on team effort and performance, and the moderating role of team members' internal motivation on the relations between the tool and team effort, we conducted an experiment. We examined the effect of the tool on the effort and performance of geographically distributed MBA students as they worked together on the Test of Collective Intelligence (TCI: Kim et al., 2017), a set of synchronous games designed to measure how well a group works together. As the teams completed the TCI we tested the moderating role of team members' conscientiousness on the impact of the effort visualization tool on team effort and performance. In the next section we review past research on task effort, awareness tools, feedback, and team members' internal motivation. By integrating these different streams of research and providing an empirical test of the proposed model, this article suggests a new approach for both researching and intervening in the distribution of effort in teams.

Task Effort

Effort is a limited-capacity resource that could be allocated to a range of task-relevant and task-irrelevant activities (Yeo and Neal, 2004). Management research has long connected employees' investment of intense task-relevant effort to successful job performance (Hackman, 1987; Blau, 1993; Byrne et al., 2005; Salas et al., 2005). In investigating the motivational factors leading to individuals' tendency to invest or withhold task-relevant effort in teams, research has addressed both team composition, or the individual traits that enhance motivation and task-related effort (van Vianen and De Dreu, 2001; Judge and Ilies, 2002; LePine, 2003), as well as the characteristics of the social context (Latané, 1981; Kidwell and Bennett, 1993).

Chief among the team composition factors investigated with respect to effort is the individual characteristic of conscientiousness, shown to affect both motivation and task-oriented effort (Bell, 2007). Conscientiousness has been found to correlate with commitment, diligence, performance motivation and self-regulation in individual work and in collaboration (Humphrey et al., 2007; Kelsen and Liang, 2018). In terms of social context influence, despite the positive motivational aspect of conducting work in a group setting (Hart et al., 2004), research has demonstrated that the social context of teams, where others can do the work, tends to reduce individuals' effort (Ingham et al., 1974). The tendency to make less effort when working in a team in comparison to working alone is known as social loafing (Latané et al., 1979).

Social loafing might vary across teams and is highly dependent on team characteristics such as team members' geographic dispersion (Chidambaram and Tung, 2005; Blaskovich, 2008), which makes members more anonymous and their contributions less observable. The growing use of geographically dispersed virtual teams in contemporary organizations highlights the need to better understand the phenomenon of social loafing in this setting and effective ways to decrease it.

Task Effort in Distributed Teams

Past research has identified several reasons behind the increased tendency of team members to withhold effort in distributed teams. For instance, Chidambaram and Tung (2005) suggested that the negative impact of team members' dispersion on effort could be explained by the immediacy gap. Building upon Social Impact Theory (Latané, 1981) and research on social loafing (Kidwell and Bennett, 1993), Chidambaram and Tung argued that when members of a group become more isolated (and

hence less immediate) their participation in and contribution to a group decreases. The immediacy gap relates to the difficulty in making social comparisons, which in turn decreases the salience of other members and their actions (Weisband, 2002). Comparing between collocated and dispersed virtual teams, Chidambaram and Tung (2005) found that physical dispersion, while not affecting the quality of the ideas teams produced, decreases the team members' effort - the relative quantity of the produced ideas per team member, which in turn harms decision quality (performance).

Blaskovich (2008), also building upon Social Impact theory, suggested that the reliance on technology in distributed teams decreases the social impact and thus allows team members to disengage from the group, assuming the disengagement is not visible. Blaskovich (2008) found lower cognitive effort among members of the distributed teams in comparison to collocated teams. The time spent on the task did not differ, yet members in the dispersed teams were less attentive to the details of the task, and reported investing less effort.

Alnuaimi et al. (2010) followed Karau and Williams (1993) model of "collective effort," as well as Bandura's notion of moral disengagement (Bandura et al., 1996) and directly examined three possible mechanisms that might explain the impact of geographical dispersion on the tendency to withhold effort: attribution of blame, diffusion of responsibility and dehumanization. Their findings suggest that social loafing, driven by team members' dispersion, was partially mediated by the dehumanization of the other team members, which was driven by the low identifiability of the distant teammates.

While team members' relative anonymity may play an essential role in the low social presence of distant teammates and the consequent withholding of effort, the specific focus of the social comparisons and monitoring may also be essential (Salas et al., 2000). For instance, Mulvey and Klein (1998) argued that the actual withholding of effort may differ from the perceived team effort, with perceptions being the main driver of team motivation. Reasoning that team members might be particularly averse to carrying the workload while others free ride (Kerr, 1983), Mulvey and Klein (1998) found a significant negative relationship between perceived social loafing and team performance.

In a similar vein, Peñarroja et al. (2017) suggested that the inability of distributed team members to observe and monitor each other's actual effort leads to greater reliance on assumptions and perceptions, which could be biased and erroneously negative. Researchers also noted that in order to correct the inaccuracy of the perceptions of social loafing thereby decreasing the overall withholding of effort and increasing team performance, teams need trustworthy feedback regarding its' effort-related processes (Geister et al., 2006; Peñarroja et al., 2017).

Team Feedback in Distributed Teams

Team feedback is defined as communication of information provided by (an) external agent(s) concerning actions, events, processes, or behaviors relative to task completion or teamwork (Gabelica et al., 2012). Performance feedback is conceptualized as the provision of information about individual or group outcomes, and process feedback is defined as information regarding the way one is performing a task, and thus relates to team dynamics, including team effort (Salas et al., 2012). Despite the overall value of feedback for increasing team effort and performance, its effectiveness is known to be limited (Kluger and DeNisi, 1996). Performance feedback in geographically dispersed teams has been explored with the intention to overcome the relative anonymity of individual effort driven by geographical dispersion. For instance, Fang and Chang (2014) looked at the effect of performance feedback, but found no significant difference between the outcomes of identifiable versus unidentifiable (anonymous) contributors. Similarly, Suleiman and Watson (2008) did not find an effect of identifiability or performance feedback on team members' social loafing. Looking into the elements of social comparison, Chen et al. (2014) found that feedback regarding others' high performance increased the effort of those whose contribution was identifiable, but not for unidentifiable participants.

As geographical distribution impacts the visibility of team members' effort and motivation, Geister et al. (2006) suggested that process feedback could be especially useful for assessing others' contribution, and thus minimizing social loafing. Peñarroja et al. (2017) provided feedback on both performance and process, and helped participants to understand the feedback via a session of guided reflexivity. They found that feedback decreased the perceptions of social loafing, which in turn increased team cohesion. Geister et al. (2006) tested the effect of an online process feedback system on team members' motivation and performance. Their findings demonstrate that process feedback is useful for increasing trust and the effort of the least motivated team member (Geister et al., 2006).

A recent review of the impact of process and performance feedback recognized specific limitations to the efficiency of feedback, such as feedback timing, level of sharedness and feedback valence (Gabelica et al., 2012). Delayed feedback has less impact on team motivation than immediate feedback (e.g., Kerr et al., 2005). Feedback information only available to specific individual team members is less effective than feedback available to all team members (e.g., Barr and Conlon, 1994). And feedback communicated with a negative tone has been shown to have a negative effect on team processes (e.g., Peterson and Behfar, 2003).

While most of the studies on the effect of feedback were conducted in collocated teams, the technology that supports collaboration among geographically-dispersed team members may provide feedback that overcomes these limitations. Specifically, collaborative platforms may provide a vehicle for process feedback that (1) is automatically generated as team interaction is happening, and therefore is immediate; (2) is displayed on the shared platform, and thus is accessible to all team members; and (3) is visual, in that it does not rely on specific wording that often reflects a positive or negative tone. Existing research on this type of feedback to date has been conducted largely by researchers in education and technology, who examine the impact of awareness systems on team learning and communication in classroom settings. In the next section we provide a short review of this literature, and highlight the

opportunity it provides for understanding the effect of feedback on effort and social loafing in geographically distributed teams.

Team Awareness Systems and Visualization Tools

Team awareness refers to the ability to know what is going on in a team in real time. It helps the development of dynamic knowledge that is acquired and maintained via interactions within a team, and as a secondary goal, it aims to reflect process and assists in accomplishing a task (Gutwin and Greenberg, 2002, p. 416). Team awareness systems were developed to overcome the limitations of dispersed learning teams that use technology to communicate, thereby improving team processes and outcomes. Aiming to bring to awareness the hidden or unconscious team members' behaviors, such as dominating a team conversation, team awareness systems are mostly used in the field of computer-supported collaborative work (CSCW, Gutwin and Greenberg, 2002) computer-supported collaborative learning (CSCL, Bodemer and Dehler, 2011) and group support systems (GSS, Dennis, 1996). However, the GSS research has rarely addressed the impact of team awareness on team effort or performance (Briggs et al., 2003).

Many awareness systems use visualization tools, as visualization produces an easier way to display and interpret complex and extensive information than verbal description (Ware, 2005). Specifically, visualization is typically used to reflect relative team member participation in communication-related activities (Janssen et al., 2007, 2011; Jermann and Dillenbourg, 2008; Kim et al., 2012). For instance, DiMicco et al. (2004) showed participants a graph that reflected the relative participation of each team member in a discussion. Jermann and Dillenbourg (2008) compared the effect of tools which reflected the relative or cumulated team members' contribution to a specific discussion topic. Streng et al. (2009) created a visualization of the quality of a discussion, measuring it in comparison to a pre-scripted discussion structure. They compared a diagram-like visualization that included graphs and figures, with a metaphoric picture, in which objects represented the discussants' roles (Streng et al., 2009). Similarly, Leshed et al. (2010), also aiming to reflect discussion quality, visualized the relative use of specific words categorized to themes, such as emotional or self-reference words, and compared the effect of visualization by bar-charts with visualization via an animated image.

Despite the common notion that visualizations mirror team participation across these studies, the empirical findings vary with respect to their effect on regulating effort and performance. For example, aiming to reach more equality in discussion, and examining the discourse of collocated teams, DiMicco et al. (2004) found that presenting the relative team members' contribution to a discussion significantly reduced the amount of speech of the most active team member, but had no effect on the least active team member. Kim et al. (2012) examined collocated and distributed teams, and found that a representation of team members' relative contribution to a conversation increased the overall discussion volume, and improved the level of cooperation among distributed team members. Similarly, Janssen et al. (2011) examined the effect of time that team members spent looking at the participation visualization, and found that time spent with the tool increased the amount of participation in online discussion, as well as the equality of participation among the team members, however, no effect was found on the actual team performance. Streng et al. (2009) found that metaphoric representation was more effective than chart-like representation and led to a quicker change in undesirable behavior. In contrast, Jermann and Dillenbourg (2008) did not find any effect of a visualization tool.

These inconsistencies draw attention to several distinctions among the mentioned visualization tools. The first distinction relates to the subjective versus objective reflection of teamwork. While some studies presented participants with the reflection of their actual measured level of participation (e.g., Janssen et al., 2007), others presented team members with subjective perceptions of participation (Geister et al., 2006). The subjective perception (peer feedback), though highly important, does not allow for a continuous immediate reflection of one's own action, and as a result of subjectivity could be viewed as biased and distrusted by team members. The second distinction refers to how behavior was represented; some of the tools emphasized the amount of actual behavior (Janssen et al., 2007), thus increasing awareness of team processes, while others were more focused on the gap between the actual and the desirable behaviors for the task at hand (e.g., Streng et al., 2009). The establishment of a normative standard to which to compare team behavior interjects the same drawbacks that exist for more traditional verbal feedback: elements of subjectivity and context specificity. In contrast, automatic visualization of self and others' effort should provide a more objective, valence-free feedback that increases team awareness, with less backlash due to a sense of subjectivity or manipulation. Over-complexity or over-gamification of the representation could also be a drawback, as it may draw more attention toward understanding the tool than to the actual teamwork (Leshed et al., 2010).

Balanced discussion that aims at equally distributed communication means reducing the contribution of the over-participator (DiMicco et al., 2004). In contrast, balancing team members' effort on the work itself aims at reducing social loafing, which potentially means increasing the contribution of all team members, and especially the least contributing member. Thus, we suggest that automatic and dynamic visualization of team members' actual task-related effort will increase team members' awareness of other members' effort, and serve as an external motivator to increase the overall level of team task-related effort.

> H1: A visualization of the relative team members' effort will increase overall team effort.

The Moderating Role of Team Composition

Examining feedback on the individual and team levels, researchers have long conceptualized that the effectiveness of feedback depends on team composition (e.g., DeShon et al., 2004). Team members' abilities and predispositions influence

both the actual team processes, as well as the ability to adjust to feedback. These differences could partially explain the inconsistency of feedback effectiveness documented in previous studies (Kluger and DeNisi, 1996). Nevertheless, existing team research has rarely studied the interaction of feedback and team composition.

Technological development facilitates the evolution of support systems, which are capable of visualizing team members' effort. These capabilities provide a relatively easy and inexpensive way to increase team awareness in distributed teams. In addition, this mode of feedback can be easily altered and managed, such as by switching it on or off, or moving from team to individual level and vice versa. Thus, the use of such a tool could be adjusted to a specific team, taking into consideration team members' predisposition and their initial motivation.

Building on the demonstrated importance of intrinsic motivation for reducing social loafing and increasing team effort (George, 1992), team composition researchers have looked at team members' personality trait of conscientiousness (Bell, 2007; Hoon and Tan, 2008). Conscientiousness refers to the extent to which a person is self-disciplined and organized (Costa and McCrae, 1992), and has been found as the most consistent predictor of individual performance (Hurtz and Donovan, 2000; Salgado, 2003). Peeters et al. (2006) meta-analysis supported the claim that team members' conscientiousness is positively related to team performance in professional and student teams. Looking to explain the mechanism through which conscientiousness influences team performance, researchers found that it is negatively related to social loafing (Ferrari and Pychyl Timothy, 2012; Schippers, 2014). Furthermore, Schippers (2014) found that teams with high levels of conscientiousness were able to overcome the negative effects of social loafing, as highly conscientious members compensated for the lack of effort of other teammates. This means that teams with a high proportion of conscientious members may demonstrate high levels of motivation and effort regardless of the visibility of their and other members' effort. George (1992) demonstrated that when intrinsic motivation was low, task visibility significantly lowered social loafing. However, when intrinsic motivation was high, task visibility had no effect on team effort. Bringing these lines of research together, we suggest that effort visualization tools represent a way to enhance team extrinsic motivation via social comparison, and team members' conscientiousness represents team members' internal motivation. Thus, teams with a majority of members low in conscientiousness will have lower internal motivation and are likely to benefit more from an extrinsic motivation-inducing visualization of team effort, than teams where most members are high in conscientiousness. Raising awareness of the effort of other members can augment the motivation of members who are low in conscientiousness and reduce the withholding of task-oriented effort.

> H2: The impact of an effort visualization tool on team effort will be moderated by team composition, such that the effort visualization tool will increase team effort in teams with a low number of highly conscientious members, but not in teams where most members are highly conscientious.

Building on the literature that connects effort to team performance (Hackman, 1987; Yeo and Neal, 2004; Byrne et al., 2005), we suggest that by increasing team members' effort, a visualization tool focused on team effort will contribute to team performance. However, this effect will be moderated by team composition. Thus, we predict the following:

> H3: The impact of an effort visualization tool on performance will be mediated by team effort and moderated by team composition.

MATERIALS AND METHODS

Sample and Procedure

We randomly assigned 335 MBA students to 80 distributed virtual project teams (3–4 members) as part of a cross-cultural management course. Males comprised 55% of the sample, and the average age was 29.23 years old (*SD* = 8.23). All teams had members located across different countries (geographically dispersed), with no previous familiarity. At the beginning of the project, participants individually completed a survey assessing their demographics and personality traits. As part of the team project, members of each team worked together to complete the Test of Collective Intelligence (TCI; Kim et al., 2017), which includes eight collaborative tasks. All teams were randomly assigned to one of the two conditions: effort visualization tool condition or control condition. Due to different technical problems experienced by eight teams, the final number of teams included in the study is 72. During the team task (TCI), team members' effort was objectively measured. Team performance was measured as the aggregate t performance on all of the TCI tasks[1]. The data was collected under approval of Behavioral Sciences Research Ethics Committee, Technion – Israel Institute of Technology.

Manipulations and Measures

Effort visualization tool: Building upon the Platform for Online Group Studies (POGS; Kim et al., 2017) we integrated a visual awareness system, which reflected the relative effort of team members based on the number of keystrokes they made within the task collaboration space. Whenever a team member would type within the workspace the proportion of their contribution to the team's work product was calculated relative to other team members and displayed as a bar across the top of the screen. Each team member is indicated by their unique color, which was also used to highlight the members' keystrokes in the workspace. The more a team member contributed relative to other team members, the wider their colored bar got in real time (see **Figure 1**).

Team effort was operationalized by aggregating the total number of keystrokes made by the members of a given team while interacting with the tasks comprised in the TCI. The average number of keystrokes was 1468.35 per team (*SD* = 408.86). For

[1]The data underlying the study is available per request.

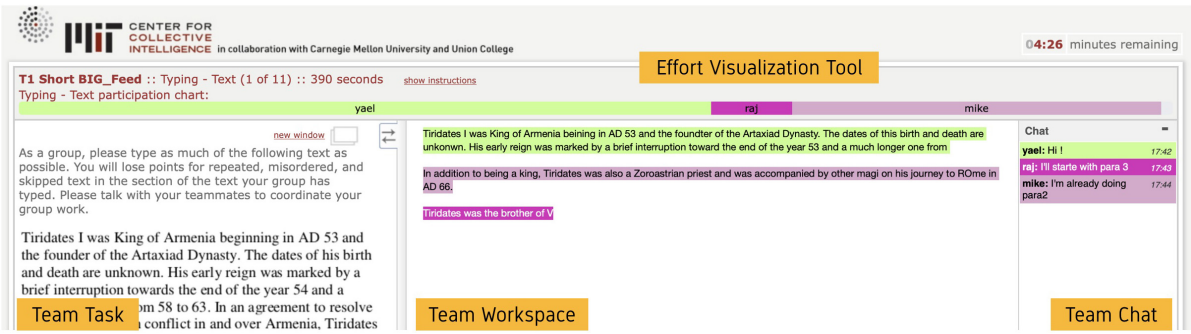

FIGURE 1 | Illustration of the effort visualization tool. The bars represent each team member by color and the name. Bars automatically change their width based on the relative effort operationalized as the real-time count of valid keystrokes.

correlations of the measure with performance and other variables see **Table 1**. The average number of keystrokes made by the most contributing team member $M_{(\max)} = 566.10$ ($SD = 116.19$) which was significantly higher than the average of the keystrokes made by the least contributing team member $M_{(\min)} = 227.06$ ($SD = 156.13$) $t(71) = 16.15$, $p < 0.05$.

Performance was measured as the team's score on TCI. The TCI includes eight collaborative tasks, designed to capture diverse group processes (e.g., generating, memorizing, problem solving, and executing; Engel et al., 2014; Kim et al., 2017). For example, for the generating task, team members had to brainstorm as many ideas as they could for the usage of a brick. The memorizing task required team members to remember words placed in grids of various sizes and reproduce the word grids together. An example of problem solving tasks includes solving matrix reasoning puzzles similar to Raven's Progressive Matrices. To measure teams' executing process, we used a typing task where teams had to copy as much and as accurately as possible from paragraphs of text. The TCI score is a weighted average of the teams' task scores with the weights chosen to maximize correlation with all the tasks. The measured reliability of the TCI was Cronbach's alpha = 0.68. An advantage of using the TCI to measure team performance is that it focuses on a holistic measure of groups' ability to work together across different types of tasks (teams' collective intelligence), which more reliably generalizes to and predicts teams' future performance than performance on a single task (Kim et al., 2017).

Team composition was measured by calculating the proportion of highly conscientious team members. Conscientiousness was measured on the individual level using the FFM scale (Gosling et al., 2003). The measured reliability of the scale was Cronbach's alpha = 0.71. The sample of participants was (median) split into two categories: highly and low conscientiousness (*Median* = 4, on 5 items Likert-like scale; 1 - not at all, 5 - to a great extent; $M = 3.95$, $SD = 0.83$). After categorizing individual participants, the proportion of highly conscientiousness members was calculated for each team. This has been shown to be a better representation of the presence of a trait in a team compared to looking at team mean levels as it factors in the number of different people who possess the trait at a high or low level (for similar procedure, see Miron-Spektor et al., 2011).

Control variables used in analyses included the number of team members (3 or 4), proportion of females in the team and team members' level of English proficiency (measured by self-evaluation, 1 = not proficient; 7 = fluent, overall average = 6.08).

RESULTS

Descriptive statistics and correlations among variables are presented in **Table 1**.

TABLE 1 | Means, standard deviations and correlations (team-level variables).

	Mean	*SD*	1	2	3	4	5	6
(1) Performance	0.01	0.51						
(2) Effort visualization tool[1]	0.49	0.50	0.09					
(3) Team effort	1468.35	408.86	0.46**	0.29*				
(4) Team composition[2]	0.36	0.28	−0.04	−0.13	−0.06			
(5) Team size	3.88	0.33	0.29*	0.03	0.14	0.04		
(6) Proportion of females	0.36	0.28	−0.25*	−0.07	0.05	0.19	−0.19	
(7) English proficiency	6.17	0.40	0.26*	−0.01	0.18	−0.13	−0.03	0.04

*$p < 05$; **$p < 0.01$. $N = 72$. Team performance was standardized according to the TCI procedure (Kim et al., 2017).*
[1]Effort visualization tool is a binary indicator of our experimental manipulation (0 = not present, 1 = present) and therefore correlations with this variable are Point-Biserial correlations; all remaining correlations are Pearson Bivariate.
[2]Team composition is indexed here as proportion of highly conscientious members.

TABLE 2 | Hierarchical regression model for team effort.

	Model 1 (Controls)	Model 2	Model 3	Model 4
Team size	0.163	0.157	0.163	0.151
Proportion of female team members	0.074	0.094	0.107	0.119
English proficiency	0.178	0.179	0.183	0.146
Effort visualization tool		0.295*	0.287*	0.647*
Team composition			−0.064	0.158
Visualization × Composition				−0.48*
F	1.41	2.84*	2.31	3.08*
p-value	0.25	0.03	0.05	0.01
R^2	0.06	0.15	0.15	0.22
Adj R^2	0.02	0.09	0.08	0.15
Significance of F change	0.25	0.01	0.59	0.02

*$p < 0.05$

The first hypothesis regarding the effect of a visualization tool on team members' effort was tested using a hierarchical regression model and revealed a significant effect of the visualization tool on team effort ($b = 239.33$, $SE = 92.48$, $p = 0.01$; see **Table 2**; Model 3). The effect of team composition on team effort was insignificant (**Table 2**; Model 3). The moderating effect of team composition (H2) was significant ($b = -826.33$, $SE = 335.99$, $p = 0.02$, see **Table 2**; Model 4).

Looking into the team composition distribution, we found that almost half of the teams (38 out or 72) had none or only one highly conscientious team member. Splitting the sample based on this characteristic allowed us to gain a better understanding of the interaction. Following Aiken and West (1991) we conducted simple slopes analysis, which revealed that for teams with a low percentage of highly conscientious members (i.e., teams with 0 or one highly conscientious team member) the impact of effort visualization tool led to a significant increase in team effort ($b = 291.94$, $SE = 131.10$, $p < 0.05$). However, for teams with a higher percentage of highly conscientious team members the impact of effort visualization tool was not significant ($b = -28.67$, $SE = 140.03$, $p = 0.84$; see **Figure 2**).

Although we did not articulate a specific hypothesis regarding the effect of the effort visualization tool on highest and lowest team contributor, we suspected that due to the visualization of the relative effort social comparisons would become easier and therefore the effort visualization would increase the effort of the lowest contributor, but not the effort of the highest contributor. Indeed the results indicate that for the highest contributor there was no significant direct effect of the effort visualization tool, and no significant moderation effect of team composition. In contrast, for the lowest contributor the direct effect of the effort visualization tool was significant [$F(1,70) = 3.69$, $p < 0.07$]; lowest contributor without the tool ($M_{(\min)} = 193.32$; $SD = 149.28$; lowest contributor with the tool ($M_{(\min)} = 262.71$; $SD = 157.36$)). The moderation effect of team composition on the effort of the lowest contributor was also significant [$F(3,68) = 4.00$, $p < 0.05$] and similar to what we found for the total amount of contribution. We observed a significant effect of the effort visualization tool on the effort of the lowest contributor for teams with a low proportion of highly conscientious members (simple slope for -1SD; $b = 110.42$, $SE = 51.47$, $p < 0.05$), and an insignificant effect of the effort visualization tool on the effort of the lowest contributor for teams with a high proportion of highly conscientious members (simple slope +1SD; $b = -14.96$, $SE = 51.62$, $p = 0.77$).

To further validate our findings we looked at the variance in effort within teams, measured as standard deviation of the effort. The effort visualization tool and proportion of highly conscientious members each had no direct effect on the variance in effort within teams, however the interaction of them was significant [$F(3,68) = 2.69$, $p < 0.07$], and revealed that effort visualization tool had a significant negative effect on the variance in effort for teams with a low proportion of highly conscientious members (simple slope for -1SD; $b = -0.04$, $SE = 0.02$, $p < 0.07$) such that the effort visualization reduces the variance in effort in teams with fewer highly conscientious members. For teams with a high proportion of highly conscientious members the effect of the effort visualization tool was insignificant (simple slope for +1SD; $b = 0.02$, $SE = 0.02$; $p = 0.24$).

The third hypothesis suggested that the impact of the visualization tool on performance will be mediated by team effort and moderated by team composition. First, we examined the effect of the effort visualization tool and team conscientiousness on team performance. The results demonstrated a similar effect as found for team effort: the interaction effect was significant [$b = 0.44$; $F(5,66) = 2.99$, $p < 0.05$]. Similar to the effect on effort, the effort visualization led to a significant increase in team performance for teams with a low percentage of highly conscientious members ($b = 0.35$, $SE = 0.17$, $p < 0.05$), but not for teams with high percentage of highly conscientious members ($b = -0.20$, $SE = 0.18$, $p = 0.14$). The moderated mediation model was tested using bootstrap sampling produced by PROCESS macro in SPSS (Model 7; Hayes, 2013) and was significant [$F(6,65) = 2.72$, $p < 0.05$, $R^2 = 0.20$]. Specifically the mediation was significant for teams with a low proportion of highly conscientious team members [CI 95% $b = 545.64$, $SE = 150.71$, $p < 0.001$, *LL-UL* (244.64; 846.64)], but not for teams with a high proportion of highly conscientious members [CI 95% $b = -116.75$, $SE = 162.10$, $p = 0.47$, *LL-UL* (−44.48; 206.88)].

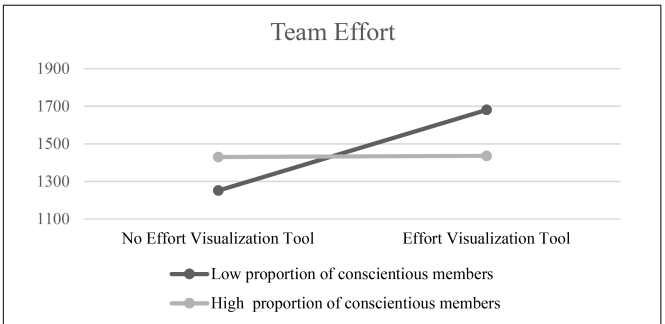

FIGURE 2 | The moderating effect of team composition on the impact of effort visualization tool on team members' effort.

DISCUSSION

The management of task-oriented effort in teams provides a great challenge for managers and researchers. While process feedback remains the most effective intervention for inducing task-oriented effort (Peñarroja et al., 2017), its availability and delivery could dramatically change, based on current technological developments (Streng et al., 2009; Leshed et al., 2010). Integrating the knowledge of the importance of one's perceptions for regulating self-effort (e.g., Mulvey and Klein, 1998), with the literature on computer-mediated collaboration awareness systems (e.g., Bodemer and Dehler, 2011), this study demonstrated a way the visualization of team member effort may serve to provide efficient and effective process feedback.

In addition, incorporating team composition research that suggests the impact of team members' traits on team motivation and effort (e.g., Bell, 2007), we theorized and found a moderating role of team members' conscientiousness on the effect of the visualization tool on team effort and performance. Specifically, we found that the visualization tool was effective for teams with a low proportion of highly conscientious members, but not for teams with a high proportion of highly conscientious members. Thus, we have also demonstrated a boundary condition for this type of process feedback, based on team composition characteristics. We suggest that our study serves as an example for effective visualized process feedback, which when targeted appropriately based on team composition, may facilitate the effort and performance in geographically distributed virtual teams.

This study makes several theoretical contributions. First, it bridges several research streams which address task effort from different perspectives. By integrating the literature on social loafing (Chidambaram and Tung, 2005), team perceptions (Peñarroja et al., 2017), and feedback and awareness systems (e.g., Janssen et al., 2011), we demonstrated the positive role that automatic visualization may play in facilitating task effort. Research on social loafing addresses the role of social comparison, identification and fairness in understanding one's effort in the context of teamwork (Mulvey and Klein, 1998; Alnuaimi et al., 2010). Illuminating these subjective processes, this line of research suggests a need for external intervention, which may influence or correct these perceptions via feedback (Peñarroja et al., 2017; Salas et al., 2008). However, the external facilitation required to produce effective integration of traditional feedback might limit its use due to the associated effort and cost required. At the same time, technological developments give us the ability to produce automatic visualized feedback (DiMicco et al., 2004; Jermann and Dillenbourg, 2008). This type of feedback has been studied mostly by education and technology researchers, and has not yet gained popularity among teams' researchers. Integrating these new developments within the existing streams of research opens an opportunity for future research that may suggest different conceptualizations and operationalizations of process feedback, reflecting both the available technology and the aggregated past knowledge.

In addition, this study draws on the team composition literature (Peeters et al., 2006; Bell, 2007; Kelsen and Liang, 2018), and illustrates the need to address team composition when considering feedback interventions, by examining the moderating effect of team members' conscientiousness on the effectiveness of the visualization tool. While technological developments open up the possibility of providing feedback in automated ways, such an approach requires strong and empirically-supported theories demonstrating the fit of feedback tools to a given team composition. Integrating these lines of research would allow for a better understanding of the interaction between internal and external motivations within a team, and their implications for team processes and performance.

Finally, this study emphasizes the importance of team processes and the potential for process feedback. The developing technology enables researchers and leaders to capture different aspects of team process, such as team effort, which were previously largely tacit and unobservable or solely reliant on team self-report. Embracing these abilities may contribute to a more profound understanding of team process and its responsiveness to process feedback.

Practical Implications

This study suggests two main practical implications. First, it presents how visualization of team members' effort may reduce social loafing in distributed virtual teams. Using an automatic visualization may encourage team members to put more effort into their work, decreasing the misperceptions regarding other members' under-participation. The use of such a tool could be especially effective for encouraging the effort of the least contributing member of the team (Geister et al., 2006).

In more general terms, technology provides new ways for capturing, measuring and managing team members' effort. While in the past, effort was an elusive factor that was highly difficult to measure, today any computerized work allows for the possibility that effort could be objectively assessed and managed (e.g., Google Docs' edit history, Slack's workspace data). Nevertheless, it is important to note that technology use in teams can also activate negative mechanisms, producing adversarial and unintended consequences (Marjchrzak et al., 2013; Ter Hoeven et al., 2016). Effort does not always lead to better performance, and an abuse of "effort management" using technology may lead to loss of motivation, reactance, and unproductive behaviors. Therefore, there is a need for future research to suggest and test the effectiveness as well as the limitations of using technology to manage effort.

Our second practical implication relates to the need to fit process feedback to a team's composition. As team facilitation in general and feedback in particular become more automated, there are more opportunities to address the specific needs of a team, based on its members' characteristics. Our study demonstrates that the same effort visualization tool that is effective for teams with a low proportion of highly conscientious members is totally ineffective for teams with a high proportion of highly conscientious members. It is also possible that under some conditions, the same feedback will have the opposite effect. Looking into the future of team management, there is a growing need to understand what type of feedback would be more effective for different types of teams.

Limitations and Future Research

This study provides an integration of different lines of research and an empirical study that demonstrated the effect of an effort visualization tool on team effort and performance. On a general note, visualization tools aimed to raise team members' awareness may increase the overall sense of being observed, and thus might lead to increased effort simply due to the mere presence of an observer, or, on the flip side may evoke participant reactivity. Here, in the context of our laboratory study, all participants were being "observed," only the additional information about relative effort was manipulated, and the response to that observation was indeed the effect of interest. Conversely, participant reactivity may lead to mixed results, including negative feelings, and to an intentional withholding of effort. In this study, we did not observe such reactions, as could be evident from the additional analyses described which demonstrated an overall increase in effort related to the effort visualization tool, along with a decrease in variance in team members' effort. However, future studies need to address this possibility, and examine the factors which may evoke such reaction.

An additional limitation of this study relates to the fact that the visualization tool was used during a short-term intervention. Future research should examine the long-term effects of an effort visualization tool, to realize its potential for learning, as well as the potential habituation that could occur if it was present in an ongoing way.

In addition, automation provides a range of different types of visualization and presentation (Janssen et al., 2007; Jermann and Dillenbourg, 2008; Streng et al., 2009). In this study we tested only one way of visualizing the relative effort in teams. The evolving research on awareness systems had started to address the different aspects of visualization, such as use of metaphoric representation or animated images (e.g., Leshed et al., 2010). However, more interdisciplinary research is needed to address both the psychological and perception-related aspects of team reflection.

While we focused on team members' conscientiousness due to its relation to team members' internal motivation, other aspects of team composition may also play an important role for team members' acceptance of visualized team effort. For instance, team members with more independent self-construal (Triandis, 1989) might be less responsive to the relative representation of team effort than team members with more interdependent self-construal. Furthermore, the timing of the intervention could also serve as a moderating factor. In some teams it could be useful to reflect the effort at the initial stage of teamwork, while in others, it could be more efficient to introduce such feedback after the initial relationships in team have been established.

CONCLUSION

The purpose of this study was to present a developing area for the management of team effort via team visualization tools, thereby integrating new and more established lines of research from different disciplines, and to empirically test the effect of one such tool on effort and performance in geographically distributed teams. Consistent with our hypotheses, we found that the effect of team effort visualization tool was moderated by team composition, demonstrating that only teams with a low proportion of highly conscientious members benefited from the visualization. Integrating different lines of research, we demonstrate the way new technology enables objective, immediate, and visual process feedback, which may improve effort in geographically-distributed teams, and the way team composition moderates the effect of such feedback on team effort and consequently on team performance.

ETHICS STATEMENT

The data was collected under approval of Behavioral Sciences Research Ethics Committee, "Technion – Israel Institute of Technology."

AUTHOR CONTRIBUTIONS

EG, AW, PG, and YK contributed conception and design of the study. YK and PG made part of the statistical analyses. EG and AW wrote the first draft of the manuscript.

FUNDING

This work was supported by the U.S. Army Research Laboratory, the U.S. Army Research Office grant number W911NF-16-1-0005, and DARPA grant number W911NF-17-1-0104.

REFERENCES

Aiken, L. S., and West, S. G. (1991). *Multiple Regression: Testing and Interpreting Interactions*. Thousand Oaks, CA: SAGE Publications.

Alnuaimi, O. A., Robert, L. P., and Maruping, L. M. (2010). Team size, dispersion, and social loafing in technology-supported teams: a Perspective on the theory of moral disengagement. *J. Manag. Inform. Syst.* 27, 203–230. doi: 10.2753/MIS0742-1222270109

Bandura, A., Barbaranelli, C., Caprara, G. V., and Pastorelli, C. (1996). Mechanisms of moral disengagement in the exercise of moral agency. *J. Pers. Soc. Psychol.* 71, 364–374. doi: 10.1037/0022-3514.71.2.364

Barr, S. H., and Conlon, E. J. (1994). Effects of distribution of feedback in work groups. *Acad. Manag. J.* 37, 641–655. doi: 10.5465/256703

Bell, S. T. (2007). Deep-level composition variables as predictors of team performance: a meta-analysis. *J. Appl. Psychol.* 92, 595–615. doi: 10.1037/0021-9010.92.3.595

Blaskovich, J. L. (2008). Exploring the effect of distance: an experimental investigation of virtual collaboration, social loafing, and group decisions - proquest. *J. Inform. Syst.* 12, 27–46. doi: 10.2308/jis.2008.22.1.27

Blau, G. (1993). Operationalizing direction and level of effort and testing their relationships to individual job performance. *Organ. Behav. Hum. Decis. Process.* 55, 152–170. doi: 10.1006/OBHD.1993.1028

Bodemer, D., and Dehler, J. (2011). Group awareness in CSCL environments. *Comput. Hum. Behav.* 27, 1043–1045. doi: 10.1016/J.CHB.2010.07.014

Breuer, C., Hüffmeier, J., and Hertel, G. (2016). Does trust matter more in virtual teams? A meta-analysis of trust and team effectiveness considering virtuality and documentation as moderators. *J. Appl. Psychol.* 101, 1151–1177. doi: 10.1037/apl0000113

Briggs, R. O., de Vreede, G.-J., and Nunamaker, J. F. (2003). Collaboration engineering with thinklets to pursue sustained success with group support systems. *J. Manag. Inform. Syst.* 19, 31–64. doi: 10.1080/07421222.2003.11045743

Buder, J. (2011). Group awareness tools for learning: current and future directions. *Comput. Hum. Behav.* 27, 1114–1117. doi: 10.1016/j.chb.2010.07.012

Byrne, Z. S., Stoner, J., Thompson, K. R., and Hochwarter, W. (2005). The interactive effects of conscientiousness, work effort, and psychological climate on job performance. *J. Vocat. Behav.* 66, 326–338. doi: 10.1016/J.JVB.2004.08.005

Chen, F., Zhang, L., and Latimer, J. (2014). How much has my co-worker contributed? The impact of anonymity and feedback on social loafing in asynchronous virtual collaboration. *Int. J. Inform. Manag.* 34, 652–659. doi: 10.1016/j.ijinfomgt.2014.05.001

Chidambaram, L., and Tung, L. L. (2005). Is out of sight out of mind? An empirical study of social loafing in technoligy-supported teams. *Inform. Syst. Res.* 16, 149–168. doi: 10.1287/isre.1050.0051

Costa, P. T., and McCrae, R. R. (1992). Normal personality assessment in clinical practice: The NEO Personality Inventory. *Psychol. Assess.* 4, 5–13. doi: 10.1037/1040-3590.4.1.5

Dennis, A. R. (1996). Information exchange and use in small group decision making. *Small Group Res.* 27, 532–550. doi: 10.1177/1046496496274003

DeShon, R. P., Kozlowski, S. W. J., Schmidt, A. M., Milner, K. R., and Wiechmann, D. (2004). A multiple-goal, multilevel model of feedback effects on the regulation of individual and team performance. *J. Appl. Psychol.* 89, 1035–1056. doi: 10.1037/0021-9010.89.6.1035

DiMicco, J. M., Hollenbach, K. J., Pandolfo, A., and Bender, W. (2007). The impact of increased awareness while face-to-face. *Hum. Comput. Interact.* 22, 47–96.

DiMicco, J. M., Pandolfo, A., and Bender, W. (2004). "Influencing group participation with a shared display," in *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work, CSCW 2004*, Chicago, IL. doi: 10.1145/1031607.1031713

Engel, D., Woolley, A. W., Jing, L. X., Chabris, C. F., and Malone, T. W. (2014). Reading the mind in the eyes or reading between the lines? Theory of mind predicts collective intelligence equally well online and face-to-face. *PLoS One* 9:e115212. doi: 10.1371/journal.pone.0115212

Fang, H.-M., and Chang, W.-C. (2014). The Effects of member familiarity, task results visibility and perceived co-worker loafing on technology-supported team performance: social loafing effect perspective. *Asia Pac. Manag. Rev.* 19, 361–373. doi: 10.6126/APMR.2014.19.4.02

Ferrari, J. R., and Pychyl Timothy, A. (2012). "If I wait, my partner will do it." The role of conscientiousness as a mediator in the relation of academic procrastination and perceived social loafing. *North Am. J. Psychol.* 14, 13–24.

Gabelica, C., Van Den Bossche, P., Segers, M., and Gijselaers, W. (2012). Feedback, a powerful lever in teams: a review. *Educ. Res. Rev.* 7, 123–144. doi: 10.1016/j.edurev.2011.11.003

Geister, S., Konradt, U., and Hertel, G. (2006). Effects of process feedback on motivation, satisfaction, and performance in virtual teams. *Small Group Res.* 37, 459–489. doi: 10.1177/1046496406292337

George, J. M. (1992). Extrinsic and intrinsic origins of perceived social loafing in organizations. *Acad. Manag. J.* 35, 191–202.

Gilson, L. L., Maynard, M. T., Jones Young, N. C., Vartiainen, M., and Hakonen, M. (2014). Virtual teams research: 10 years, 10 themes, and 10 opportunities. *J. Manag.* 41, 1313–1337. doi: 10.1177/0149206314559946

Gosling, S. D., Rentfrow, P. J., and Swann, W. B. (2003). A very brief measure of the Big-Five personality domains. *J. Res. Pers.* 37, 504–528. doi: 10.1016/S0092-6566(03)00046-1

Gutwin, C., and Greenberg, S. (2002). A descriptive framework of workspace awareness for real-time groupware. *Comput. Support. Coop. Work* 11, 411–446. doi: 10.1023/A:1021271517844

Hackman, J. R. (1987). "The design of work teams," in *Handbook of Organizational Behavior*, ed. J. W. Lorsch (Englewood Cliffs, NJ: Prentice-Hall), 315–342.

Harkins, S. G., and Szymanski, K. (1989). Social loafing and group evaluation. *J. Pers. Soc. Psychol.* 56, 934–941. doi: 10.1037/0022-3514.56.6.934

Hart, J. W., Karau, S. J., Stasson, M. F., and Kerr, N. A. (2004). Achievement motivation, expected coworker performance, and collective task motivation: working hard or hardly working? *J. Appl. Soc. Psychol.* 34, 984–1000. doi: 10.1111/j.1559-1816.2004.tb02580.x

Hayes, A. F. (2013). *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*. New York, NY: Guilford Press.

Hoon, H., and Tan, T. M. L. (2008). Organizational citizenship behavior and social loafing: the role of personality, motives, and contextual factors. *J. Psychol.* 142, 89–108. doi: 10.3200/JRLP.142.1.89-112

Humphrey, S. E., Hollenbeck, J. R., Meyer, C. J., and Ilgen, D. R. (2007). Trait configurations in self-managed teams: a conceptual examination of the use of seeding for maximizing and minimizing trait variance in teams. *J. Appl. Psychol.* 92, 885–892. doi: 10.1037/0021-9010.92.3.885

Hurtz, G. M., and Donovan, J. J. (2000). Personality and job performance: the Big Five revisited. *J. Appl. Psychol.* 85, 869–879. doi: 10.1037/0021-9010.85.6.869

Ingham, A. G., Levinger, G., Graves, J., and Peckham, V. (1974). The Ringelmann effect: studies of group size and group performance. *J. Exp. Soc. Psychol.* 10, 371–384. doi: 10.1016/0022-1031(74)90033-X

Janssen, J., Erkens, G., Kanselaar, G., and Jaspers, J. (2007). Visualization of participation: does it contribute to successful computer-supported collaborative learning? *Comput. Educ.* 49, 1037–1065. doi: 10.1016/J.COMPEDU.2006.01.004

Janssen, J., Erkens, G., and Kirschner, P. A. (2011). Group awareness tools: it's what you do with it that matters. *Comput. Hum. Behav.* 27, 1046–1058. doi: 10.1016/J.CHB.2010.06.002

Jermann, P., and Dillenbourg, P. (2008). Group mirrors to support interaction regulation in collaborative problem solving. *Comput. Educ.* 51, 279–296. doi: 10.1016/J.COMPEDU.2007.05.012

Judge, T. A., and Ilies, R. (2002). Relationship of personality to performance motivation: a meta-analytic review. *J. Appl. Psychol.* 87, 797–807. doi: 10.1037/0021-9010.87.4.797

Karau, S. J., and Williams, K. D. (1993). Social loafing: a meta-analytic review and theoretical integration. *J. Pers. Soc. Psychol.* 65, 681–706. doi: 10.1037/0022-3514.65.4.681

Kelsen, B. A., and Liang, H.-Y. (2018). Role of the Big Five personality traits and motivation in predicting performance in collaborative presentations. *Psychol. Rep.* doi: 10.1177/0033294118795139 [Epub ahead of print].

Kerr, N. L. (1983). Motivation losses in small groups: a social dilemma analysis. *J. Pers. Soc. Psychol.* 45, 819–828. doi: 10.1037/0022-3514.45.4.819

Kerr, N. L., Messé, L. A., Park, E. S., and Sambolec, E. J. (2005). Identifiability, performance feedback and the Köhler effect. *Group Process. Intergroup Relat.* 8, 375–390. doi: 10.1177/1368430205056466

Kidwell, R. E., and Bennett, N. (1993). Employee propensity to withhold effort: a conceptual model to intersect three avenues of research. *Acad. Manag. Rev.* 18, 429–456. doi: 10.5465/amr.1993.9309035146

Kim, T., Hinds, P., and Pentland, A. (2012). "Awareness as an antidote to distance," in *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work - CSCW '12* (Seattle, WA: ACM Press), 1237–1246. doi: 10.1145/2145204.2145391

Kim, Y. J., Engel, D., Woolley, A. W., Lin, Y.-T. J., McArthur, N., and Malone, T. W. (2017). "What makes a strong team: using collective intelligence to predict team performance in League of Legends," in *Proceedings of the 20th ACM Conference for Conference on Computer-Supported Cooperative Work and Social Computing CSCW'17*, Portland, OR. doi: 10.1145/2998181.2998185

Kluger, A. N., and DeNisi, A. (1996). The effects of feedback interventions on performance: a historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychol. Bull.* 119, 254–284. doi: 10.1037/0033-2909.119.2.254

Konradt, U., Schippers, M. C., Garbers, Y., and Steenfatt, C. (2015). Effects of guided reflexivity and team feedback on team performance improvement: the role of team regulatory processes and cognitive emergent states.

Eur. J. Work Organ. Psychol. 24, 777–795. doi: 10.1080/1359432X.2015.1005608

Latané, B. (1981). The psychology of social impact. *Am. Psychol.* 36, 343–356. doi: 10.1037/0003-066X.36.4.343

Latané, B., Williams, K., and Harkins, S. (1979). Many hands make light the work: the causes and consequences of social loafing. *J. Pers. Soc. Psychol.* 37, 822–832. doi: 10.1037/0022-3514.37.6.822

Leinonen, P., Järvelä, S., and Häkkinen, P. (2005). Conceptualizing the awareness of collaboration: a qualitative study of a global virtual team. *Comput. Support. Coop. Work* 14, 301–322. doi: 10.1007/s10606-005-9002-z

LePine, J. A. (2003). Team Adaptation and postchange performance: effects of team composition in terms of members' cognitive ability and personality. *J. Appl. Psychol.* 88, 27–39. doi: 10.1037/0021-9010.88.1.27

Leshed, G., Cosley, D., Hancock, J. T., and Gay, G. (2010). "Visualizing language use in team conversations," in *Proceedings of the 28th of the International Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '10* (New York, NY: ACM Press), 4567–4582. doi: 10.1145/1753846.1754195

Marjchrzak, A., Faraj, S., Kane, C. G., and Azad, B. (2013). The contradictory influence of social media affordances on online communal knowledge sharing. *J. Comput. Mediat. Commun.* 19, 38–55. doi: 10.1111/jcc4.12030

Marlow, S. L., Lacerenza, C. N., and Salas, E. (2017). Communication in virtual teams: a conceptual framework and research agenda. *Hum. Resour. Manag. Rev.* 27, 575–589. doi: 10.1016/j.hrmr.2016.12.005

Miron-Spektor, E., Erez, M., and Naveh, E. (2011). The effect of conformist and attentive-to-detail members on team innovation: reconciling the innovation paradox. *Acad. Manag. J.* 54, 740–760. doi: 10.5465/amj.2011.64870100

Mulvey, P. W., and Klein, H. J. (1998). The impact of perceived loafing and collective efficacy on group goal processes and group performance. *Organ. Behav. Hum. Decis. Process.* 74, 62–87. doi: 10.1006/obhd.1998.2753

Peeters, M. A. G., van Tuijl, H. F. J. M., Rutte, C. G., and Reymen, I. M. M. J. (2006). Personality and team performance: a meta-analysis. *Eur. J. Pers.* 20, 377–396. doi: 10.1002/per.588

Peñarroja, V., Orengo, V., and Zornoza, A. (2017). Reducing perceived social loafing in virtual teams: the effect of team feedback with guided reflexivity. *J. Appl. Soc. Psychol.* 47, 424–435. doi: 10.1111/jasp.12449

Peterson, R. S., and Behfar, K. J. (2003). The dynamic relationship between performance feedback, trust, and conflict in groups: a longitudinal study. *Organ. Behav. Hum. Decis. Process.* 92, 102–112. doi: 10.1016/S0749-5978(03)00090-6

Ringelmann, M. (1913). Recherches sur les moteurs animes: Travail de rhomme [Research on animate source of power: the work of man]. *Annales de I'lnstitut National Agronomique* 12, 1–40.

Salas, E., Burke, S., and Cannon-Bowers, J. A. (2000). Teamwork: emerging principles. *Int. J. Manag. Rev.* 2, 339–356. doi: 10.1111/1468-2370.00046

Salas, E., Cooke, N. J., and Rosen, M. A. (2008). On teams, teamwork, and team performance: discoveries and developments. *Hum. Factors* 50, 540–547. doi: 10.1518/001872008X288457

Salas, E., Sims, D. E., and Burke, C. S. (2005). Is there a "Big Five" in teamwork? *Small Group Res.* 36, 555–599. doi: 10.1177/1046496405277134

Salas, E., Weaver, S. J., and Shuffler, M. L. (2012). "Learning, training and development in organizations," in *The Oxford Handbook of Organizational Psychology*, Vol. 1, ed. S. W. Kozlowski (New York, NY: Oxford University Press), 330–372.

Salgado, J. F. (2003). Predicting job performance using FFM and non-FFM personality measures. *J. Occup. Organ. Psychol.* 76, 323–346. doi: 10.1348/096317903769647201

Schippers, M. C. (2014). Social loafing tendencies and team performance: the compensating effect of agreeableness and conscientiousness. *Acad. Manag. Learn. Educ.* 13, 62–81. doi: 10.5465/amle.2012.0191

Streng, S., Stegmann, K., Hussmann, H., and Fischer, F. (2009). "Metaphor or diagram: comparing different representations for group mirrors," in *Proceedings of the 21st Australasian Computer-Human Interaction Conference, OZCHI 2009: Open 24/7*, Melbourne. doi: 10.1145/1738826.1738866

Suleiman, J., and Watson, R. T. (2008). Social loafing in technology-supported teams. *Comput. Support. Coop. Work* 17, 291–309. doi: 10.1007/s10606-008-9075-6

Ter Hoeven, C. L., van Zoonen, W., and Fonner, K. L. (2016). The practical paradox of technology: the influence of communication technology use on employee burnout and engagement. *Commun. Monogr.* 83, 239–263. doi: 10.1080/03637751.2015.1133920

Triandis, H. C. (1989). The self and social behavior in differing cultural contexts. *Psychol. Rev.* 96, 506–520. doi: 10.1037/0033-295X.96.3.506

Triplett, N. (1898). The dynamogenic factors in pacemaking and competition. *Am. J. Psychol.* 9, 507–533. doi: 10.2307/1412188

van Vianen, A. E. M., and De Dreu, C. K. W. (2001). Personality in teams: its relationship to social cohesion, task cohesion, and team performance. *Eur. J. Work Organ. Psychol.* 10, 97–120. doi: 10.1080/13594320143000573

Ware, C. (2005). "Visual queries: the Foundation of visual thinking," in *Knowledge and Information Visualization. Lecture Notes in Computer Science*, Vol. 3426, eds S. O. Tergan and T. Keller (Berlin: Springer), 27–35. doi: 10.1007/11510154_2

Weisband, S. (2002). "Maintaining awareness in distributed team collaboration: implications for leadership and performance," in *Distributed Work*, eds P. Hinds and S. B. Kielser (Cambridge, MA: The MIT Press), 311–333.

Yeo, G. B., and Neal, A. (2004). A multilevel analysis of effort, practice, and performance: effects of ability, conscientiousness, and goal orientation. *J. Appl. Psychol.* 89, 231–247. doi: 10.1037/0021-9010.89.2.231

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Glikson, Woolley, Gupta and Kim. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

ORIGINAL RESEARCH
published: 17 April 2019
doi: 10.3389/fpsyg.2019.00812

Organizational Meeting Orientation: Setting the Stage for Team Success or Failure Over Time

Joseph E. Mroz[1], Nicole Landowski[2], Joseph Andrew Allen[2] and Cheryl Fernandez[3]*

[1] Denison Consulting, Ann Arbor, MI, United States, [2] Department of Psychology, University of Nebraska Omaha, Omaha, NE, United States, [3] Gallup Inc., Omaha, NE, United States

Teams are an integral tool for collaboration and they are often embedded in a larger organization that has its own mission, values, and orientations. Specifically, organizations can be oriented toward a variety of values: learning, customer service, and even meetings. This paper explores a new and novel construct, organizational meeting orientation (the set of policies and procedures that promote or lead to meetings), and its relationship to perceived team meeting outcomes and work attitudes. An organization's policies, procedures, and overall orientation toward the use of team meetings—along with the quality and perceived effectiveness of those meetings—set the stage for how teams develop and collaborate. Across two exploratory studies, we demonstrate that perceptions of an organization's orientation toward meetings is associated with the perceived quality and satisfaction of team meetings, along with work engagement and intentions to quit. Employees who feel meetings lack purpose or are overused tend to be less engaged with their work and more likely to consider leaving the organization. Based on the findings, we conclude with a robust discussion of how meeting orientation may set the stage for team interactions, influencing how their team operates over time on a given project or series of projects. An organization's orientation toward meetings is a new construct that may exert an influence on team dynamics at *the organizational level*, representing a factor of the organization that affects how and when teams meet and collaborate.

Keywords: meetings, groups, teams, job attitudes, time

OPEN ACCESS

Edited by:
Eduardo Salas,
Rice University, United States

Reviewed by:
Ricardo Martinez Cañas,
University of Castilla–La Mancha, Spain
Mario Arias-Oliva,
University of Rovira i Virgili, Spain

***Correspondence:**
Joseph Andrew Allen
josephallen@unomaha.edu

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *31 October 2018*
Accepted: *26 March 2019*
Published: *17 April 2019*

Citation:
Mroz JE, Landowski N, Allen JA and Fernandez C (2019) Organizational Meeting Orientation: Setting the Stage for Team Success or Failure Over Time. Front. Psychol. 10:812. doi: 10.3389/fpsyg.2019.00812

INTRODUCTION

Workplace meetings are essential to both the functioning of organizations and employees' workplace experiences. Of the estimated 55 million meetings occurring daily in the United States, managers in large organizations are dedicating over three-quarters of their time preparing for, attending, leading, and processing meeting results (Keith, 2015). Among the various reasons to call a meeting, workplace meetings can be used to share information (McComas, 2003), brainstorm (Reinig and Shin, 2002), socialize (Horan, 2002), and solve problems (e.g., McComas et al., 2007). Being that meetings are an integral part of organizations, firms may have a unique culture of policies, procedures, and practices that promote, emphasize, and result in meetings – that is, a meeting orientation (Hansen and Allen, 2015). Meeting orientation is a relatively unexplored topic in meeting science, and no empirical studies have looked at its relationship to employee attitudes concerning meetings or their broader work environments

(Allen and Hansen, 2011; Hansen and Allen, 2015). An organization's overall culture toward meetings (i.e., meeting orientation) may have important consequences for how groups and teams develop over time by, for instance, influencing how often, when, and under what circumstances group members come together to work and discuss problems.

Across two studies, we propose that there are a number of ways in which individuals' belief about the meeting orientation of their organization may influence how people view various meeting and organizational outcomes, which can subsequently influence team development over time. Specifically, building upon the original theory and conceptualization by Hansen and Allen (2015), we argue that meeting orientation is related to employees' satisfaction with meetings and the perceived effectiveness of meetings, along with broader work-related attitudes such as intentions to quit (ITQ) and work engagement. Consistent with other theories of and empirical evidence for organizational orientations (e.g., market orientation; Kirca et al., 2005), we believe meeting orientation will relate to both proximal (team meeting satisfaction) and distal (work engagement) individual outcomes. After establishing meeting orientation as an important construct of interest in meeting science and for organizations, we provide a discussion and testable propositions for future research regarding how meeting orientation, and a firm's overall cultural toward meetings, can influence how teams develop and grow over time.

Organizational Orientations and the Meeting Orientation

Organizational orientations provide a potential competitive advantage for firms and examples include a market orientation or entrepreneurial orientation (Kirca et al., 2005; Rauch et al., 2009). A particularly relevant organizational characteristic that may affect team meeting processes and outcomes, as well as employee attitudes toward the organization, is an organization's meeting orientation, or the policies, procedures, and practices that emphasize, promote, or leads to meetings (Hansen and Allen, 2015). As market, entrepreneurial, and learning orientations affect how an organization structures itself and operates (e.g., Matsuno et al., 2005), a meeting orientation describes the value that an organization places on meetings (i.e., team meetings) and how often meetings are used as a collaborative tool. The meeting orientation serves as the mode by which other organizational orientations permeate and are enacted across the organization. That is, unlike other organizational orientations, meeting orientation is a process focused orientation specific to how people in the organization interact with one another in, through, and around their group and team meetings.

The degree to which an organization is oriented toward the use of group and team meetings is best represented on a continuum from low to high (Hansen and Allen, 2015). Organizations with a high meeting orientation implicitly or explicitly encourage employees to use group and team meetings as an important form of interaction and the overall work process. Therefore, high meeting orientation organizations may hold many workplace meetings, but those group and team meetings are not necessarily *good* meetings. Likewise, low meeting orientation organizations may hold fewer meetings, and meetings are not necessarily higher or lower quality than in organizations with a different meeting orientation. For example, meetings may be viewed negatively when a meeting culture inhibits employees from doing their job because they attend too many group and team meetings. Alternatively, additional meetings that provide employees the opportunity to pose questions to executive management can be viewed positively (Hansen and Allen, 2015). Depending on the context, these meeting cultures may be advantageous or disadvantageous.

Meeting orientation is composed of four facets: policy focus, rewards for meetings, strategic use of meetings, and overuse of meetings (Hansen and Allen, 2015). Policy focus refers to the strength of formal policies and procedures at the organizational level with respect to meetings. Rewards for meeting speaks to how much organizational members believe that the organization rewards people who attend, lead, or organize meetings. Strategic use of meetings deals with how much an organization relies on meetings to gather, disseminate, or respond to information. Finally, meeting overuse refers to how much an organization utilizes meetings too often or holds meetings that are too long.

Despite the potential relevance and impact that an organization's meeting orientation may have on the way employees interact, no published research has empirically evaluated the relation between meeting orientation and meeting outcomes. As previously mentioned, a high or low meeting orientation does not necessarily provide an indication as to the quality of an organization's meetings or how satisfied employees are with their group and team meetings at work. However, based on the nature of several meeting orientation facets, there are a number of ways in which individuals' beliefs about the meeting orientation of their organizations may influence how people view their meetings. Further it may influence how they view their organization and it may enable or constrain their team's ability to function over time.

Overview of Studies

We conducted two studies to investigate the concept of meeting orientation and its relation to team meeting and organizational outcomes. These were exploratory studies designed to be a "first look" at the concept of a meeting orientation and how it may be related to organizationally relevant employee attitudes. Our first study sought to explore whether policy focus, rewards, strategic usage, and potential overuse were advantageous or disadvantageous to perceptions of team meeting quality. Given that meetings are events that can be strategically used to foster employee engagement (Allen and Rogelberg, 2013), in Study 2 we explored whether the facets of meeting orientation were related to work-related outcomes such as employee engagement and ITQ.

STUDY 1

The four facets of meeting orientation will likely differentially relate to team meeting outcomes. First, one facet of meeting orientation is group and team meeting overuse, or how much

an organizational member thinks that the organization has too many meetings, has meetings that are too long, or routinely holds meetings just because meetings are scheduled. Individuals who believe that their organization overuses group and team meetings are likely to think that, in general, meetings are not effective or satisfying. One aspect of an effective meeting is having and achieving goals. Routine or "standing" meetings, and other meetings generally, may have no clear goals, making it difficult for the meeting to be effective. Likewise, people tend to dislike meetings (Tracy and Dimock, 2004), and this dislike may intensify if individuals believe that their organizations have too many meetings. Finally, people may not trust their group or team meeting leader's managerial abilities or capacity to "do the right thing" if meeting attendees think the organization has too many meetings. Employees may view managers, who typically lead team meetings at work, as embodiments of the organization (Eisenberger et al., 1986), and if the organization overuses meetings, then the manager overuses group and team meetings. Therefore, we hypothesize the following:

Hypothesis 1: Overuse will be negatively related to team meeting effectiveness (1a) and team meeting satisfaction (1b).

The other three facets should have a markedly different relationship to meeting outcomes. Strategic use of meetings, or how much meeting attendees believe their organizations use group and team meetings to gather, exchange, and act on information, may be positively related with both team meeting effectiveness and team meeting satisfaction. People who believe that their organizations have meetings for a purpose, namely to interact with information, are likely to believe that those group and team meetings are effective and satisfying because the purpose is readily apparent and aligns with important, widely held assumptions about what a work meeting should be (Allen et al., 2014).

Policy focus and rewards may also influence how supported group and team meeting attendees feel from the organization. Support in this case derives from perceived organizational support (POS) theory (Eisenberger et al., 1986), which refers to the extent to which employees believe that their work organization cares about their wellbeing and values their contribution. A team meeting leader is supportive by valuing contributions of attendees and by fostering a caring atmosphere in their group or team meetings. If an organization has an orientation toward the strategic use of meetings and the organization rewards the use of meetings, team meeting attendees may feel that the meeting leader is supportive. For instance, if a meeting has a purpose for information sharing and the organization encourages these sorts of group and team meetings, meeting leaders may become adept at conducting these meetings by supporting and encouraging the participation of all attendees. Likewise, if group and team meetings are overused and lack purpose, attendees may not feel supported because their meeting role is unclear or the meeting is generally unnecessary.

Hypothesis 2: Policy focus (2a), rewards (2b), and strategic use of meetings (2c) will be positively related to team meeting satisfaction.
Hypothesis 3: Policy focus (3a), rewards (3b), and strategic use of meetings (3c) will be positively related to team meeting effectiveness.

Figure 1 includes hypothesized relationships in Study 1.

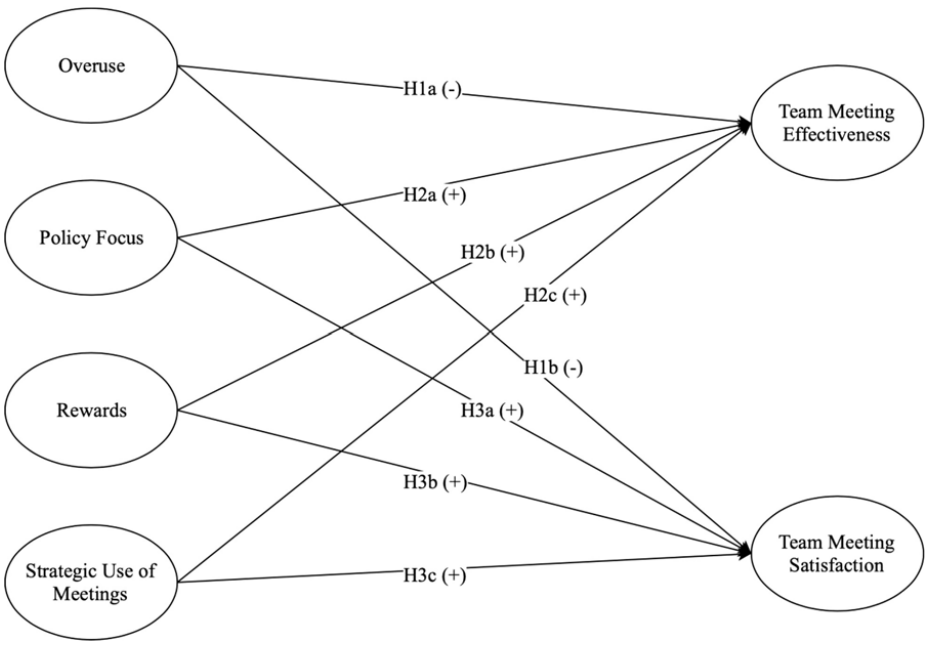

FIGURE 1 | Hypothesized relationships in Study 1.

Methods

Participants and Procedure

In exchange for course credit, students in an undergraduate psychology course recruited working adults to participate in the study through Qualtrics, an online survey tool. A total of 22 students sent invitations to potential participants, 174 of whom finished the survey. Thus, the final sample consisted of 174 well-educated adults (59% held a four-year degree) who ranged from 19 to 68 years old (M = 38.72, SD = 13.03). Of participants who provided information, 30% were men. Respondents worked in a variety of industries such as healthcare, education, and the military. Workers who supervised at least one employee comprised 48% of the sample.

Due to the cross-sectional nature of the design, we implemented several procedures to mitigate concerns of common method bias (Podsakoff et al., 2003). Adhering to the recommendations proposed by Podsakoff et al. (2003), which are aimed at reducing demand characteristics and evaluation apprehension, participants were assured that they would be provided with anonymity, and that their responses would not be considered right or wrong. We also followed recommendations suggested by Conway and Lance (2010), which include utilizing counterbalancing of measures and demonstrating adequate evidence of measure reliability. In an effort to mitigate concerns of item-context-induced mood states, priming effects, and biases related to the order of measures or individual items, all measures and items were counterbalanced via randomization. Furthermore, each item utilized simple and precise language, addressing one particular concept, as suggested by Tourangeau et al. (2000).

Measures

Team meeting effectiveness

Participants indicated how effective they felt their last meeting was across six areas (e.g., "Achieving your own work goals" and "Providing you with an opportunity to acquire useful information") using a 5-point Likert scale (1 = *very ineffective*; 5 = *very effective*). Cronbach's alpha for this measure was 0.83.

Team meeting satisfaction

Meeting satisfaction was measured using a 6-item measure developed by Rogelberg et al. (2010). Participants read a question stem ("My last meeting was. . .") followed by series of adjectives and indicated how well each one described their last meeting (e.g., "stimulating" and "boring") from 1 (*strongly disagree*) to 5 (*strongly agree*). Cronbach's alpha estimate of internal consistency was 0.85.

Meeting orientation

Allen and Hansen's (2011) meeting orientation scale consists of four facets: policy focus, rewards, strategic use, and overuse. Three items comprise each facet. Participants indicated their agreement or disagreement to statements for each facet. Items for policy focus included my firm "has policies that promote meetings," "has a lot of standard procedures associated with meetings," and "has what could be called a meeting orientation." Items for rewards were my firm "rewards those who attend meetings," "rewards those who lead meetings," and "rewards those who organize meetings." For strategic use, items were my firm "holds meetings to gather information," "holds meetings to disseminate (share) information with attendees," and "holds meetings to respond to (gathered) information." Lastly, overuse was measured with the following items: my firm "has more meetings than what is required," "has longer meetings than what is required," and "holds meetings for meetings sake." Participants responded to all items on a scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Hansen and Allen (2015) conducted a factor analysis of the scale and found that the four-factor solution fit the data best and explained 79% of the variability in the rotated sum of square factor loadings. Further, average variance extracted for each factor exceed 0.71 for all factors and Cronbach's alpha was 0.79 or greater. In the current study, rewards (0.85), strategic use (0.67), and overuse (0.77) demonstrated acceptable internal consistency as assessed by Cronbach's alpha, whereas the internal consistency of the policy focus measure was somewhat low (0.58).

Meeting and demographic variables

Participants reported on several factors of their last workplace meeting including meeting type, purpose (Allen et al., 2014), and number of attendees. Demographic variables included age, race/ethnicity, education level, job status, job tenure, and job level.

Results

Descriptive statistics, alpha estimates of internal consistency, and correlations between study variables are included in **Table 1**. Hierarchical regression analyses were used to test each hypothesis. All hypotheses related to each outcome were tested concurrently in the same regression models.

Team Meeting Satisfaction

Hypotheses 1a and 2a,b predicted that overuse would be negatively related to team meeting effectiveness, whereas policy focus, rewards, and strategic use of group and team meetings would be positively related to team meeting satisfaction. In order to separate the influence of demographic factors on meeting satisfaction, the first step of the regression model included age, number of meetings attended per week, supervisory status, and job level as control variables, following best practice recommendations for statistical controls (Becker, 2005). Meeting load, or the number of meetings participants attend within a given period, has been demonstrated to affect employee job attitudes (Luong and Rogelberg, 2005). This step accounted for a significant amount of variance in meeting team satisfaction, $F(4, 153) = 4.47$, $p = 0.002$, $R^2 = 0.11$.

In the second step of the analysis, the meeting orientation dimensions were jointly added to the model in order to test the relationships of interest and accounted for an additional 18% of variance in team meeting satisfaction, $F(8, 149) = 7.46$, $p < 0.001$. Results indicated that overuse ($\beta = -0.20$, $p = 0.007$) and strategic use of meetings ($\beta = 0.36$, $p < 0.001$) were significantly related to meeting satisfaction, thus providing support for hypotheses 1a

TABLE 1 | Descriptive statistics and correlations of focal variables in study 1.

Variable	*M*	*SD*	1	2	3	4	5	6	7
1. Meetings per week	3.37	3.82	–						
2. Rewards	2.71	0.87	0.02	(0.85)					
3. Strategic use	3.75	0.68	0.21*	0.39**	(0.67)				
4. Overuse	2.82	0.95	0.17*	0.08	0.12	(0.77)			
5. Policy	3.04	0.76	0.07	0.36**	0.45**	0.32**	(0.58)		
6. Team meeting effectiveness	3.65	0.67	0.09	0.22*	0.51**	−0.18*	0.17*	(0.83)	
7. Team meeting satisfaction	3.53	0.75	0.17*	0.26**	0.36**	−0.18*	0.09	0.48**	(0.85)

*N = 158. Diagonal values represent internal consistency estimates. *p < 0.05, **p < 0.001.*

and 2c. Policy focus ($\beta = -0.01$, $p = 0.88$) and rewards ($\beta = 0.10$, $p = 0.18$) were not related to meeting satisfaction so hypotheses 2a and 2b were not supported.

Team Meeting Effectiveness

The analytic strategy described for team meeting effectiveness as the outcome variable was followed to test hypotheses related to team meeting effectiveness. Hypothesis 1b predicted that overuse would be negatively related to team meeting effectiveness, and hypothesis 3a,c proposed that policy focus, rewards, and strategic use of meetings would be positively related to team meeting effectiveness.

As in the earlier test of meeting satisfaction, the first step of the regression model included age, number of meetings attended per week, supervisory status, and job level as control variables. These demographic variables did not account for a significant portion of the variability in meeting effectiveness, $F(4, 156) = 0.72$, $p = 0.56$, $R^2 = 0.02$. The meeting orientation facets were then added to the model in the second step and explained an additional 29% of meeting effectiveness variance, $F(8, 152) = 8.60$, $p < 0.001$. Overuse ($\beta = -0.22$, $p = 0.002$) and strategic use of meetings ($\beta = 0.53$, $p < 0.001$) were significantly related to meeting effectiveness, which provided support for hypotheses 1b and 3c. Policy focus ($\beta = -0.01$, $p = 0.89$) and rewards ($\beta = -0.01$, $p = 0.88$) were not related to meeting satisfaction so hypotheses 3a and 3b were not supported. Complete results analyses are displayed in **Table 2**.

TABLE 2 | Hierarchical multiple regression analyses predicting meeting satisfaction and meeting effectiveness in study 1.

	Meeting satisfaction		Meeting effectiveness	
Variable	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Controls				
Age	0.24*	0.23*	0.03	0.02
Meetings/week	0.12	0.10	0.09	0.04
Supervisory status	−0.17	−0.22*	0.02	−0.05
Job level	−0.05	−0.10	0.09	0.02
Focal variables				
Policy focus		−0.01		−0.01
Rewards		0.10		−0.01
Strategic use		0.36**		0.53**
Overuse		−0.20*		−0.22**
F	4.47*	7.46**	0.72	8.60**
Adjusted R^2	0.11	0.29	0.02	0.31
ΔR^2		0.18		0.29

*Standardized regression coefficients are displayed. N = 158. *p < 0.05, **p < 0.001.*

STUDY 2

The dimensions of meeting orientation may uniquely relate to employee work-related attitudes. According to Hansen and Allen's (2015) theoretical propositions, meeting orientation should impact the culture, structure, and resources within an organization. Workplace meetings provide a setting in which supervisors and subordinates come together and interact in meaningful ways. Therefore, organizations with a high meeting orientation allow employees more opportunities for such meaningful interactions. High quality interactions are associated with trust, loyalty, respect, and obligation (Cropanzano and Mitchell, 2005). As a result, high quality leader-member exchange can result in organizational outcomes including: organizational commitment, turnover intentions, actual turnover, and job performance (Graen and Uhl-Bien, 1995).

However, certain facets of meeting orientation may be advantageous or disadvantageous relative to employee attitudes. For instance, employees who believe that their organization overuses group and team meetings—meeting overuse is a negative facet of meeting orientation that refers to the degree to which employees believe the organizations has too many meetings—may have poor work attitudes. Building from social exchange theory and POS theory, if employees believes that the organization does not value their time and wastes it on unnecessary group and team meetings, the employees are likely to have less favorable work attitudes. These positive (or negative) interactions may represent something beyond the dyadic relationship because leaders represent a proxy for the organization (Graen and Uhl-Bien, 1995). Subordinates who perceive their supervisors to be supportive may construe this interaction as an extension of the organization's support. Through social exchange mechanisms, subordinates may further identify with the organization's goals and care about organizational outcomes (Eisenberger et al., 1986). Therefore, we propose the following hypotheses:

Hypothesis 4: Overuse will be positively related to ITQ.
Hypothesis 5: Overuse will be negatively related to work engagement.

An organization's emphasis on meeting orientation may contribute to both employee engagement and ITQ. Previous research demonstrated that employee engagement can be fostered in the context of workplace meetings (Allen and Rogelberg, 2013). Specifically, effectively managed group and team meetings create the conditions necessary for employees to engage in their work. Organizations with a stronger meeting orientation may provide employees with group and team meeting opportunities that assist with their ability to perform at optimal levels, connect with their role in the organization, and become fully immersed in their work (Bakker and Shaufeli, 2008).

In contrast, the group and team meeting context may also allow employees to engage in withdrawal behaviors—temporarily or permanently separating from their work roles (Harrison et al., 2006). For example, there are a variety of counterproductive team meeting behaviors that precipitously decrease employees' attitudes related to their meetings and their organization overall (Lehmann-Willenbrock et al., 2016). As meetings are repeatedly held in contexts that are not conducive to the team's best interests, individuals may feel drained and burned out since they are relying on this form of collaboration to facilitate the accomplishment of their goals. Thus, we believe that supervisors that exemplify the positive aspects of an organizations meeting orientation will enable engagement and reduce feelings related to quitting. The following are hypothesized:

Hypothesis 6: Policy focus (6a), rewards (6b), and strategic use of meetings (6c) will be negatively related to ITQ.
Hypothesis 7: Policy focus (7a), rewards (7b), and strategic use of meetings (6c) will be positively related to work engagement.

Although we expect that an organization's meeting orientation is related to various job attitudes, such as ITQ and work engagement, additional team factors seem relevant in the context of this framework. That is, if meeting orientation is optimal or suboptimal, there are team factors that may strengthen positive job attitudes or reduce negative job attitudes. One good condition for teamwork, perceptions of voice, may promote good team behaviors (Gorden and Infante, 1991).

Voice refers to the degree in which employees feel as if they have voice and freedom to discuss their concerns (Gorden and Infante, 1991). Traditionally, this concept has been used as an important variable for employees who feel the need to change dissatisfying working conditions (Hirschman, 1970). Employees that perceive themselves to have a high voice may feel that: their ideas are valuable, they may share such ideas with others, and they may feel like they can actively participate in solving problems rather than simply acknowledging to decisions made by management (Gorden and Infante, 1991). In the context of meeting orientation, voice may serve as a resource that augments the effect of meeting orientation on positive workplace attitudes and depresses the effect of meeting orientation on negative workplace attitudes. In other words, we expect that the act of allowing dissenting views, ideas, or opinions in meetings may build a context of openness that empowers employees to take ownership of their work; in turn, this should promote feelings of engagement and reduce ITQ. Thus, we hypothesize:

Hypothesis 8: Voice in team meetings moderates the relationship between policy focus (8a) and strategic use of meetings (8b) and ITQ, such that the relationships will be more strongly negative when voice is low compared to high.
Hypothesis 9: Voice in team meetings moderates the relationship between policy focus (9a) and strategic use of meetings (9b) and engagement, such that the relationships will be more strongly positive when voice is high compared to low.

Figure 2 includes all hypothesized relationships tested in Study 2.

Methods

Participants and Procedure

Participants in this study were recruited through a snowball sampling technique. Undergraduate students attending a large southeastern university enrolled in a psychology course were given a description of the study and Qualtrics link to share with full-time working adults in exchange for course extra credit. At the end of the survey, participants were encouraged to forward the survey link to other working adults who might be interested in participating. Participants were required to be employees in the United States who attend at least one work meeting per week. The sample consisted of 213 primarily White (66%) working adults, nearly split between males (48%) and females (52%).

Measures

Meeting orientation

The 12-item meeting orientation scale (Allen and Hansen, 2011) described in Study 1 was used in Study 2. Estimates of internal consistency as assessed by Cronbach's alpha exceed 0.79 for all scales.

Work engagement

Employee work engagement was assessed using the Utrecht Work Engagement Scale (Schaufeli and Bakker, 2003). The scale consists of 17 items that measure three dimensions of work engagement: vigor, dedication, and absorption. Sample items include "At my work, I feel bursting with energy" (vigor), "I find the work that I do full of meaning and purpose" (dedication), and "I am immersed in my work" (absorption). Participants responded using a 7-point scale to indicate how often they feel each way at work from *never* to *always*. Engagement is typically examined as one factor due to high inter-correlations between the three dimensions (Allen and Rogelberg, 2013), as is the case in the present study. Internal consistency for this measure was 0.94.

Intentions to quit

A 3-item measure developed by Landau and Hammer (1986) was used to capture employees' ITQ their work organization. Along a 7-point scale, participants reported the extent to which they agree with the statements (e.g., "I am actively looking for a job outside my current company") from *not at all* to *extremely*. This measure demonstrated acceptable internal consistency with a Cronbach's alpha of 0.88.

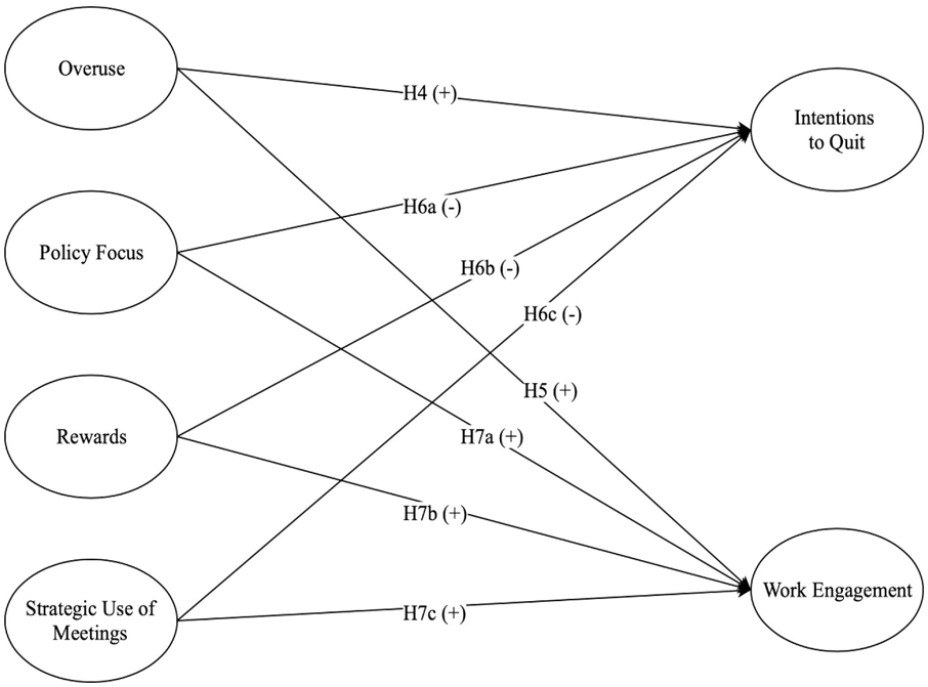

FIGURE 2 | Hypothesized relationships in Study 2.

Voice

Voice was assessed using a 5-item measure from Gorden and Infante (1991) focusing on the degree to which employees felt they had voice and freedom to discuss concerns in their company or organization. Sample items included: "there was fear of expressing your true feelings on work issues" and "employees were penalized if they openly disagreed with management practices." Ratings were made on a 7-point scale ranging from 1 (*never*) to 7 (*always*). Internal consistency for this measure was 0.75.

Results

Descriptive statistics, alpha estimates of internal consistency, and correlations between study variables are included in **Table 3**. Hierarchical regression analyses were used to test each hypothesis, and complete results of the final models are displayed in **Table 4**.

Intentions to Quit

Hypotheses 4 stated that overuse would be positively related to ITQ, whereas Hypotheses 6a,c proposed that policy focus, rewards, and strategic use of meetings would be negatively related to ITQ. Our control, number of meetings per week did not explain a significant amount of variability in ITQ, $F(1, 211) = 0.02$, $p = 0.88$, $R^2 = 0.00$.

The meeting orientation facets were jointly added to the model in the second step and accounted for an additional 19% of variance in ITQ, $F(5, 207) = 9.81$, $p < 0.05$, $R^2 = 0.19$. Overuse ($\beta = 0.32$, $p < 0.001$) and policy focus ($\beta = -0.29$, $p < 0.05$) were significantly related to ITQ, which supported Hypothesis 4 and 6a. Rewards ($\beta = 0.07$, $p = 0.30$) and strategic use of meetings

TABLE 3 | Descriptive statistics and correlations of focal variables in study 2.

Variable	*M*	*SD*	1	2	3	4	5	6	7	8
1. Meetings per week	2.69	2.90	–							
2. Reward	3.59	1.63	0.07	(0.91)						
3. Strategic use	5.04	1.31	0.16*	0.38**	(0.84)					
4. Overuse	3.87	1.62	0.26**	0.16*	0.12	(0.84)				
5. Policy	4.49	1.35	0.08	0.34**	0.53**	0.20*	(0.79)			
6. Voice	4.80	1.26	0.04	−0.08	0.16*	−0.35**	0.08	(0.75)		
7. Engagement	4.80	1.11	0.02	−0.15*	0.36**	−0.03	0.38**	0.22*	(0.94)	
8. Intention to quit	3.39	1.85	−0.01	−0.16*	−0.24*	0.23*	−0.30**	−0.44**	−0.48**	(0.88)

*N = 213. Diagonal values represent internal consistency estimates. *p < 0.05, **p < 0.01.*

TABLE 4 | Hierarchical multiple regression analyses predicting intentions to quit and work engagement in study 2.

	Intentions to quit		Work engagement	
Variable	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Meetings per week	−0.01	−0.02	−0.03	−0.03
Policy focus	−0.73**	−0.26**	0.18	0.27**
Rewards	−0.12	−0.11	0.01	0.01
Strategic use	−0.01	−0.56*	0.20*	0.24
Overuse	0.18*	0.19*	−0.05	−0.05
Voice	−0.78**	−0.89**	0.07	0.19
Voice x policy focus	0.66*	–	0.13	–
Voice x strategic use	–	0.83*	–	−0.06
F	13.29**	13.38**	7.68**	7.65**
Adjusted R^2	0.29	0.29	0.18	0.18
ΔR^2	0.02*	0.02*	0.01	< 0.01

*N = 230. Standardized regression coefficients are displayed. N = 192. *p < 0.05, **p < 0.001. ΔR^2 is from the model that included all variables aside from the interaction term.*

($\beta = -0.08$, $p = 0.28$) were not related to ITQ, which did not support Hypotheses 6b or 6c.

We also hypothesized that the relationship between policy focus and strategic use of meetings and ITQ would be moderated by voice, such that the relationships would be stronger when voice was high compared to low. First, we calculated an interaction term between policy and strategic use of meeting sand ITQ. For the regression analyses, the first step contained the control, number of meetings per week, the second step contained voice, the third step contained the four meeting orientations, and the interaction term was entered in the final step. The interaction term between policy and voice was significant and accounted for a significant portion of variance in ITQ, $\Delta R^2 = 0.02$, $\beta = 0.66$, $p < 0.05$, within the context of the entire model, $F(7, 205) = 13.30$, $p < 0.05$, $R^2 = 0.31$, supporting Hypothesis 8a. Similarly, the interaction term between strategic use in meetings and voice was significant, $\Delta R^2 = 0.02$, $\beta = 0.07$, $p < 0.05$, within the context of the entire model, $F(7, 205) = 13.38$, $p < 0.05$, $R^2 = 0.31$, supporting Hypothesis 8b. The interactions are depicted in **Figures 3**, **4**.

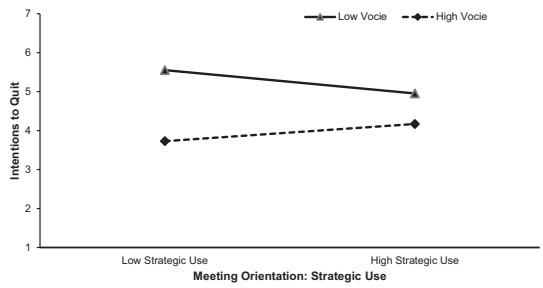

FIGURE 3 | Strategic use of meetings interacted with voice such that using meetings strategically was most beneficial in reducing intentions to quit when voice was low (1 SD below the mean) compared to high (1 SD above the mean).

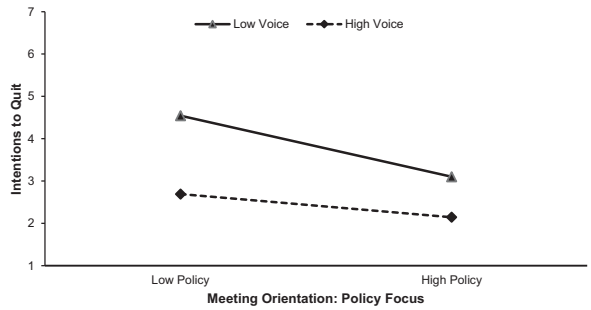

FIGURE 4 | Policy focus interacted with voice such that the negative relationship between ITQ and policy focus was stronger when voice was low compared to high.

Work Engagement

Hypotheses 5 proposed that overuse of meetings would be negatively related to work engagement, and Hypotheses 7a,c stated that policy focus, rewards, and strategic use of meetings would be positively associated with work engagement. The first step with the control variable, number of meetings per week, did not explain a significant amount of variance in work engagement, $F(1, 211) = -0.08$, $p = 0.78$, $R^2 = 0.00$.

The four meeting orientation facets were added to the model in the second step and accounted for an additional 19% of variance in work engagement, $F(5, 207) = 9.97$, $p < 0.05$, $R^2 = 0.19$. Policy ($\beta = 0.28$, $p < 0.05$) and strategic use of meetings ($\beta = 0.23$, $p < 0.05$) were significantly related to work engagement in the appropriate directions so Hypotheses 7a and 7c were supported. Overuse ($\beta = -0.11$, $p = 0.09$) and rewards ($\beta = -0.01$, $p = 0.86$), however, were not related to ITQ, which did not support Hypothesis 5 or 7b.

We also hypothesized that the relationship between policy focus and strategic use of meetings and engagement would be moderated by voice, such that the relationship would be stronger for those with greater policy focus or strategically focused orientations. First, we calculated an interaction term between policy and strategic use of meeting sand ITQ. For the regression analyses, the first step contained the control, number of meetings per week, the second step contained voice, the third step contained the four meeting orientations, and the interaction term was entered in the final step. The interaction term was not significant for either policy ($\Delta R^2 = 0.00$, $\beta = 0.13$, $p = 0.70$) or strategic use ($\Delta R^2 = 0.00$, $\beta = -0.06$, $p = 0.88$).

GENERAL DISCUSSION

This paper represents the first empirical investigation of the meeting orientation construct. As the first, exploratory step in a broader investigation of organizational meeting orientation, the results of this study confirm a series of hypotheses that relate facets of meeting orientation, policy focus, rewards, strategic use,

and potential overuse, to perceived team meeting effectiveness and team meeting satisfaction as well as ITQ and work engagement. In Study 1 which included all variables, strategic use was positively related to perceived team meeting effectiveness and satisfaction; overuse, on the other hand, was negatively related to perceived team meeting effectiveness and satisfaction, whereas rewards and policy were not related to either outcome. Extending our findings from Study 1, we explored the extent to which an organization's orientation toward meetings influences employee attitudes toward the organization. We found that employees in firms with a stronger, positive meeting orientation (defined as high on strategy, policy, and rewards and low on overuse) were more engaged in their work than employees in firms with a weak or negative meeting orientation. Policy, rewards, and strategic use were positively related to engagement, whereas meeting overuse was negatively related. Similarly, our findings indicate that meeting orientation is also related to employee ITQ. Greater meeting overuse was associated with higher turnover intentions, whereas strategic use of meetings was negatively related to ITQ.

In Study 2, we expanded our focus to an important variable related to group dynamics: perceived voice in meetings. Employees who believe they have high voice in meetings are more likely to speak up to voice their concerns, thoughts, and opinions during a group meeting context (Gorden and Infante, 1991). Indeed, we found that voice moderated the relationship between some facets of meeting orientation and ITQ. In general, a stronger organizational meeting orientation toward strategic use of team meetings for sharing, reacting to, and action upon information and having specific policies for the use of group and meetings was more beneficial to lower ITQ when voice was low compared to high. These findings illustrate that, in the absence of productive climates toward group interactions, factors specific to the organizational team meeting context can compensate, thereby leading to a more favorable employee attitude.

Despite the strong pattern of results linking aspects of meeting orientation to group and team meeting outcomes and employees' work attitudes, several of our hypotheses were not supported. Controlling for number of meetings attended per week and the unique contribution of each facet of meeting orientation, policy focus and rewards explained unique variability only in work engagement. One reason for the relatively small contributions of these facets may be that these facets are more nebulous and less concrete than the others. For example, many organizations may not have specific policies that promote group and team meetings that employees can readily identify, meaning that the policy focus aspect of meeting orientation may not be useful or that the scale needs to be modified. Similarly, employees may have difficulty recalling specific rewards that their organizations offer to people who attend, lead, or organize team meetings.

Theoretical Implications

The results of these studies have several implications. First, although the fact of being unstudied does not necessarily warrant research into a new area, this paper provided preliminary evidence that facets of organizational meeting orientation are related, and in some cases quite strongly, to important team meeting outcomes. For instance, prior research has demonstrated that satisfaction with meetings is a unique component of overall job satisfaction, even controlling for all traditional predictors of job satisfaction (Rogelberg et al., 2010). Across the two studies reported in this paper, organizational meeting orientation explained 33% of the variability in team meeting effectiveness, 20% of team meeting satisfaction, 19% of ITQ, and 19% of employee engagement. Much research on improving group and team meetings focuses on individual meeting practices, such as using an agenda, which may be helpful in improving the meetings of specific managers, but does not address meeting processes and procedures fostered at the organizational level.

Second, a variety of meeting scholars (cf. Allen et al., 2015) have suggested that technological advances in the workplace have nearly made informational meetings, or meetings in which people gather and exchange information, irrelevant, and that these irrelevant and unnecessary team meetings have contributed to the negative view of meetings in popular culture. The results of the study, however, indicate that people are more satisfied and believe that their group and team meetings are more effective when the organization supports and extensively utilizes information sharing in team meetings.

Third, group and team meetings may serve as an important tool which allows for the facilitation of employee-supervisor interactions; guided by an organizational meeting orientation, these exchanges can be advantageous and disadvantageous toward work attitudes. For instance, if an employee evaluates the dyadic relationship positively, they may construe the interactions as an extension of the organization's support, thus, may be more motivated to accomplish work tasks (Eisenberger et al., 1986). However, if an employee feels as if their supervisor requires attendance to too many irrelevant team meetings, the employee may evaluate these interactions negatively, thus, engage in withdrawal behaviors (Allen and Rogelberg, 2013). The effects of these interactions may ripple across work attitudes.

Practical Implications

Organizations may have various organizational-level orientations (e.g., market, customer, technology) meant to advance the topic of interest (Hansen and Allen, 2015). Although meeting orientation is not an overarching business aim like those previously mentioned, there are potentials for positive outcomes related to employee engagement, transfer of knowledge, and dynamic capabilities (i.e., response to change) as explained by Hansen and Allen (2015) in their theoretical framework. Being that policy and overuse meeting orientations are related to these job outcomes, there seem to be high costs associated with overuse and turnover intentions but gains related to policy and managerial support. Our findings warrant several managerial and organizational implications.

In terms of managerial implications, our findings suggest that meeting leaders have the discretion to capitalize on planning and leadership behaviors associated with the various meeting orientation dimensions. First, managers should consider whether it is necessary to schedule a team meeting; if the information

can easily be shared through email or one-on-one conversations, managers should take advantage of these alternative forms of communication rather than holding pointless meetings. Second, when calling employees for a necessary group or team meeting, leaders should only invite people for which the content is relevant. For instance, rather than a manager calling their entire team, managers can make decisions as to which collaborators are essential to accomplish the meeting's purpose. Third, to respect everyone's time, meeting leaders should use an agenda as a roadmap to guide and end the team meeting when the items are completed. Fourth, it is crucial that meeting leaders utilize group and team meetings as a strategic tool to gather, disseminate, and respond to information relevant to all attendees.

In terms of organizational implications, our findings suggest that organizations can use meeting orientation as a competitive advantage to guide skills, behaviors, and processes of leaders and employees. First, organizations should assess where they fall within the four dimensions of meeting orientation; if necessary, organizations should make adjustments to the policies, procedures, and practices surrounding their meeting usage. Second, since group and team meetings may be perceived as interruptions from daily work tasks, organizational leaders should instruct on when it is appropriate to hold team meetings. Third, organizations should institute policies, procedures, or training programs to instruct managers on good team meeting practices (e.g., temporal, physical, cross-cultural considerations).

Limitations

The findings of the study are an encouraging first step in the exploration of organizational level attitudes toward team meetings that can affect individual level outcomes, but a number of limitations must be considered when interpreting these findings. Most importantly, data examined in this study is cross-sectional in nature, which precludes drawing causal connections between variables, especially considering the scant literature and theorizing on meeting orientation generally. Furthermore, the cross-sectional, same-source data also makes the findings less potent. Although the models in this study depict meeting orientation leading to team meeting effectiveness, team meeting satisfaction, ITQ, and work engagement, it is entirely plausible that the opposite is true. For example, perhaps people who think their meetings are effective and satisfying believe that the organization strategically uses (and does not overuse) meetings. Future research should examine meeting orientation using a variety of data sources, such as objective, behaviorally based measures of team meeting effectiveness or quality, and relate these two ratings of meeting orientation.

Second, participants in this study represented a wide variety of organizations and were therefore each rating different organizations and different meetings. This is both a strength (i.e., increases generalizability) and limitation (i.e., hard to make specific predictions) of the studies. To strengthen the design, future research on meeting orientation should contain a combination of individual and organizational levels of analyses, such that multiple data points are collected within each organization to make comparisons across organizations possible. As meeting orientation is inherently an organizational level factor, of interest to meeting researchers should be how organizations with different meeting orientations conduct and approach group and team meetings, and another area that he may be how individuals with in those organi zations perceive their meetings.

Third, we implemented several strategies to mitigate concerns of common method variance given the cross-sectional nature of these studies (Podsakoff et al., 2003). To reduce demand characteristics and evaluation apprehension, we assured participants that their responses would remain anonymous and that there were no right or wrong answers. To mitigate order effects, priming effects, and item-context-induced mood states, we counterbalanced the measures and items through randomization (Podsakoff et al., 2003; Conway and Lance, 2010). To optimize comprehension, each item was simple, specific, and concise.

Future Directions and Propositions for Teams Over Time

Although the forgoing studies substantiate the existence of meeting orientation, they cannot directly speak to how meeting orientation impacts teams at initial formation and over time as they work in the organization. However, an organization's orientation toward the use of team meetings in each of the four facets could have implications for the ways in which teams develop and evolve over time. In our approach to meeting orientation, a "positive" orientation includes high levels of strategic use, policy focus, and rewards, whereas a negative orientation is low on those facets and high on overuse. Based on the findings reported in this paper, we develop several propositions below regarding meeting orientation. With respect to how teams develop over time, a positive meeting orientation may play an important role in establishing the working environment of new teams, acclimating new team members to the team and organization's culture, fostering high-quality interactions with co-workers, enhancing commitment to the team and organization, and creating more stable team memberships.

Future research on team meeting orientation should focus on the measurement of full teams given that perceptions of meeting quality may be driven by the role held by the meeting participant (e.g., leader, attendee). Decades of organizational research have compared self, peer, and supervisor ratings on perceptions of traits, skills, abilities, and performance levels; at best, self-ratings demonstrate a moderate relationship to objective measures (Mabe and West, 1982; Harris and Schaubroeck, 1988; Bass and Yammarino, 1991). Team meetings may serve as another context in which there are discrepant ratings between roles, driven by various biases (e.g., Greenwald, 1980; Goethals, 1986). In fact, Cohen et al. (2011) noted that employees in higher positions of power tended to rate their meetings as higher quality compared to others. Perhaps these discrepant meeting perceptions are more complicated than a role differences but also a function of meeting type. For instance, status update meetings may be more valuable to the project manager than the attendees, however, a strategic planning meeting may be valuable to all attendees involved.

Organizational leaders are often hiring new employees and launching new teams targeting projects of interest (Lester et al., 2002). Team comprised predominantly of new organizational members enter an environment where newcomer challenges exist (Chen and Klimoski, 2003), socialization to the organization is needed (Allen et al., 1999), and meeting orientation essentially defines how the team operates from a team meeting perspective. Given these challenges, it is likely that a positive meeting orientation as just defined would facilitate team performance generally, while a negative meeting orientation may hinder such progress in these newly formed and newly constituted teams. Further, over time, we anticipate that although team performance of new teams general improves with familiarity and codification of group processes, the stable meeting orientation (positive or negative) will create an artificial boundary condition on team performance either enabling maximal performance (i.e., positive meeting orientation) or constraining performance to a less than optimal level (i.e., negative meeting orientation). Thus, the following propositions are suggested:

Proposition 1a: Newly constituted teams will perform better in organizations with a positive compared to a negative meeting orientation.

Proposition 1b: Newly constituted teams performance will be optimized over time in an organization with a positive meeting orientation compared to a negative meeting orientation.

Team member change is one of the most common forms of changes in teams (Summers et al., 2012). Team member change can occur for a variety of reasons, but member change can often lead to, or be, a disruptive event (Olekalns et al., 2003). Member change has been conceptualized as a possible stimulant of team creativity as new members bring new ideas (Choi and Thompson, 2005), as a disruptive event that can lead to teams examining their processes and interaction strategies with an eye toward improvement (Zellmer-Bruhn, 2003), or as an opportunity for knowledge transfer and team functioning to decrease if core members change (Summers et al., 2012). We anticipate that team members will change less frequently as employees are less likely to think about quitting the organization entirely, and are more engaged in their work, when they perceive the organization to have a positive meeting orientation.

Proposition 2: Teams will experience less member change over time in organizations with a positive compared to a negative meeting orientation.

A critical role of meetings in team functioning is to act as a space for knowledge transfer among team members (Allen et al., 2014). Knowledge transfer includes passing information between individuals, groups, or organizations (Argote and Ingram, 2000), and knowledge/information sharing is a positive predictor of team performance (Mesmer-Magnus and DeChurch, 2009). As team members share information more frequently, the pool of information available for other team members to use increases, which can improve team performance (Hackman, 1987). When team meetings are used strategically and when necessary, teams may engage in increased information sharing behaviors, which may result in increased performance over time. Therefore, we propose:

Proposition 3: There is a positive a relationship between team information sharing over time and an organization's meeting orientation.

CONCLUSION

Unlike other organizational orientations (e.g., entrepreneurial), no empirical studies have investigated the consequences of meeting orientation. Studies 1 and 2 suggest that meeting orientation is related to individual perceptions of team meeting effectiveness, team meeting satisfaction, ITQ, and employee engagement even when controlling for several demographic variables. Although meeting orientation is not a predominant business aim, we see potential costs associated with meeting overuse but potential gains associated with strategic usage. Additionally, meeting orientation is an organizational level environmentally constraining construct with implications for new teams and for established teams. Over time, the meeting orientation of an organization has the potential to enable or constrain team performance and our hope is that the studies and propositions here will spur additional work by researchers on this important meeting science domain.

ETHICS STATEMENT

The institutional review board (IRB) for the University of Nebraska Medical Center and the University of Nebraska at Omaha approved an exempt IRB protocol for the forgoing study. In this case, consent was given by participation in the surveys provided and completion of the survey was that consent and no identifying information was asked on the survey.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

REFERENCES

Allen, J. A., Beck, T., Scott, C. W., and Rogelberg, S. G. (2014). Understanding workplace meetings: a qualitative taxonomy of meeting purposes. *Manag. Res. Rev.* 37, 791–814. doi: 10.1108/MRR-03-2013-0067

Allen, J. A., and Hansen, J. (2011). Meeting orientation: conceptualization, antecedents, and outcomes. *Paper Presented at the INGRoup Conference*, Minneapolis, MN.

Allen, J. A., Lehmann-Willenbrock, N., and Rogelberg, S. G. (2015). *The Cambridge Handbook of Meeting Science*. New York, NY: Cambridge University Press.

Allen, J. A., and Rogelberg, S. G. (2013). Manager-led group meetings: a context for promoting employee engagement. *Group Organ. Manag.* 38, 543–569. doi: 10.1177/1059601113503040

Allen, T. D., McManus, S. E., and Russell, J. E. (1999). Newcomer socialization and stress: formal peer relationships as a source of support. *J. Vocat. Behav.* 54, 453–470. doi: 10.1006/jvbe.1998.1674

Argote, L., and Ingram, P. (2000). Knowledge transfer: a basis for competitive advantage in firms. *Organ. Behav. Hum. Decis. Process.* 82, 150–169. doi: 10.1006/obhd.2000.2893

Bakker, A. B., and Shaufeli, W. B. (2008). Positive organizational behavior: engaged employees in flourishing organizations. *J. Organ. Behav.* 29, 147–154. doi: 10.1002/job.515

Bass, B. M., and Yammarino, F. J. (1991). Congruence of self and others' leadership ratings of naval officers for understanding successful performance. *Appl. Psychol. Int. Rev.* 40, 437–454. doi: 10.1111/j.1464-0597.1991.tb01002.x

Becker, T. E. (2005). Potential problems in the statistical control of variables in organizational research: a qualitative analysis with recommendations. *Organ. Res. Methods* 8, 274–289. doi: 10.1177/1094428105278021

Chen, G., and Klimoski, R. J. (2003). The impact of expectations on newcomer performance in teams as mediated by work characteristics, social exchanges, and empowerment. *Acad. Manag. J.* 46, 591–607. doi: 10.5465/30040651

Choi, H. -S., and Thompson, L. (2005). Old wine in a new bottle: impact of membership change on group creativity. *Organ. Behav. Hum. Decis. Process.* 98, 121–132. doi: 10.1016/j.obhdp.2005.06.003

Cohen, M. A., Rogelberg, S. G., Allen, J. A., & Luong, A. (2011). Meeting design characteristics and attendee perceptions of staff/team meeting quality. *Group Dyn. Theor. Res. Pract.* 15, 90–104. doi: 10.1037/a0021549

Conway, J. M., and Lance, C. E. (2010). What reviewers should expect from authors regarding common method bias in organizational research. *J. Bus. Psychol.* 25, 325–334. doi: 10.1007/s10869-010-9181-6

Cropanzano, R., and Mitchell, M. S. (2005). Social exchange theory: an interdisciplinary review. *J. Manag.* 31, 874–900. doi: 10.1177/0149206305279602

Eisenberger, R., Huntington, R., Hutchison, S., and Sowa, D. (1986). Perceived organizational support. *J. Appl. Psychol.* 71, 500–507. doi: 10.1037/0021-9010.71.3.500

Goethals, G. R. (1986). "Fabricating and ignoring social reality: Self-serving estimates of consensus," in *Social Comparison and Relative Deprivation: The Ontario Symposium,* eds J. M. Olson, C. P. Herman, and M. P. Zhanna (Hillsdale, NJ: Erlbaum), 135–157.

Gorden, W. I., and Infante, D. A. (1991). Test of a communication model of organizational commitment. *Commun. Quart.* 39, 144–155. doi: 10.1080/01463379109369792

Graen, G. B., and Uhl-Bien, M. (1995). Relationship-based approach to leadership: development of leader-member exchange (LMX) theory of leadership over 25 years: applying a multi-level multi-domain perspective. *Leadersh. Quart.* 6, 219–247. doi: 10.1016/1048-9843(95)90036-5

Greenwald, A. G. (1980). The totalitarian ego: fabrication and revision of personal history. *Am. Psychol.* 35, 603–618.

Hackman, J. R. (1987). "The design of work teams," in *Handbook of Organizational Behavior*, Ed J. W. Lorsch (Upper Saddle River, NJ: Prentice Hall), 315–342.

Hansen, J., and Allen, J. A. (2015). "An organizational meeting orientation: The construct, scales, and research propositions," in *The Cambridge Handbook of Meeting Science*, eds J. A. Allen, N. Lehmann-Willenbrock, and S. G. Rogelberg (New York: NY: Cambridge University Press), 347–383.

Harris, M. M., and Schaubroeck, J. (1988). A meta-analysis of self-supervisor, self-peer, and peer-supervisor ratings. *Pers. Psychol.* 41, 43–62. doi: 10.1111/j.1744-6570.1988.tb00631.x

Harrison, D. A., Newman, D. A., and Roth, P. L. (2006). How important are job attitudes? meta-analytic comparisons of integrative behavioral outcomes and time sequences. *Acad. Manag. J.* 49, 305–325. doi: 10.5465/AMJ.2006.20786077

Hirschman, A. O. (1970). *Exit, Voice, and Loyalty: Responses to Decline in Firms, Organizations, and States*. Cambridge, MA: Harvard University Press.

Horan, A. P. (2002). An effective workplace stress management intervention: Chicken soup for the soul at work employee groups. *Work* 18, 3–13.

Keith, E. (2015). *55 Million: A Fresh Look at the Number, Effectiveness, and Cost of Meetings in the U.S. [Blog Post]*. Available at: https://blog.lucidmeetings.com/blog/fresh-look-number-effectiveness-cost-meetings-in-us (accessed October 20, 2018).

Kirca, A. H., Jayachandran, S., and Bearden, W. O. (2005). Market orientation: a meta-analytic review and assessment of its antecedents and impact on performance. *J. Mark.* 69, 24–41. doi: 10.1509/jmkg.69.2.24.60761

Landau, J., and Hammer, T. H. (1986). Clerical employees' perceptions of intraorganizational career opportunities. *Acad. Manag.* 29, 385–404. doi: 10.2307/256194

Lehmann-Willenbrock, N., Allen, J. A., and Belyeu, D. (2016). Our love/hate relationship with workplace meetings: relating good and bad meeting behaviors to meeting outcomes, engagement, and exhaustion. *Manag. Res. Rev.* 39, 1293–1312. doi: 10.1108/MRR-08-2015-0195

Lester, S. W., Meglino, B. M., and Korsgaard, M. A. (2002). The antecedents and consequences of group potency: a longitudinal investigation of newly formed work groups. *Acad. Manag. J.* 45, 352–368. doi: 10.5465/3069351

Luong, A., and Rogelberg, S. G. (2005). Meetings and more meetings: the relationship between meeting load and the daily well-being of employees. *Group Dyn. Theory Res. Pract.* 9, 58–67. doi: 10.1037/1089-2699.9.1.58

Mabe, P. A., and West, S. G. (1982). Validity of self-evaluation of ability: a review and meta-analysis. *J. Appl. Psychol.* 67, 280–296. doi: 10.1037/0021-9010.67.3.280

Matsuno, K., Mentzer, J. T., and Rentz, J. O. (2005). A conceptual and empirical comparison of three market orientation scales. *J. Bus. Res.* 58, 1–8. doi: 10.1016/S0148-2963(03)00075-4

McComas, K. A. (2003). Citizen satisfaction with public meetings used for risk communication. *J. Appl. Commun. Res.* 31, 164–184. doi: 10.1080/0090988032000064605

McComas, K. A., Tuit, L. S., Waks, L., and Sherman, L. A. (2007). Predicting satisfaction and outcome acceptance with advisory committee meetings: the role of procedural justice. *J. Appl. Soc. Psychol.* 37, 905–927. doi: 10.1111/j.1559-1816.2007.00192.x

Mesmer-Magnus, J. R., and DeChurch, L. A. (2009). Information sharing and team performance: a meta-analysis. *J. Appl. Psychol.* 94, 535–546. doi: 10.1037/a0013773

Olekalns, M., Brett, J. M., and Weingart, L. R. (2003). Phases, transitions and interruptions: modeling processes in multi-party negotiations. *Int. J. Confl. Manag.* 14, 191–211. doi: 10.1108/eb022898

Podsakoff, P. M., MacKenzie, S. B., Lee, J. Y., and Podsakoff, N. P. (2003). Common method biases in behavioral research: a critical review of the literature and recommended remedies. *J. Appl. Psychol.* 88, 879–903. doi: 10.1037/00219010.88.5.879

Rauch, A., Wiklund, J., Lumpkin, G. T., and Frese, M. (2009). Entrepreneurial orientation and business performance: an assessment of past research and suggestions for the future. *Entrepreneursh. Theor. Pract.* 33, 761–787. doi: 10.1111/j.15406520.2009.00308.x

Reinig, B. A., and Shin, B. (2002). The dynamic effects of group support systems on group meetings. *J. Manag. Inform. Syst.* 19, 303–325. doi: 10.1080/07421222.2002.11045728

Rogelberg, S. G., Allen, J. A., Shanock, L., Scott, C., and Shuffler, M. (2010). Employee satisfaction with meetings: a contemporary facet of job satisfaction. *Hum. Res. Manag.* 49, 149–172. doi: 10.1002/hrm.20339

Schaufeli, W. B., and Bakker, A. B. (2003). *UWES–Utrecht Work Engagement Scale: Test Manual*. Utrecht: Department of Psychology, Utrecht University.

Summers, J. K., Humphrey, S. E., and Ferris, G. R. (2012). Team member change, flux in coordination, and performance: effects of strategic core roles, information transfer, and cognitive ability. *Acad. Manag. J.* 55, 314–338. doi: 10.5465/amj.2010.0175

Tourangeau, R., Rips, L. J., and Rasinski, K. (2000), *The Psychology of Survey Response*, New York, NY: Cambridge University Press.

Tracy, K., and Dimock, A. (2004). Meetings: Discursive sits for building and fragmenting community. *Commun. Yearbook* 28, 127–165. doi: 10.1207/s15567419cy2801_4

Zellmer-Bruhn, M. E. (2003). Interruptive events and team knowledge acquisition. *Manag. Sci.* 49, 514–528. doi: 10.1287/mnsc.49.4.514.14423

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Mroz, Landowski, Allen and Fernandez. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

ORIGINAL RESEARCH
published: 24 April 2019
doi: 10.3389/fpsyg.2019.00847

There Is Light and There Is Darkness: On the Temporal Dynamics of Cohesion, Coordination, and Performance in Business Teams

Pedro Marques-Quinteiro[1], Ramón Rico[2], Ana M. Passos[3] and Luís Curral[4]*

[1] William James Center for Research, ISPA – Instituto Universitário, Lisbon, Portugal, [2] Business School, University of Western Australia, Perth, WA, Australia, [3] Business Research Unit, ISCTE – Instituto Universitário de Lisboa, Lisbon, Portugal, [4] CICPSI, Faculdade de Psicologia, Universidade de Lisboa, Lisbon, Portugal

This study examines teams as complex adaptive systems (tCAS) and uses latent growth curve modeling to test team cohesion as an initial condition conducive to team performance over time and the mediational effect of team coordination on this relationship. After analyzing 158 teams enrolled in a business game simulation over five consecutive weeks, we found that change in team coordination was best described by a continuous linear change model, while change in team performance was best described by a continuous nonlinear change model; and the mediation latent growth curve model revealed a negative indirect effect of team cohesion on the level of change in team performance over time, through the level of change in team coordination. This study contributes to the science of teams by combining the notions of initial conditions with co-evolving team dynamics, hence creating a more refined temporal approach to understanding team functioning.

Keywords: team coordination, team cohesion, complex adaptive systems, team performance, latent growth curve models

OPEN ACCESS

Edited by:
Eduardo Salas,
Rice University, United States

Reviewed by:
M. Teresa Anguera,
University of Barcelona, Spain
Rita Berger,
University of Barcelona, Spain

****Correspondence:***
Pedro Marques-Quinteiro
pquinteiro@ispa.pt

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *29 October 2018*
Accepted: *29 March 2019*
Published: *24 April 2019*

Citation:
Marques-Quinteiro P, Rico R, Passos AM and Curral L (2019) There Is Light and There Is Darkness: On the Temporal Dynamics of Cohesion, Coordination, and Performance in Business Teams. Front. Psychol. 10:847. doi: 10.3389/fpsyg.2019.00847

INTRODUCTION

Team cohesion is an emergent affective state that is at the heart of teamwork dynamics (Kozlowski and Chao, 2012; Maynard et al., 2015). It is a multidimensional construct that includes a task, a social, and a group pride dimension. Accordingly, team cohesion is defined as the tendency for a team to stick together and remain united in its pursuit of instrumental objectives and the satisfaction of members' affective needs (Carron and Brawley, 2000). Team cohesion is especially important for the performance of business teams (e.g., Menges and Kilduff, 2015). Indeed, since the early 50s (e.g., Festinger, 1950) teamwork literature has dedicated great attention to the relationship between team cohesion and team performance in organizational settings with cross-sectional, meta-analytical, and longitudinal studies suggesting a positive relationship between the two constructs (e.g., Zaccaro et al., 1995; Beal et al., 2003; Mathieu et al., 2015).

Thanks to the accumulating body of research we now know more about the dynamic nature of the cohesion–performance relationship. For instance, we know that the relationship between team cohesion and team performance (a) takes an inverted U-shaped distribution (Wise, 2014); (b) is stronger when performance is operationalized as behavior rather than an outcome; and (c) that efficiency measures are better for capturing this relationship (Beal et al., 2003). And yet, whereas

the importance of team cohesion to team performance is unequivocal, the number of longitudinal studies trying to uncover the developmental dynamics between them is scarce (e.g., Kozlowski and Chao, 2012; Kozlowski, 2015; Mathieu et al., 2015). Studying how phenomena co-evolve over time is informative about how change in one construct can help explain change in another construct and how their influences reciprocate longitudinally (Selig and Preacher, 2009). Such an approach allows for a more in-depth examination of how teamwork dynamics happen; hence, clarifying what we know about how teams do their work (Ployhart and Vandenberg, 2010). Regarding the cohesion–performance relationship, this approach helps clarify previous debate on the dynamic nature of cohesion (Kozlowski and Chao, 2012). However, we also believe that more about the cohesion–performance relationship in management teams can be learned if framing cohesion as an initial condition for team performance trajectories over time is utilized.

In order to make progress in the temporal consideration of team cohesion dynamics and because their study cannot be dissociated from the study of time (e.g., Kozlowski and Chao, 2012; Mathieu et al., 2015); we build on the theory of teams as complex adaptive systems' (tCAS) fundamental premise, that teamwork dynamics are sensitive to teams' initial conditions at the beginning of any performance cycle (i.e., the period of time that starts with the commencement of a project or a mission and ends when the project or the mission is completed or fulfilled—Arrow et al., 2000; Marks et al., 2001). *Accordingly, this* study examines the team cohesion–team performance relationship from a new perspective: we test the general hypothesis that teams' levels of cohesion, when a team begins a performance cycle, are an initial condition impacting team performance dynamics across the entire duration of the performance cycle. Furthermore, the theory of tCAS also suggests that team cohesion is an initial condition to the developmental dynamics of team performance and that this relationship should be driven by the developmental dynamics of team coordination (i.e., how team members manage their task interdependencies during goal-directed action—Rico et al., 2008).

Although the former affirmations are apparently logical and intuitively appealing, a black box remains in the teamwork literature since these affirmations remain neglected inside the team cohesion–team performance causal link. To redress this situation, in this study we contribute to extant literature by integrating longitudinal theory with the theory of tCAS and the episodic framework of team processes to disentangle the developmental dynamics of team cohesion, team coordination, and team performance (Arrow et al., 2000; Marks et al., 2001; Kozlowski and Chao, 2012; Mathieu et al., 2015). Through our research we will help address the question of why and how team cohesion is related with team performance over time. We examine which are the forms of change that team coordination and team performance take over time, and how such change relates to team cohesion as an initial condition, from the beginning to the end of a business management simulation competition.

Theoretical Background

Complex adaptive systems (CASs) are central for dynamical systems (NDS) theory (Lewin, 1993). Under this theoretical framework, tCAS are regarded as "a set of independent agents acting in parallel to develop models of how things function in their setting, and to refine such models through learning and adaptation (. . .) CAS are open systems characterized by uncertainty about their evolution over time, due to the interaction of their components" (Ramos-Villagrasa et al., 2018, p. 136). According with Arrow et al. (2000), team dynamics are characterized by emergent interactions between local (i.e., team members characteristics), contextual (i.e., team processes and emergent states like coordination and cohesion), and global dynamics (i.e., contextual features such as task) as they unfold over time. These interactions drive teams toward self-organization, which is an optimum state of team functioning where teams become fully adapted to the task and/or the environment in which they are performing. Occasionally, either driven by internal or external triggers, the relative stability that exists in self-organized states is disrupted. Such discontinuities in team functioning are well documented in the work of authors such as Gersick's (1991) punctuated equilibrium model, or Uitdewilligen et al. (2018), who found that team processes and team performance unfold over time through longer periods of stability, which alternate with shorter periods of instability where discontinuities occur.

Roe's (2008) framework helps in integrating the aforementioned perspectives by suggesting that the dynamic relationship between constructs can be understood via paired combinations of three temporal features: the beginning of phenomena, which describes the initial value of any given variable (i.e., the onset/ intercept); the change in phenomena, which describes the form, direction, and intensity of development (i.e., the slope); and the duration in phenomena, which is the amount of time phenomenon persists, is observable, or behaves in a particular way (Roe, 2008). In this study, we focus on the beginning of phenomena addressing team cohesion as an initial condition; and on the dynamics of phenomena addressing the evolution of team performance *via* team coordination over time.

Team Cohesion as an Initial Condition to Change in Team Performance Over Time

Team cohesion is considered of greatest importance for team performance over time. Team cohesion emerges in the early stages of the team life cycle, stabilizes quickly, and is expected to become a *sine qua non* condition to the integrity of teams (Festinger, 1950; Weiss and Cropanzano, 1996; Arrow et al., 2000). Cohesion is understood as a performance antecedent, and research findings have systematically shown a positive relationship between both constructs (e.g., Gully et al., 1995; Beal et al., 2003). However, few studies have examined this relationship from a longitudinal lens, despite the advantages that collecting data longitudinally entails clarifying the relational patterns between constructs that are hardly identifiable in data collected on a single occasion

(Roe, 2008). In this regard, research by Mathieu et al. (2015) found meta-analytical support to the reciprocal influence between cohesion and performance over time in management teams. Mathieu et al. (2015) further extended this finding by conducting two empirical studies where they found that cohesion and performance were related positively, and reciprocally, over time. Their longitudinal model worked best when cohesion predicts performance over time, but not the other way around.

By framing team cohesion as an initial condition to team performance dynamics over time we are not ignoring the temporal nature of cohesion, nor its dynamic relationship with performance; but rather acknowledging the role that cohesion levels at early stages of a team performance cycle might have predicting how and why different teams show distinct performance trajectories over time. Building on Arrow et al. (2000) and Roe (2008), we theorize that team cohesion is an initial condition to teamwork dynamics over time. Our argument is also built over Hackman's (2012) idea of team enabling conditions, which are regarded as the optimal set of team conditions (e.g., affectivity, knowledge) at the beginning of a project or a mission, that will set the stage for a team to be the most effective it could be. Consequently, and by combining the ideas of Roe (2008); Hackman (2012), and Arrow et al. (2000), we propose that high cohesion levels at the beginning of a performance cycle will be positively related with team performance dynamics across one complete performance cycle.

Team cohesion builds the teams' structures that allow team members to engage in open communication, debate their ideas, and learn from each other (e.g., Festinger, 1950; Mathieu et al., 2015; Maynard et al., 2015). This means that, in cohesive teams, when teams start defining a plan or a strategy, team members will more confidently participate in its elaboration. The fact that teams have higher cohesion at the beginning of a task might also be helpful if it encounters some kind of obstacle early in the team performance cycle because more cohesive teams will be more likely to work together to overcome such an obstacle. Additionally, teams that begin a project or a mission with high cohesion levels have a strong sense of mission and are more willing to invest in helping the team to achieve its goals (Kozlowski and Chao, 2012).

In contrast, for teams with low cohesion at the beginning of a new performance cycle it is less likely that team members will feel motivated to fully invest their efforts in the achievement of the team's goals, or that all team members will contribute to the definition of a team strategy (e.g., Zaccaro et al., 1995). Plus, the low cohesion levels at the beginning of a performance cycle might facilitate the emergence of conflict, which will impair team members' collective capacity to work together and perform well over time (Kozlowski and Chao, 2012). Following these arguments, we propose that at the beginning of a performance cycle, cohesion will function as an initial condition that promotes positive performance trajectories over time. Thus, we hypothesize that:

> *Hypothesis 1:* The level of team cohesion at the beginning of the team performance cycle is positively related with the level change in team performance over time.

Because the way teamwork dynamics develop over time can display different patterns (e.g., continuous vs. discontinuous; linear vs. nonlinear), it is first necessary to elaborate on the changing dynamics of team performance (e.g., Ployhart and Vandenberg, 2010; Navarro et al., 2015). Later in this section, we will do the same for team coordination.

The minimum entropy principle suggests that efficient performance in tCAS can only be achieved if systems develop a minimum number of alternative behavioral strategies that they can use to adapt to their environment (Arrow et al., 2000; Guastello et al., 2013). It is the existence of a minimum number of behavioral options that allows tCAS to be effective (Arrow et al., 2000). Interestingly, although high performance is often regarded as the most desirable outcome in the teamwork literature, the minimum entropy principle suggests that some variability in performance is what allows the system to thrive in the face of change and uncertainty (Ramos-Villagrasa et al., 2012; Guastello et al., 2013; Curral et al., 2016). It is as if living-social systems need to alternate between moments of high and low performance in order to secure systems' sustainability in the long term. This idea finds support in an accumulating body of empirical evidence showing that the dynamics of change in team performance over time have chaotic properties in the sense that change in the level of team performance has sensitiveness to initial conditions and follows a *nonlinear trend* (e.g., Guastello, 2010; Ramos-Villagrasa, et al., 2012; Guastello et al., 2013; Curral et al., 2016; Ramos-Villagrasa et al., 2018).

The minimum entropy principle is also supported by the idea of healthy variability, a property of living systems where healthy functioning only exists if those systems show a minimum degree of entropy in their functioning over time (Navarro and Rueff-Lopes, 2015; Ramos-Villagrasa et al., 2018). In living and social systems, rather than linear, curvilinear, or random variability, healthy variability is characterized by nonlinear dynamics in the sense that the level of change in one particular variable follows a *slightly disorganized* pattern of ups and downs (i.e., organized chaos). As an example, Ramos-Villagrasa et al. (2012) found that team performance dynamics showing healthy variability were related with higher team performance in the long term. The outcomes of their research also showed that team performance dynamics characterized by linear and random variation (unhealthy variability) were related with poorer team performance in the long term.

In line with previous findings and taking the view of tCAS, we expect that team performance developmental dynamics over time will be in line with the minimum entropy system and the healthy variability principle, i.e., team performance over time will change nonlinearly. Hence, we hypothesize that:

> *Hypothesis 2:* Team performance dynamics over time will display a nonlinear trajectory across the performance cycle.

Team Cohesion as an Initial Condition to Change in Team Coordination Over Time

It is through team coordination that teams implement their strategy to achieve collective goals (e.g., Schmutz et al., 2015). Coordination happens when team members manage their multiple interdependencies. It regards the intentional use of task programming mechanisms and communication strategies in order to meet performance standards (Rico et al., 2018). Team coordination implies behaviors such as team members openly providing feedback to each other about the task environments and performance achievements, or communicating performance goal adjustment to meet unexpected situations (Rico et al., 2008; Jarzabkowski et al., 2012; Marques-Quinteiro et al., 2013).

Studies established the existence of a positive relationship between cohesion and team coordination (e.g., LePine et al., 2008). Cohesive teams have stronger social ties and experience less affective conflict, and the connectedness between team members facilitates team planning and information elaboration over time (Festinger, 1950). Thus, cohesion might be a coordination catalyst because it increases team members' connectedness and facilitates their interaction and open communication, both of which are needed for coordination (Ensley et al., 2002).

According to the former rationales, cohesion will function as an initial condition for coordination. Evidence supporting this can be found in Zaccaro et al. (1995), who found that high task-cohesive teams invest more time in planning and information exchange during the planning period and communicate task-relevant information more frequently during the performance period than low task-cohesive teams did. These findings suggest that team coordination can be predicted over time by cohesion measured at the beginning of the performance cycle. Accordingly, we argue that at the beginning of a team performance cycle cohesion will function as an initial enabling condition promoting positive coordination trajectories over time. Thus, we hypothesize that:

> *Hypothesis 3:* The level of team cohesion at the beginning of the performance cycle is positively related with the level of change in team coordination over time.

There are two major theories in the teamwork literature that allow us to theorize about the nature of team coordination development: Arrow et al.'s (2000) tCAS theory and Gersick's (1991) punctuated equilibrium theory of team development. Both theories suggest that team coordination development is characterized by short periods of radical change happening halfway across the performance cycle, alternating with periods of stability where change is either smooth or nonexistent. This means that teams often spend the first half of a project or mission using a team coordination strategy and wait until halfway into that same project or mission to reformulate how they are sharing information and implementing decisions. Most interestingly, these dynamics should happen systematically, regardless of the duration of the teams' performance cycles (e.g., minutes to months) or the number and length of meetings that the teams have at the beginning of the team performance cycle (Gersick, 1991).

Thus, we anticipate that the dynamics of team coordination over time are characterized by a discontinuity; that is, sudden, abrupt changes in coordination at the midpoint of the team performance cycle (Gersick, 1991; Arrow et al., 2000). Such discontinuity should happen because of the way teams develop and mature over time (Gersick, 1991; Arrow et al., 2000). Once a team is assembled, team members are likely to dedicate time learning how to work together, and how to relate with each other. During this period, team members will engage in team coordination behaviors, only making small adjustments until they finally reach self-organization, which is an orderly state that emerges almost spontaneously from the interactions between team members and often leads to higher performance (Kozlowski et al., 1999; Arrow et al., 2000). Whereas limited, there is empirical evidence revealing the occurrence of discontinuities in the way team processes change over time. In this regard, studies from the tCAS literature reported that team processes such as team learning (Rebelo et al., 2016) and team coordination (Guastello and Guastello, 1998) display discontinuous shifts. In addition, very recent research found that team action patterns (a proxy of team task coordination) exhibit discontinuous growth trajectories over time (Uitdewilligen et al., 2018).

Before self-organization is reached and when team members perceive the team has spent half of the time available to conclude a project or a mission, the team will go through a short period of disruptive change (Gersick, 1991). During this period, the quantity and quality of the feedback that is shared among team members increases. Team members learn from their own performance across the first half of the performance cycle and devise a new strategy to improve their performance in the second half. Through feedback and learning, team members develop a new shared understanding of the team and task reality, which should have direct influence on the quality of team coordination (e.g., Guastello and Guastello, 1998; Arrow et al., 2000). Once the team has self-organized by finding a new way of coordinating and performing, the team enters the second half of the team performance cycle and the number of modifications that team members do to their coordination strategy are more-or-less constant until the end of the team performance cycle (Gersick, 1991). Hence, building on these theories we hypothesize that coordination will display a smooth and incremental trajectory during the first and second half of the team performance cycle and that a discontinuity will take place at the midterm.

> *Hypothesis 4:* The developmental dynamics of team coordination over time will display a discontinuous and linear trajectory, with a major change happening halfway across the performance cycle.

Team Cohesion, Team Coordination, and Team Performance Over Time

We argued above that at the beginning of a team performance cycle, cohesion will function as an initial enabling condition promoting both coordination and performance trajectories over time. We expect that during the first half of the team

performance cycle, team cohesion will be positively related with smooth and incremental changes in team coordination levels. Team cohesion gives teams the necessary plasticity to work through difficult situations without team member loss or process failures and facilitates coordination (Zaccaro et al., 1995; Kozlowski et al., 1999; Maynard et al., 2015). These changes should also be related with fluctuations in the level of team performance until halfway through the team performance cycle. However, as teams learn how to coordinate to perform their tasks, performance will vary because team members might not adopt the best coordination strategy from the beginning (Gersick, 1991; Guastello and Guastello, 1998). With the minimum entropy principle in consideration, fluctuations in team performance are likely for teams that perform high early in the team performance cycle (Guastello et al., 2013). The extent to which such nonlinear trajectories happen will be related with team cohesion as an initial condition.

At the midterm of the team performance cycle, teams tend to experience a radical increase in team coordination behaviors (Gersick, 1991). For teams who display a greater increase in the level of team coordination halfway through the team performance cycle and are capable of maintaining or slightly improving that level across the second half, team performance should preserve its nonlinear variability over time. Most importantly, cohesion will be beneficial to the evolution of coordination and team performance because the stronger connectedness between team members will ease the flow of valuable information within the team (Zaccaro et al., 1995; Arrow et al., 2000). Team members will elaborate more on what strategy they should follow to pursue teams' goals and will coordinate wittingly in order to assure that the team is on the right track (Reagans and McEvily, 2003; Greer, 2012). For teams capable of effectively coordinating, it is expected that they will achieve higher performance over time (e.g., Arrow et al., 2000). We hypothesize that:

> *Hypothesis 5:* The level of team cohesion at the beginning of the team performance cycle is positively related with the level of continuous and nonlinear change in team performance over time and this relationship is mediated by discontinuous and linear change in team coordination over time.

MATERIALS AND METHODS

Research Context

Data collection took place during the first stage of a business simulation competition where each team had to run an entire company with the aim of achieving the highest investment performance. The criterion measured was the investment "return" for the original shareholders. On the first day of the competition, the market share value of every participating team was the same and the business market in which they competed was identical. Teams experienced real world-like events, such as currency devaluation, a hostile takeover or strikes.

Participants received all information necessary about the rules and the gaming environment 1 month before the competition began. Two weeks before the start of the competition, participating teams received two training sessions. This gave team members time to become familiar with the task and with each other. On day 1 of the competition teams received a general report that characterized their company and the business environment in which they were competing. During the competition, participants made top management decisions, analyzed financial and economic indicators, interacted with the different functional areas of a company (e.g., finance, human resource management, marketing), and were made aware of the impact their decisions had on the organization itself. During the competition, teams made 66 decisions weekly related to marketing, production, personnel, purchasing, and finance. Teams were also given a vast array of data to consider before making any decision. As in real financial markets, the competing companies' stock trading was sensitive to the decisions made by the company's management team. Teams had to upload their decisions to the competition online platform on the last day of the week, and received a report about their companies and their rivals' performance 24 h later. The winner was the team that finished with the highest simulated share price. Teams were given absolute freedom to organize their work.

The business game competition where the participants of this study were enrolled is a high-fidelity simulation of a business company embedded in a virtual stock market abided by exactly the same rules of a real market. It offers an optimal data collection environment for the testing of new theory because experimenters have more control and data accessibility than in naturalistic settings (Marlow et al., 2017). In addition, the adoption of simulations has been proven highly effective in I/O Psychology and Human Factors research, and the number of empirical studies showing that simulations are most beneficial for research and training is growing (e.g., Uitdewilligen et al., 2018).

Participants

A total of 158 teams comprised of 509 individuals participated voluntarily in this study (26% of the original population: 512 teams integrating 2163 individuals). Team size ranged between 3 (7.6%), 4 (28.5%), and 5 (63.4%) members (M = 4.56, SD = 0.64). The age of team members varied between 18 and 60 years old (M = 29.51, SD = 9.31), and 46% of the participants were women. Regarding experience in participating in previous editions of this business game competition, 69.4% of the participants had never been enrolled before, 17.8% had been enrolled once, and 12.6% had been enrolled in 3–10 editions. Regarding education, 53% of the participants had one college degree and 5.1% had at least two (Ph.D. = 0.4%, Master = 3.7, MBA = 1.0%). Fifty-four percent of the participants had (or were taking) a degree in a management-related program (15.7% of which were from General Management), and 26.1% of the participants had (or were taking) a degree in an engineering-related program. Finally, regarding team type, 51.3% of the teams were comprised of only professional workers coming from business companies, 44.8% were only integrated students

(undergraduates and graduates), and 3.9% were mixed (i.e., professional workers and students).

Design and Procedure

This study follows a longitudinal and correlational design because we collected data in more than three occasions over time (Roe, 2008), and we did not manipulate the independent variable (i.e., team cohesion). The business game competition lasted for five consecutive weeks. In light of Roe (2008) and Marks et al. (2001), the 5 weeks represented a full performance cycle, while each week represented one performance episode. Week 1 was the onset or beginning of the performance cycle, while week 5 was the end or offset of the performance cycle.

We approached the designing of our study following methodological recommendations by Ployhart and Vandenberg (2010), and Ramos-Villagrasa et al. (2018) pointing to the need that longitudinal studies should be driven by (a) available theory informing which is the more adequate direction of causality between variables (e.g., Mathieu et al., 2015), or when certain forms of change are likelier to happen (e.g., Gersick, 1991), (b) the research question that is being pursuit (e.g., will team coordination dynamics mediate the relationship between initial team cohesion and team performance dynamics, from the beginning until the end of the performance cycle that is the business game competition?), (c) the nature of the variables under examination (e.g., psychological constructs and performance measures), and (d) practicality (e.g., when/how/for how long can data collection be performed). Because our research question was to study how team cohesion as an initial condition relates with change in team performance over time, through team coordination over time, we needed to ensure that (1) team cohesion was measured in the beginning of the business game competition (i.e., beginning of the team performance cycle), (2) team coordination and team performance were measured across the entire performance cycle (i.e., on each of the five performance episodes), and (3) that how and when each variable was collected reflected the causal relationship being hypothesized (i.e., team cohesion » team coordination » team performance). Whereas it could be argued that measuring team cohesion, team coordination, and team performance all together on week 1, and team coordination and team performance all together on weeks 2–5; could raise common method concerns and doubts about the assumption of causality, these were avoided (1) by measuring team cohesion in the first week of the business game competition, (2) by measuring team coordination and team performance in all 5 weeks, and (3) because team cohesion was measured first and team coordination was measured before teams could receive their weekly performance report (hence preventing that same-week team performance would input team coordination self-reports). Additionally, team cohesion and team coordination can be reliably measured through psychological scales such as the ones we have used. More, while the timing to measure team cohesion had to be at the end of the first performance episode (week 1) for practicality reasons (i.e., we could not measure it before), the timing to measure team coordination had to be at the end of each of the five performance episodes to allow us to know the teams' overall coordination in each performance episode. The link to the online questionnaires remained active until participants received their performance report. **Figure 1** illustrates the data collection process throughout the business game competition.

Finally, participants applied for the competition as intact teams coming from business companies and universities. This is why team familiarity was regarded as a control variable in our study. Participation in the competition was voluntary, and participants were invited to enroll upon registering for the event via email.

Measures

Team members were asked to share their level of agreement regarding cohesion and coordination using a Likert-type scale ranging from *totally disagree* (1) to *totally agree* (7). Team cohesion as an initial condition, as well as team member familiarity and demographic variables, was measured in the first week (performance episode 1) of the business game competition. Team coordination was measured every week, from the beginning (performance episode 1) until the end (performance episode 5) of the business game competition. Team performance was objectively measured. As team coordination, it was measured on a weekly basis.

Team Cohesion

Team cohesion was measured as a multidimensional construct, using three items from the group environment questionnaire based on the saturation level of the items shown in Carless and DePaola (2000). One item measured *task cohesion* ("Our team is united in trying to reach its goals for performance in the competition)," one item measured *social cohesion* ("Our team likes to spend time together when we are not working"), and one item measured *individual attraction to the group* ("For me, this team is one of the most important social groups I belong to"). The three-items had acceptable reliability, $\alpha = 0.70$. Since teams were formed 1 month before the start of the competition and had the opportunity to train together for the competition, they had enough time to establish cohesion (Festinger, 1950). Team cohesion as an initial condition was measured at the end of the first week of the competition.

Team Coordination

Team coordination was measured over 5 weeks using four items developed by West et al. (2004): "we are aware of what we want to accomplish," "we debate the best ways to get things done," "we meet several times to guarantee effective cooperation and communication," and "we share task related information with each other." The four-items had good reliability, $\alpha_{week\ 1} = 0.84$, $\alpha_{week\ 2} = 0.81$, $\alpha_{week\ 3} = 0.82$, $\alpha_{week\ 4} = 0.82$, and $\alpha_{week\ 5} = 0.84$.

Team Performance

To win the competition teams had to manage the company in such a way that provided the highest investment performance at the end of the simulation. The investment performance reflects the return on investment to the respective investors, not only by stock market capitalization, but also after considering the issue or repurchase of shares and the dividends distributed.

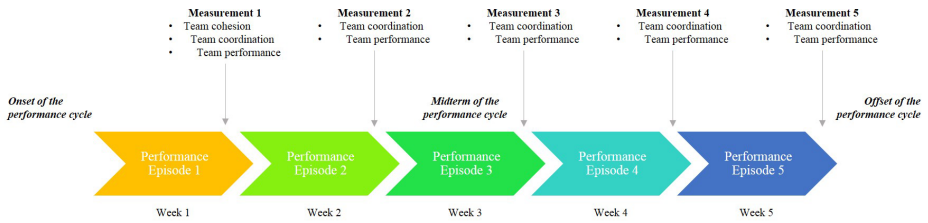

FIGURE 1 | Illustration of the temporal structure of the business game competition and the data collection process.

The measure of team performance was based on each team's company stock share price at the end of the competition. This was automatically calculated by the computer program running the virtual environment in which teams competed.

Control Variables

Because participating teams could have a previous history of working together and past performance predicts future performance, team familiarity and initial team performance were controlled (LePine et al., 2008). Team performance was examined using the intercept of the team performance's growth model. Team familiarity was measured with one item asking participants about the percentage of team members they already knew before enrolling. Responses could range from *I am not familiar with any of them* (0%) to *I am totally familiar with all of them* (100%).

Aggregation

Before proceeding with data aggregation, we examined the within-group agreement index r_{wg} (James et al., 1984) and the intra-class correlation coefficients (ICC 1 and ICC 2; Bliese, 2000) to decide whether to proceed with data aggregation (Kozlowski and Klein, 2000).

Analysis

Missing Data

In this study, the attrition level for individual responses varied between 31% (week 1) and 60% (week 5). The overall percentage of incomplete cases was 74.64%, and the overall percentage of incomplete values was 43.55%. The attrition level for team aggregated responses varied between 1% (week 1) and 15.2% (week 5). The overall percentage of incomplete cases was 19.05%, and the overall percentage of incomplete values was 2.34%. Decisions regarding how to handle missing data should be established by examining their pattern (Graham, 2009; Schlomer et al., 2010): missing completely at random (MCAR), missing at random (MAR), and not MAR (NMAR). Thus, to determine the pattern of missing data, we performed the Little (1988) MCAR test using the missing values analysis command option in SPSS 22. We obtained a non-significant chi-square value for $\chi^2_{\text{individual responses}} = 599.601$, $df = 651$, $p = 0.926$, and for $\chi^2_{\text{team responses}} = 45.894$, $df = 38$, $p = 0.178$, indicating that the pattern of missing data is MCAR (Little, 1988). MCAR is considered as a nonproblematic missing data pattern that is best managed by using sophisticated stochastic imputation methods such as full information maximum likelihood (FIML) (Graham, 2009; Ployhart and Vandenberg, 2010; Muthén and Muthén, 2012).

Assessing Configural Invariance

We performed a confirmatory factor analysis (CFA) for each team process measured at each time point, separately. The factorial structure was determined based on the theoretical operationalization of team explicit coordination by Rico et al. (2008) and West et al. (2004). The goodness-of-fit was estimated using the Chi-square index (χ^2), which evaluates the magnitude of discrepancy between the sample and fitted covariance matrices. To complement the use of the Chi-square index, three additional model fit indexes were considered: the root mean square approximated error (RMSEA), which measures the discrepancy between the hypothesized model and data by degrees of freedom (values $\leq$ 0.08 suggest goodness of fit, although some authors have argued that values $\leq$ 0.06 are ideal); the comparative fit index (CFI), which carries out the comparison between the fit of the hypothesized model and that of a basic model being represented by a null model (it can range between 0.90 and 1.00, with ideal fit values being $\geq$ 0.95); and the standardized root mean square of residual (SRMR), that should be $\leq$0.08 for good fit (Hu and Bentler, 1998).

Table 2 shows the model fit for team coordination over 5 weeks. Hu and Bentler (1998) suggest that decisions about the adequacy of model fit should be done using a minimum 2-index strategy to reject reasonable proportions of various types of true-population and misspecified models. The results of the CFA for team coordination show RMSEA values $\leq$0.17, which are above the minimum cutoff criteria point to assume good model fit. Nevertheless, Hu and Bentler (1998) suggest that the RMSEA alone is less preferable when dealing with very small sample sizes $\leq$600 and that combining the CFI and the SRMR can provide a more reliable alternative. The results displayed in **Table 2** suggest that for all cases except one (team coordination in the second week, CFI = 0.90), both CFI and SRMR index values were within the recommended cutoff criteria point to assume good model fit (Hu and Bentler, 1998). Therefore, we considered that the factorial structure for each team coordination measurement, for every week, had an acceptable model fit. Having established configural invariance, we then tested measurement invariance (Chen, 2007).

Assessing Measurement Invariance

We followed a four-step approach in which four models were tested for team coordination (Chan, 1998; Lance et al., 2000;

Muthén and Muthén, 2012; van de Schoot et al., 2012): Model 1, where only the factor loadings were set as equal over time but the intercepts were allowed to differ between weeks; Model 2, where only the intercepts were equal over time, but the factor loadings were allowed to differ between weeks. Model 3, where the loadings and intercepts were constrained to be equal over time; and Model 4, where the residual variances were also fixed to be equal over time [for further detail please regard, Lance et al. (2000) and van de Schoot et al. (2012)]. The minimum fit requirements to assume measurement invariance are that the fit of Model 3 cannot be significantly worse than Model 1 or Model 2 (Lance et al., 2000).

Since the χ^2 difference test is very sensitive to sample size, the testing of measurement invariance should be done with alternative fit indexes such as RMSEA, CFI, and SRMR. Following Chen (2007), for sample sizes ≤600, measurement invariance of factor loadings (e.g., Model 1) can be assumed when one observes a change of ≤0.010 in CFI, supplemented by a change of ≤0.015 in RMSEA, or a change of ≤0.030 in SRMR; and measurement invariance of intercept (e.g., Model 3) or residual (e.g., Model 4) invariance can be assumed when one observes a change of ≤0.010 in CFI, supplemented by a change of ≤0.015 in RMSEA, or a change of ≤0.010 in SRMR. Among the three indexes, CFI should be regarded as the main criterion to determine measurement invariance because RMSEA and SRMR tend to over reject invariant models (Chen, 2007). Given the small sample size, bootstrap estimation with 5000 cases was used. The results in **Table 2** suggest that both ΔCFI and ΔRMSEA for team coordination were null, or equal to 0.01. This is close to optimal fit conditions since both indexes did not change regardless of accumulating model constraints (Chen, 2007). Therefore, measurement invariance for team coordination was assumed.

Before we proceed to the main results section, it is important to highlight that performing the measurement invariance tests is computationally demanding and benefits from large sample sizes ($N > 1000$). Therefore, weak model fit under measurement invariance testing should not be considered as a model rejection criterion, especially when performed with small samples. Indeed, despite the weak model fit displayed in **Table 2** for the measurement invariance test, what should be regarded is the stability of the model fit indicators across models. As suggested by Hopwood and Donnellan (2010), strict rejections of models based upon rigid adherence to fit index cutoffs should be considered only with regard to theoretical or substantive issues. Since the model fit for configural invariance was adequate, and keeping in mind that the testing of measurement invariance was performed using a small sample size (Hu and Bentler, 1998; Chen, 2007), we decided to proceed with further analyses.

RESULTS

Table 1 displays the main descriptive statistics, correlations, and reliability scores for all variables studied. The results suggest that 29 out of 66 correlations were positive and significant, $rs \geq 0.20$, $ps \leq 0.01$, and team cohesion was negatively and significantly correlated with team performance on week 2, $r = -0.02$, $p < 0.05$.

Table 3 displays the aggregation indexes for team cohesion and team coordination. The results show that both the r_{wg} index and the ICC (1) index were according to standards (James et al., 1984; Bliese, 2000), hence suggesting that the aggregation of data was possible. Regarding the values of the ICC (2) index, these were below the recommended threshold of 0.70, which can be explained by the small sample size of the teams examined in our research. Bliese (2000) argues that small ICC (2) values are not an impediment to data aggregation. For constructs with low ICC (2), the strength of the relationship between research variables might be attenuated. Thus, low ICC (2) values may have made the testing of team level relationships somewhat conservative.

The Dynamics of Team Processes

To determine the dynamics of change for team coordination and team performance we built four competing models describing different forms of change: linear change (Model 1), quadratic change (Model 2), nonlinear change (Model 3), and discontinuous change (Model 4). The linear and quadratic temporal terms were modeled using polynomials. This means that whereas the linear trend was modeled by defining each temporal term as 0, 1, 2, 3, and 4 (with 0 marking the intercept or initial status of the research variable), the quadratic term was modeled by squaring the linear time metric, i.e., 0, 1, 4, 9, 16. Additionally, to model nonlinearity we fixed the onset and offset temporal terms of each team process as 0 and 1, allowing all other terms to adopt nonlinear trajectories (in case there were any). To model discontinuity, because this was hypothesized to occur between the third and fourth week of the competition, we modeled change as 0, 0, 0, 1, 1. This allows us to determine if there is a discontinuity (either positive or negative) in the slope of team coordination on the third week of the business game competition (for in-depth description of these approaches, please regard Ployhart and Vandenberg, 2010).

Table 4 summarizes the modeling procedure for each of the four growth models and reports the growth model fit statistics for each of them. The results suggested that team coordination, χ^2 (df) = 21.98 (10), p = 0.015, RMSEA = 0.09, CFI = 0.93, SRMR = 0.09, was best described by a continuous linear change model (Model 1); and team performance was best described by a continuous nonlinear change model (Model 3), χ^2 (df) = 19.62 (7), $p < 0.01$, RMSEA = 0.11, CFI = 0.97, SRMR = 0.07. These findings do not support hypothesis 4 and support hypothesis 2. The model fit for team coordination and team performance was good because at least two model fit indexes scored within recommended cutoff point criteria (Hu and Bentler, 1998). Although the RMSEA was above the recommended threshold of 0.08, it can still be considered a fair model fit (Hu and Bentler, 1998), especially because RMSEA is very sensitive to small sample sizes. Based on these results, the linear continuous model for team coordination and the nonlinear continuous model for team performance were set as the baseline growth models in following analyses (Lance et al., 2000).

The Descriptives of Change

The latent growth model parameter estimates (i.e., factor means, variances, and covariances) were regarded with the goal of

TABLE 1 | Unstandardized correlations for team cohesion, team coordination, and team performance.

	1	2	3	4	5	6	7	8	9	10	11	*M*	*SD*
Team familiarity	1	–	–	–	–	–	–	–	–	–	–	74.29	25.62
Team cohesion	0.33**	1	–	–	–	–	–	–	–	–	–	5.26	0.84
Team coordination time 1	0.07	0.56**	1	–	–	–	–	–	–	–	–	5.71	0.70
Team coordination time 2	0.04	0.29**	0.55**	1	–	–	–	–	–	–	–	5.80	0.69
Team coordination time 3	−0.09	0.25**	0.48**	0.48**	1	–	–	–	–	–	–	5.57	0.82
Team coordination time 4	−0.010	0.21*	0.37**	0.58**	0.65**	1	–	–	–	–	–	5.76	0.72
Team coordination time 5	0.04	14	0.34**	0.46**	0.51**	0.71**	1	–		–	–	5.65	0.84
Team performance time 1	0.12	−0.02	0.06	0.12	−0.05	0.06	−0.03	1	–	–	–	4.47	2.29
Team performance time 2	0.12	−0.02*	0.00	0.09	0.07	0.07	0.04	0.46**	1	–	–	4.56	2.23
Team performance time 3	0.17*	−0.15	0.00	−0.02	0.07	0.20*	0.18	0.36**	0.72**	1	–	4.73	2.27
Team performance time 4	0.18*	−0.13	0.02	−0.01	0.07	0.14	0.14	0.26**	0.65**	0.86**	1	4.85	2.23
Team performance time 5	0.12	−0.13	0.04	0.01	0.07	0.17	0.20*	0.21**	0.59**	0.79**	0.91**	4.96	2.22

N_{teams} = 158; *$p < 0.05$, **$p < 0.01$.

TABLE 2 | Configural invariance and measurement invariance for team coordination.

	Week	χ^2(*df*)	RMSEA	CFI	SRMR
Configural invariance	1	11.58 (2)*	0.12	0.97	0.03
	2	20.12 (2)*	0.17	0.90	0.05
	3	11.84 (2)*	0.13	0.93	0.04
	4	7.36 (2)*	0.11	0.97	0.03
	5	2.21 (2)	0.02	0.99	0.01
Measurement invariance	Model 1	862.58 (181)*	0.10	0.79	0.09
	Model 2	888.83 (181)*	0.10	0.79	0.10
	Model 3	940.27 (188)*	0.10	0.77	0.10
	Model 4	956.10 (192)*	0.10	0.77	0.11

$N_{individuals}$ = 509; *$p < 0.001$. *For measurement invariance testing, bootstrap estimation with 5000 cases was used. Model 1: only factor loadings constrained to be equal over time; Model 2: only intercepts constrained to be equal over time; Model 3: both factor loadings and intercepts constrained to be equal over time; and Model 4: factor loadings, intercepts, and residual variances constrained to be equal over time.*

TABLE 3 | Aggregation indexes for team cohesion and team coordination.

	r_{wg}, ICC(1), ICC(2)				
	Time 1	Time 2	Time 3	Time 4	Time 5
Cohesion	0.82, 0.24, 0.59	–	–	–	–
Coordination	0.83, 0.14, 0.44	0.88, 0.25, 0.60	0.83, 0.12, 0.39	0.85, 0.11, 0.37	0.88, 0.22, 0.55

$N_{individuals}$ = 509.

further characterizing the nature of growth trajectories for team coordination and team performance (Lance et al., 2000). The results displayed in **Table 5** show that the mean, $\mu s = -0.03$, $SE = 0.05$, $p < 0.001$, 95% CI [5.651; 5.824], and the variance, $\sigma = 0.30$, $SE = 0.05$, $p < 0.001$, 95% CI [0.218; 0.372], of the intercept for team coordination were statistically significant. Similarly, the results also suggest that the mean, $\mu = 4.42$, $SE = 0.18$, $p < 0.01$, 95% CI [4.129; 4.714], and the variance, $\sigma = 3.36$, $SE = 0.54$, $p < 0.01$, 95% CI [2.478; 4.250], of the intercept for team performance were statistically significant. Thus, there were interteam and intrateam differences in team coordination and team performance at the beginning of the performance cycle.

The analysis of the descriptives of change shows that whereas the slope factor mean for team coordination was not significant, $\mu = -0.02$, $SE = 0.02$, $p = 0.30$, 95% CI (−0.049; 0.011), the slope factor mean for team performance was positive and significant, $\mu = 0.43$, $SE = 0.22$, $p = 0.05$, 95% CI (0.073; 0.791). Furthermore, the slope factor variances for team coordination and team performance were also positive and significant, $\sigma s \geq 0.03$, $SEs \geq 0.01$, $ps \leq 0.01$, 95% CI ($\geq$3.371; $\leq$6.726). This result suggests that team coordination between teams did not change significantly over time, but that team performance did. Additionally, team coordination and team performance positively and significantly changed within teams; meaning that some teams significantly improved both their coordination and performance over time.

TABLE 4 | Model fit for the dynamics of growth trajectories of team coordination and team performance.

Variable	Nature of change	Form of change	Modeling of change	χ^2 (*df*)	RMSEA	CFI	SRMR
Team coordination	Continuous	Linear	0,1,2,3,4	21.98 (10), $p = 0.015$	0.09	0.93	0.09
		Quadratic	0,1,4,9,16	16.63 (6), $p = 0.012$	0.11	0.94	0.09
		Nonlinear	0 – – – 1	23.82 (7), $p = 0.001$	0.12	0.90	0.10
	Discontinuous	Linear	0,0,0,1,1	36.31 (10), $p < 0.001$	0.13	0.84	0.15
Team performance	Continuous	Linear	0,1,2,3,4	46.27 (10), $p < 0.001$	0.15	0.91	0.15
		Quadratic	0,1,4,9,16	3.94 (6), $p = 0.685$	0.00	1.00	0.03
		Nonlinear	0 – – – 1	19.62 (7), $p < 0.001$	0.11	0.97	0.07
	Discontinuous	Linear	0,0,0,1,1	77.75 (10), $p < 0.001$	0.21	0.83	0.22

N_{teams} = 158. The – in the nonlinear modeling, between 0 and 1, represents the freely estimated parameters in the model.

TABLE 5 | Unstandardized simple growth parameter estimates and model fit.

	Team coordination				Team performance			
	Estimate	*p*	*SE*	95% CI	Estimate	*p*	*SE*	95% CI
Intercept μ	−0.03	**	0.05	5.651; 5.824	4.42	*	0.18	4.129; 4.714
Intercept σ	0.30	**	0.05	0.218; 0.372	3.36	*	0.54	0.074; 0.791
Slope μ	−0.02	0.30	0.02	−0.049; 0.011	0.43	0.047	0.22	2.478; 4.250
Slope σ	0.03	**	0.01	0.018; 0.040	5.05	*	1.02	3.371; 6.726
Cov μ	−0.03	0.08	0.02	−0.051; −0.001	−1.87	**	0.18	−2.949; −0.782
Model fit	χ^2 (*df*)	RMSEA	CFI	SRMR	χ^2 (*df*)	RMSEA	CFI	SRMR
	21.98 (10)*	0.09	0.93	0.09	16.62 (7)**	0.11	0.97	0.07

*N_{teams} = 158. **$p < 0.001$, *$p < 0.01$. μ regards mean (e.g., intercept mean; slope mean). σ regards variance (e.g., intercept variance; slope variance).*

Finally, the results of the simple latent growth curve models for team coordination and team performance over time suggest that both constructs had a negative and significant covariance between the intercept and the slope, $cov_{coordination} = -0.03$, *SE*s = 0.02, $p = 0.08$, 95% CI (−0.051; −0.001); $cov_{performance} = -1.87$, *SE*s = 0.18, $p < 0.001$, 95% CI (2.949; −0.782). The analysis of change descriptives reveals that the higher the level of team coordination and team performance at the beginning of the team performance cycle, the less they coordinated and performed well over time.

Figures 2, **3** summarize how team cohesion as an initial condition (i.e., low, average, and high) relates with different trajectories for team performance and team coordination over time. **Figure 4** summarizes the temporal mediation results.

To summarize, whereas team cohesion is an initial condition to teamwork dynamics, our findings contradict the initial hypothesis that cohesion should enable teamwork and suggest that an excess of team cohesion at the beginning of a performance cycle may impair the way team coordination and team performance change over time.

Team Cohesion as an Initial Condition

Mediation latent growth curve models (MLGCMs) are particularly useful to test for mediations where individual trajectories (i.e., trajectories between teams) of change over time are described, and where intra-individual change (i.e., trajectories within teams) is expected (von Soest and Hagtvet, 2011). As in simpler mediation models, mediation in MLGCM is supported when the variable *X* changes the level of the mediator *M*, and the change in the mediator influences the level of the outcome variable *Y* over time. The mediational process can be modeled as the effect of *X* influencing the growth of *Y*, indirectly through the growth of *M* (Cheong et al., 2003; Selig and Preacher, 2009; von Soest and Hagtvet, 2011). Following von Soest and Hagtvet (2011), growth curves (i.e., slopes/trajectories) and the MLGCM were built based on unstandardized mean scores from team cohesion (*X*), team coordination (*M*), and team performance (*Y*). To deal with missing data we used a FIML estimator (Muthén and Muthén, 2012). Bootstrapping was used to estimate all bias-corrected CIs based on 5000 bootstrap samples (von Soest and Hagtvet, 2011). Likewise, bias-corrected bootstrap CIs were computed for mediation effects. For this purpose, we combined in Mplus the "model indirect" and the "cinterval" commands (von Soest and Hagtvet, 2011).

The overall model fit for the mediation model was satisfactory, χ^2 (53) = 119.23, $p < 0.001$, RMSEA = 0.09, CFI = 0.93, SRMR = 0.09. The results displayed in **Table 5** suggest that team cohesion was negatively related with change in team coordination over time, $B = -0.07$, $SE = 0.02$, $p < 0.001$, 95% CI (−0.102; −0.037), and unrelated with change in team performance over time, $B = -0.18$, $SE = 0.14$, $p = 0.194$, 95% CI (−0.503; 0.000). These findings do not support hypotheses 1 and 3. The results also suggest that change in team coordination over time is positively related with change in team performance over time, $B = 3.22$, $SE = 1.08$, $p = 0.001$, 95% CI (1.385; 4.962). Finally, the research findings reported in **Table 6** suggest that change in team coordination over time negatively and significantly mediates

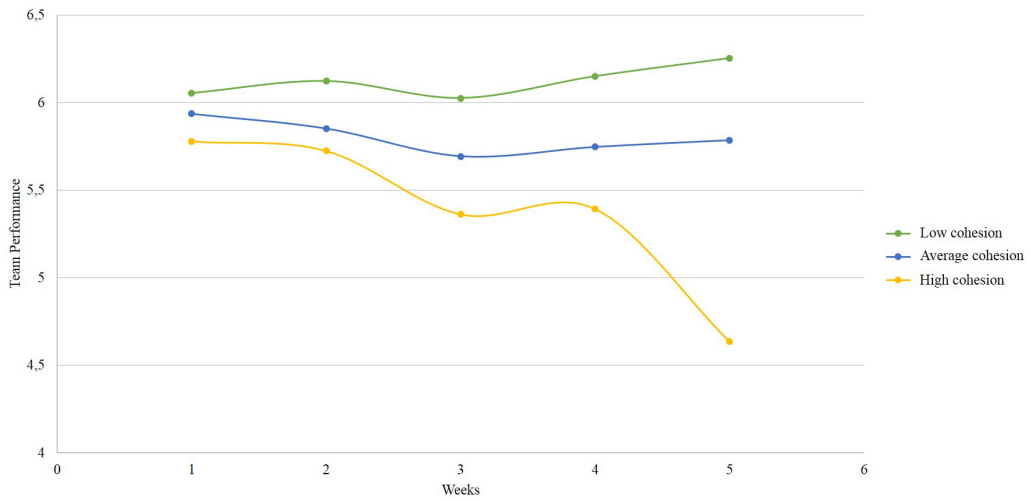

FIGURE 2 | Interteam growth trajectories for team performance over time, when initial team cohesion is low, medium, and high.

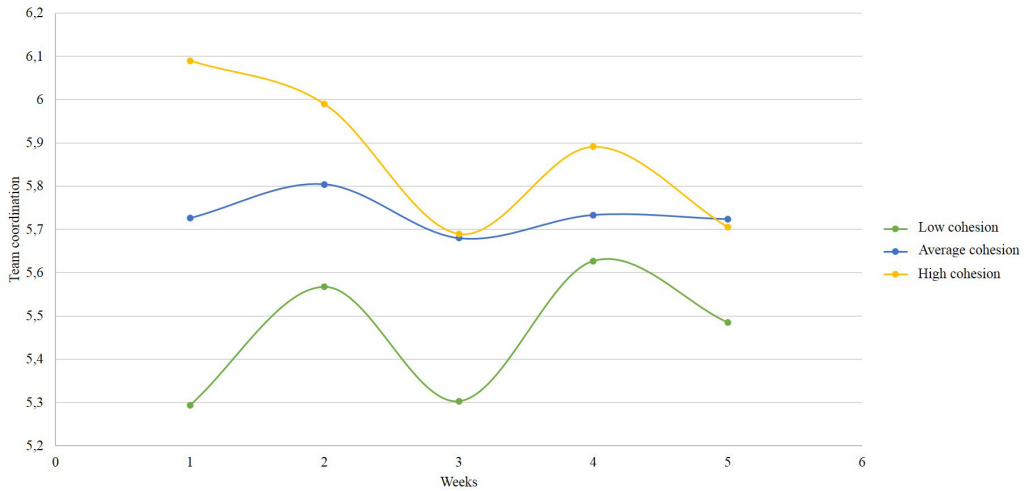

FIGURE 3 | Interteam growth trajectories for team coordination over time, when initial team cohesion is low, medium, and high.

the relationship between team cohesion and change in team performance over time, $B = -0.23$, $SE = 0.10$, $p = 0.02$, 95% CI (−0.455; −0.115). This finding does not support hypotheses 5.

DISCUSSION

The aim of this study was to examine how team cohesion contributes to performance trajectories over time, through coordination trajectories. More specifically, we tested whether coordination longitudinally mediates the relationship between cohesion and performance in a sample of teams enrolled in a business simulation competition. Overall, we found that cohesion is negatively related with team coordination and team performance over time. These findings suggest that higher cohesiveness might work as a disabling condition to coordination and performance trajectories in business teams. Although it was not part of our initial theorizing, finding that the level of team coordination and team performance at the beginning of the team performance cycle is negatively related with the level of change in both constructs over time further highlights that the extent to which team members engage in coordination behaviors such as sharing information or having meetings, or perform very highly at the beginning of a team performance cycle, can also be initial *disabling* conditions to the teamwork phenomena over time. These unexpected results have important theoretical and practical implications that deserve consideration.

Theoretical Implications

Although our findings diverge from previous research suggesting a positive relationship between team cohesion and team performance, they are not contradictory but rather

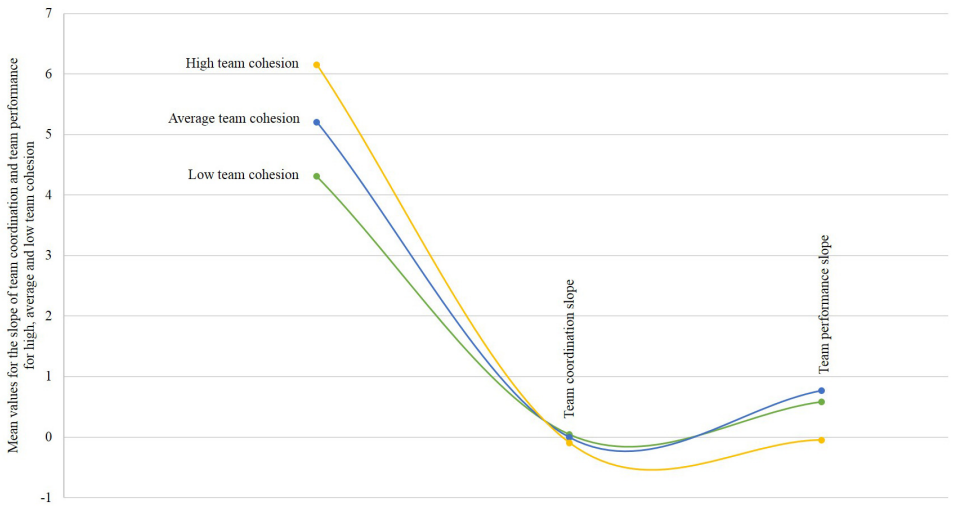

FIGURE 4 | Interteam mediation growth trajectories for the relationship between team cohesion and team performance, through team coordination, when initial team cohesion is low, medium, and high.

TABLE 6 | Unstandardized mediation latent growth curve modeling (hypotheses testing).

	B	*SE*	*p*	95% CI
Team cohesion regressed on the slope of team coordination.	−0.07	0.02	0.001	−0.102; −0.037
Slope of team coordination regressed on the slope of team performance.	3.22	0.98	<0.001	1.385; 4.962
Team cohesion regressed on the slope of team performance.	−0.18	0.29	0.835	−0.503; 0.000
Indirect effect for the slope of team coordination.	−0.23	0.10	0.022	−0.455; −0.115

N_{teams} = 158. Mediation model was tested controlling for the intercept of team performance, B = −0.13, SE = 0.09, p = 0.145, 95% CI [−0.281; 0.009], and team familiarity, B = 0.02, SE = 0.01, p < 0.001, 95% CI [0.012; 0.029], on the slope of team performance.

complementary. For instance, in Mathieu et al. (2015) the relationship between cohesion and performance was regarded longitudinally in the sense that the authors focused on the co-evolution of both constructs over time. Their findings suggest that cohesion and performance co-evolve positively over time, and their temporal relationship works better when cohesion is an antecedent of performance. Additionally, in Mathieu et al. (2015) the mean values for cohesion and performance at the beginning and end of the business simulation suggest that low cohesion management teams (sample 2) were achieving higher performance. Although this issue was not addressed by the authors, such findings are consistent with our results regarding the relationship between the level of cohesion at the beginning of a performance cycle, and the evolution of performance over time. It is possible that while looking at cohesion and performance as co-evolving constructs a positive relationship is found; when cohesion is regarded as an initial condition to the evolution of performance over time a negative relationship is found instead. This interpretation aligns with longitudinal theory suggesting that depending on how researchers study the temporal dynamics of their variables of interest, the relationship between the two same constructs may yield different patterns of results (Roe, 2008; Cronin et al., 2011; Kozlowski, 2015; Navarro et al., 2015).

We find additional explanations of our results in extant literature. Accordingly, Wise (2014) reported an inverse curvilinear relationship between team cohesion and team performance, in which team performance is lower at high and low levels of team cohesion and optimal at average levels of team cohesion. Research by Gargiulo and Benassi (2000) also suggests that highly cohesive communication networks are less likely to adapt their coordination strategies to situational requirements, thus performing poorly compared to moderately cohesive communication networks.

Another explanation of our pattern of findings could be that the high levels of team cohesion (M = 5.26, SD = 0.84) reported by participating teams in this study might have functioned as a heuristic for team members to determine to what extent the team was coordinating and performing well. In this line, Artinger et al. (2015) suggest that heuristics play a fundamental role in driving adaptive decision-making in managerial work environments. The authors advocate that heuristics provide a simple, less cognitively loaded, source of information from which fast decisions can be reached. However, such decisions can result in either a positive or negative outcome. This argument finds support in research by Callaway and Esser (1984) and Mullen et al. (1994) who found that more cohesive groups often render poorer decision-making outcomes. Thus, such findings align with *t*CAS theory (Arrow et al., 2000) and teamwork

development theorization proposing that teams performing in complex work environments (such as it is the case of *our* teams enrolled in the business game competition) perform high when the ties between team members are strong enough to keep them working together, but not too strong to prevent them to openly question and debate their ideas or be proactive in looking for external resources that might stimulate team performance (Kozlowski et al., 1999).

Our results also have implications for the study of team coordination. As previously stated, coordination is dependent on team members' ability to communicate openly, share relevant information, and plan (Ensley et al., 2002; Rico et al., 2008). However, the inefficiencies of high cohesion that cause a decrease in coordination capacity can harm team performance as well, given that team members will be less capable of articulating key information and task direct efforts (Esser, 1998). For teams whose initial cohesion levels are high, it might well be that biasing group phenomena such as groupthink and polarization interfere with the quality of the decisions that determine performance. Indeed, highly cohesive teams might avoid task/cognitive conflict because they believe that conflict will hamper team processes and outcomes. Rather than openly communicating, constructively confronting and exchanging ideas during performance episodes, team members will stick to the plan and avoid any kind of confrontation that threatens the team. Such passivity could be another good candidate in explaining why high initial levels of cohesion cause a reduction in task coordination and performance over time. Hardy et al. (2005) examined the relationship between cohesion, processes, and performance in sports teams; they found that 56% of the participants explicitly reported that cohesion was detrimental for both individual and collective dynamics. Participants reported that too much social cohesion caused wasted time during training, goal-related problems, and team member social isolation (e.g., ugly duckling effect; scapegoat effect). And importantly, participants also reported that high task cohesion often caused decreased member contribution to the team or task, reduced social relations, and communication inefficiencies.

Particularly, communication inefficiencies have been shown to be detrimental to coordination over time and to performance as well (e.g., Gargiulo and Benassi, 2000). Thus, when team members fail to assess relevant information, it is likely that errors will occur while communicating and planning (e.g., Grote et al., 2010). Such errors also result in a collective inability to build accurate team situational models, which results in poor performance (Stout et al., 1999; Rico et al., 2008). The increase of communication inefficiencies also brings several problems to task coordination because the decrease in team members' collective awareness reduces the likelihood that team members will attend task inputs and fellow team members needs in a timely manner (Driskell and Salas, 1992).

To summarize, most studies on cohesion and cohesion sub-dimensions have found empirical support for the benefits of cohesion. These results have been received without much questioning, probably because the idea of cohesion as a good thing is intuitively appealing and apparently logical. Although our findings suggest that too much cohesion is bad for team functioning, we cannot say that cohesion is not functional for coordination and performance. In fact, we show how cohesion is certainly important, but only to a certain extent. Accordingly, as elaborated above our findings echo previous research showing evidence of cohesion as having a negative effect on teamwork dynamics (e.g., Mullen et al., 1994; Wise, 2014). One important detail in our findings that cannot go unnoticed is that while a cross-sectional examination of the relationship between initial cohesion and coordination showed a positive relationship between both constructs (**Table 1**), using a longitudinal approach allowed us to identify a negative relationship. The evolution of coordination and performance over time worsened for teams whose levels of initial cohesion were higher. These findings raise an interesting point; they suggest that the way theory is built on the relationship between cohesion and teamwork dynamics should be firmly rooted in longitudinal data (Cronin et al., 2011; Kozlowski and Chao, 2012). Furthermore, these findings suggest that the way relationships between constructs are theorized and examined is heavily dependent on how levels of analysis and time are considered (Roe, 2008; Navarro et al., 2015).

Practical Implications

Looking at our results and how they build on existing practitioner literature, a key implication of this research is that for those planning to assemble a new project team or start a business venture, assuring an average level rather than a maximum level of team cohesion at the beginning of their task will pay off for key team processes and team performance over time.

Another implication is that this study may increase HR managers and team leaders' awareness that using cross-sectional versus longitudinal lenses to examine cohesion might result in conflicting information about the way teamwork dynamics will change across a full performance episode. Indeed, practitioners should note that managing performance over time requires the use of longitudinal data analysis in order to gain a more reliable perception of what is occurring.

Our findings also suggest that measuring cohesion at the beginning of a project might help toward designing better training and coaching support programs. Our results suggest that training coordination skills on teams is a valuable and important human resources management practice because being able to effectively coordinate over time is a baseline condition to achieve higher team performance in the workplace (Rico et al., 2018).

Limitations and Future Research

As in every empirical study, this research is not without its limitations. The first limitation of this research regards the fact that the unique features of the research context (i.e., a simulation) suggest caution when generalizing the research findings to real business organizations, and other work environments. Indeed, while the simulation emulates many of the characteristics of real business environments (e.g., the decisions that teams make about the way they manage their company will affect the company's value in the stock market), there are no real-world consequences resulting from good or bad managerial decisions

(e.g., the company going bankrupt and employees losing their jobs). However, the adoption of high-fidelity simulations like the business game competition in which our data were collected is not new to the study of teamwork phenomena such as team cohesion, team coordination, or team performance (e.g., Zaccaro et al., 1995; Mathieu et al., 2015). More, there is considerable growth in the number of empirical studies showing that high-fidelity simulations are most beneficial for learning and training because participants behave as if they were performing in *real life* (Marlow et al., 2017). This is particularly true for those simulations that best recreate the real-life contexts in which participants will have to perform. The closeness between simulation and reality increases the simulation's ecological validity, meaning that the likelihood that participants will behave in a similar way to how they would behave when performing in real environments is very high (Leemkuil and De Jong, 2012). Additionally, although we could not find any empirical papers addressing the extent to which the results of high-fidelity business simulations replicate in real business organizations, we found one study by Lievens and Patterson (2011), where the authors suggest that high-fidelity simulations are powerful predictors of job candidates' future job performance. This suggests that how individuals behave and perform during high-fidelity simulations can be replicated in real jobs.

Another limitation in our study could be that our sample is partially formed by teams of undergraduate students which also may affect the generalizability of our findings (Peterson, 2001). However, some teams in our sample were also entirely (or partially) composed of professional workers. In many organizations, work teams might have different degrees of maturation or professional experience. It is likely that some teams have very little experience (e.g., recently graduated team members), while others are composed of senior individuals that are highly experienced (Kozlowski et al., 1999). As in the previous limitation, we believe that this study replicates real-world conditions by considering teams that have highly experienced (professional workers) and poorly experienced (undergraduate students) teams. Therefore, we think that the fact our sample included students is not a serious threat to the generalizability of our findings. Besides, Druckman and Kam (2011) have systematically compared differences in research findings, between studies using students versus non-students as participants, thus finding little to none significant differences between them[1].

A third limitation in this study is missing data. Missing data often raises several concerns regarding how reliable research findings can be; because the results might be contingent on the characteristics of the individuals that decide to participate in the study rather than the real relationship the constructs have (Graham, 2009). However, the fact that our missing data pattern was MCAR and given the utilization of a FIML estimation to test our hypotheses, the chance that missing data had an effect on the research outcomes is very small (Graham, 2009).

Having found no support for most of our research hypotheses might hinder perceptions about the potential contribution of this study. However, recent work by authors such as Franco et al. (2014) have raised a warning regarding the potentially biasing effect of avoiding the publication of research findings that support the null hypothesis, especially in the social sciences. They stress the negative biasing effects that such practice has in knowledge development because it limits our full understanding of social systems. Thus, the communication and dissemination of unexpected or contradictory findings are important to improve social sciences (Scargle, 1999).

Finally, we see three research opportunities that are worth exploring since they could help solving most of the aforementioned limitations. To test the robustness and generalizability of our research findings, future studies could examine what will happen if: (a) individuals are randomly assigned to teams, (b) individual characteristics such as task expertise are considered, and (c) data are collected in real business environments. All of these could be addressed with two studies. Study 1 could focus on (a) and (b), while Study 2 could focus on (c). Both (a) and (b) could be addressed in an experimental setting where the main task would be performing the same business game competition that we use, and where team member allocation (random vs. intact) and expertise (low expertise vs. high expertise) are regarded as independent variables. For instance, it could be that for teams whose team members are less familiar with each other, high expertise will be fundamental to ensure more positive team coordination and team performance trajectories across the performance cycle (e.g., Zaccaro et al., 1995; Mathieu et al., 2015). More, building on recent work by Maynard et al. (2019), by measuring team cohesion (task and social) as a covariate, researchers could also learn how both team familiarity and team cohesion contribute to teamwork processes such as team coordination and team performance. Once Study 1 is performed, Study 2 could be conducted with the goal of replicating and extending our findings using a quasi-experimental setting where newly assembled teams are compared with teams with a long existence.

Besides these suggestions, we also encourage researchers to explore (a) how each sub-dimension of cohesion influences the evolution of coordination and performance over time, and (b) what would be the temporal dynamics of team cohesion, team coordination, and team performance if an event that triggered adaptation would happen at the halfway point transition of team performance cycle (Maynard et al., 2015). Social cohesion is the sub-dimension that mostly relates to the quality of the relationships within the team (Greer, 2012). Hence, it is likely that initial social cohesion will have a stronger detrimental effect on task coordination and performance over time, than task cohesion will. In our study, we could not know the extent to which participants worked together every week, and how many hours they spent together on social activities. Future studies could have access to this information and regard it as proxies

[1]The results of the independent samples t-test for team cohesion suggest that professional teams and student teams did not differ on this regard, $t\,(151) = -1.14$, $p = 0.312$. The results of the two-way repeated measures ANOVA suggest that, although that team coordination, $F(4,151) = 14.07$, $p < 0.001$, and team performance, $F(4,151) = 2.42$, $p = 0.048$, changed over time, change was not qualified by an interaction between time and group type for team coordination, $F(4,151) = 0.67$, $p = 0.617$, and team performance, $F(4,151) = 0.48$, $p = 0.753$.

of team cohesion. How each cohesion dimension contributes to coordination and performance trajectories over time might also depend on the team development stage (Kozlowski et al., 1999), and even the extent to which the need for team adaptation is triggered halfway through the team performance cycle (Maynard et al., 2015). For less experienced teams with little familiarity among team members, social cohesion and interpersonal attraction might be the most important dimensions of cohesion that need to be leveraged. The sooner team members establish stronger social ties, the better they will be able to engage in collaborative learning and performance. Engaging in such behaviors will then facilitate the development of team mental models, which are needed for task coordination and performance. Over time, as teams gain experience and forge stronger interpersonal connections, task cohesion might emerge as a more relevant dimension of team cohesion. This is because it will give team members a sense of agreement and stability that will reduce stress and cognitive load and give team members the opportunity to focus on task or goal-directed behaviors. Still, if a dramatic shift occurs halfway through the team performance cycle, high social cohesion might be fundamental to prevent team coordination breakdowns and severe performance losses (Maynard et al., 2015).

CONCLUSION

Understanding the dynamics characterizing teamwork and team members' interrelations requires considering the role of time and the incorporation of initial conditions triggering team processes trajectories (Arrow et al., 2000; Hackman, 2012; Ramos-Villagrasa et al., 2018). This study contributes to the teamwork literature by showing that the more cohesive a team is, the greater the likelihood that the team will see its ability to coordinate and perform impaired over time.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of ethical guidelines of the Ethical Committee (CE) at ISCTE Instituto Universitário, with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

All authors were involved in the righting of the theoretical background and discussion sections. PM-Q was also responsible for analyzing and reporting the results.

FUNDING

This work was partially supported by a grant from the Portuguese Foundation for Science and Technology under grant No. SFRH/BD/77614/2011; William James Center for Research, ISPA – Instituto Universitário was supported by the FCT Grant No. UID/PSI/04810/2013.

REFERENCES

Arrow, H., McGrath, J. E., and Berdahl, J. L. (2000). *Small Groups as Complex Systems: Formation, Coordination, Development, and Adaptation*. Thousand Oaks, CA: Sage Publications.

Artinger, F., Petersen, M., Gigerenzer, G., and Weibler, J. (2015). Heuristics as adaptive decision strategies in management. *J. Organ. Behav.* 36, 33–52. doi: 10.1002/job.1950

Beal, D. J., Cohen, R. R., Burke, M. J., and McLendon, C. L. (2003). Cohesion and performance in groups: a meta-analytic clarification of construct relations. *J. Appl. Psychol.* 88, 989–1004. doi: 10.1037/0021-9010.88.6.989

Bliese, P. D. (2000). "Within-group agreement, non-independence, and reliability: Implications for data aggregation and analysis," in *Multilevel Theory, Research, and Methods in Organizations: Foundations, Extensions, and New Directions*, eds J. K. Katherine and S. J. Kozlowski (San Francisco, CA: Jossey-Bass), 349–381.

Callaway, M. R., and Esser, J. K. (1984). Groupthink: effects of cohesiveness and problem-solving procedures on group decision making. *Soc. Behav. Pers.* 12, 157–164.

Carless, S. A., and DePaola, C. (2000). The measurement of cohesion in work teams. *Small Group Res.* 31, 71–88. doi: 10.1177/104649640003100104

Carron, A. V., and Brawley, L. R. (2000). Cohesion: conceptual and measurement issues. *Small Group Res.* 31, 89–106. doi: 10.1177%2F104649640003100105

Chan, D. (1998). The conceptualization and analysis of change over time: an integrative approach incorporating longitudinal mean and covariance structures analysis (LMACS) and multiple indicator latent growth modeling (MLGM). *Organ. Res. Methods* 1, 421–483. doi: 10.1177/109442819814004

Chen, F. F. (2007). Sensitivity of goodness of fit indexes to lack of measurement invariance. *Struct. Equ. Modeling* 14, 464–504. doi: 10.1080/10705510701301834

Cheong, J., MacKinnon, D. P., and Khoo, S. T. (2003). Investigation of mediational processes using parallel process latent growth curve modeling. *Struct. Equ. Modeling* 10, 238–262. doi: 10.1207/S15328007SEM1002_5

Cronin, M. A., Weingarten, L. R., and Todorova, G. (2011). Dynamics in groups: are we there yet? *Acad. Manag. Ann.* 5, 571–612. doi: 10.1080/19416520.2011.590297

Curral, L., Marques-Quinteiro, P., Gomes, C., and Lind, P. G. (2016). Leadership as an emergent feature in social organizations: insights from a laboratory simulation experiment. *PLoS One* 11:e0166697. doi: 10.1371/journal.pone.0166697

Driskell, J. E., and Salas, E. (1992). Collective behavior and team performance. *Hum. Factors J. Hum. Factors Ergon. Soc.* 34, 277–288. doi: 10.1177/001872089203400303

Druckman, J. N., and Kam, C. D. (2011). "Students as experimental participants," in *Cambridge Handbook of Experimental Political Science*, Vol. 1, eds J. M. Druckman, D. P. Green, J. H. Kuklinski, and A. Lupia (Cambridge: Cambridge University Press), 41–57.

Ensley, M. D., Pearson, A. W., and Amason, A. C. (2002). Understanding the dynamics of new venture top management teams: cohesion, conflict, and new venture performance. *J. Bus. Ventur.* 17, 365–386. doi: 10.1016/S0883-9026(00)00065-3

Esser, J. K. (1998). Alive and well after 25 years: a review of groupthink research. *Organ. Behav. Hum. Decis. Process.* 73, 116–141. doi: 10.1006/obhd.1998.2758

Festinger, L. (1950). Informal social communication. *Psychol. Rev.* 57, 271–282. doi: 10.1037/h0056932

Franco, A., Malhotra, N., and Simonovits, G. (2014). Publication bias in the social sciences: unlocking the file drawer. *Science* 345, 1502–1505. doi: 10.1126/science.1255484

Gargiulo, M., and Benassi, M. (2000). Trapped in your own net? Network cohesion, structural holes, and the adaptation of social capital. *Organ. Sci.* 11, 183–196. doi: 10.1287/orsc.11.2.183.12514

Gersick, C. J. (1991). Revolutionary change theories: a multilevel exploration of the punctuated equilibrium paradigm. *Acad. Manage. Rev.* 16, 10–36. doi: 10.5465/AMR.1991.4278988

Graham, J. W. (2009). Missing data analysis: making it work in the real world. *Ann. Rev. Psychol.* 60, 549–576. doi: 10.1146/annurev.psych.58.110405.085530

Greer, L. L. (2012). Group cohesion: then and now. *Small Group Res.* 43, 655–661. doi: 10.1177/1046496412461532

Grote, G., Kolbe, M., Zala-Mezö, E., Bienefeld-Seall, N., and Künzle, B. (2010). Adaptive coordination and heedfulness make better cockpit crews. *Ergonomics* 53, 211–228. doi: 10.1080/00140130903248819

Guastello, S. J. (2010). Nonlinear dynamics of team performance and adaptability in emergency response. *Hum. Factors* 52, 162–172. doi: 10.1177/0018720809359003

Guastello, S. J., Gorin, H., Huschen, S., Peters, N. E., Fabisch, M., Poston, K., et al. (2013). The minimum entropy principle and task performance. *Nonlinear Dynamics Psychol. Life Sci.* 17, 405–423.

Guastello, S. J., and Guastello, D. D. (1998). Origins of coordination and team effectiveness: a perspective from game theory and nonlinear dynamics. *J. Appl. Psychol.* 83, 423–437.

Gully, S. M., Devine, D. J., and Whitney, D. J. (1995). A meta-analysis of cohesion and performance effects of level of analysis and task interdependence. *Small Group Res.* 26, 497–520. doi: 10.1177/1046496495264003

Hackman, J. R. (2012). From causes to conditions in group research. *J. Organ. Behav.* 33, 428–444. doi: 10.1002/job.1774

Hardy, J., Eys, M. A., and Carron, A. V. (2005). Exploring the potential disadvantages of high cohesion in sports teams. *Small Group Res.* 36, 166–187. doi: 10.1177/1046496404266715

Hopwood, C. J., and Donnellan, M. B. (2010). How should the internal structure of personality inventories be evaluated? *Pers. Soc. Psychol. Rev.* 14, 332–346. doi: 10.1177/1088868310361240

Hu, L. T., and Bentler, P. M. (1998). Fit indices in covariance structure modeling: sensitivity to underparameterized model misspecification. *Psychol. Methods* 3, 424–453. doi: 10.1037/1082-989X.3.4.424

James, L. R., Demaree, R. G., and Wolf, G. (1984). Estimating within-group interrater reliability with and without response bias. *J. Appl. Psychol.* 69, 85–98. doi: 10.1037/0021-9010.69.1.85

Jarzabkowski, P. A., Lê, J. K., and Feldman, M. S. (2012). Toward a theory of coordinating: creating coordinating mechanisms in practice. *Organ. Sci.* 23, 907–927. doi: 10.1287/orsc.1110.0693

Kozlowski, S. W. (2015). Advancing research on team process dynamics theoretical, methodological, and measurement considerations. *Organ. Psychol. Rev.* 5, 270–299. doi: 10.1177/2041386614533586

Kozlowski, S. W., and Chao, G. T. (2012). The dynamics of emergence: cognition and cohesion in work teams. *Manage. Decis. Econ.* 33, 335–354. doi: 10.1002/mde.2552

Kozlowski, S. W. J., and Klein, K. J. (eds). (2000). "A multilevel approach to theory and research in organizations: contextual, temporal, and emergent processes," in *Multilevel Theory, Research, and Methods in Organizations: Foundations, Extensions, and New Directions* (San Francisco, CA: Jossey-Bass), 3–90.

Kozlowski, S. W., Gully, S. M., Nason, E. R., and Smith, E. M. (1999). "Developing adaptive teams: a theory of compilation and performance across levels and time," in *The Changing Nature of Performance: Implications for Staffing, Motivation, and Development*, eds D. R. Ilgen and E. D. Pulakos (Hoboken, NJ: Wiley), 240–292.

Lance, C. E., Vandenberg, R. J., and Self, R. M. (2000). Latent growth models of individual change: the case of newcomer adjustment. *Organ. Behav. Hum. Decis. Process.* 83, 107–140. doi: 10.1006/obhd.2000.2904

Leemkuil, H., and De Jong, T. O. N. (2012). Adaptive advice in learning with a computer-based knowledge management simulation game. *Acad. Manage. Learn. Educ.* 11, 653–665. doi: 10.5465/amle.2010.0141

LePine, J. A., Piccolo, R. F., Jackson, C. L., Mathieu, J. E., and Saul, J. R. (2008). A meta-analysis of teamwork processes: tests of a multidimensional model and relationships with team effectiveness criteria. *Pers. Psychol.* 61, 273–307. doi: 10.1111/j.1744-6570.2008.00114.x

Lewin, R. (1993). *Complexity: Life at the Edge of Chaos*. London: Phoenix.

Lievens, F., and Patterson, F. (2011). The validity and incremental validity of knowledge tests, low-fidelity simulations, and high-fidelity simulations for predicting job performance in advanced-level high-stakes selection. *J. Appl. Psychol.* 96, 927–940. doi: 10.1037/a0023496

Little, R. J. A. (1988). A test of missing completely at random for multivariate data with missing values. *J. Am. Stat. Assoc.* 83, 1198–1202. doi: 10.1080/01621459.1988.10478722

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manage. Rev.* 26, 356–376. doi: 10.5465/AMR.2001.4845785

Marlow, S. L., Lacerenza, C. N., Reyes, D., and Salas, E. (2017). "11 The science and practice of simulation-based training in organizations," in *The Cambridge Handbook of Workplace Training and Employee Development*, ed. K. G. Brown (New York, NY: Cambridge University Press), 256–277.

Marques-Quinteiro, P., Curral, L., Passos, A. M., and Lewis, K. (2013). And now what do we do? The role of transactive memory systems and task coordination in action teams. *Group Dyn. Theory Res. Pract.* 17, 194–206. doi: 10.1037/a0033304

Mathieu, J. E., Kukenberger, M. R., DInnocenzo, L., and Reilly, G. (2015). Modeling reciprocal team cohesion–performance relationships, as impacted by shared leadership and members competence. *J. Appl. Psychol.* 100, 713–734. doi: 10.1037/a0038898

Maynard, M. T., Kennedy, D. M., Sommer, S. A., and Passos, A. M. (2015). "Team cohesion: A theoretical consideration of its reciprocal relationships within the team adaptation nomological network," in *Team Cohesion: Advances in Psychological Theory, Methods and Practice*, ed. E. Salas (Bingley: Emerald Group Publishing), 83–111.

Maynard, M. T., Mathieu, J. E., Gilson, L. L., Sanchez, R. D., and Dean, M. D. (2019). Do i really know you and does it matter? Unpacking the relationship between familiarity and information elaboration in global virtual teams. *Group Organ. Manag.* 44, 3–37. doi: 10.1177/1059601118785842

Menges, J. I., and Kilduff, M. (2015). Group emotions: cutting the gordian knots concerning terms, levels-of-analysis, and processes. *Acad. Manag. Ann.* 9, 845–928.

Mullen, B., Anthony, T., Salas, E., and Driskell, J. E. (1994). Group cohesiveness and quality of decision making an integration of tests of the groupthink hypothesis. *Small Group Res.* 25, 189–204. doi: 10.1177/1046496494252003

Muthén, B. O., and Muthén, L. K. (2012). *Mplus Version 7 [Computer Programme]*. Los Angeles, CA: Muthén & Muthén.

Navarro, J., Roe, R. R., and Artilis, M. I. (2015). Taking time seriously: changing practices and perspectives in work/organizational psychology. *Revista de Psicología del Trabaljo y de las Organizaciones* 31, 135–145. doi: 10.1016/j.rpto.2015.07.002

Navarro, J., and Rueff-Lopes, R. (2015). Healthy variability in organizational behavior: empirical evidence and new steps for future research. *Nonlinear Dynamics Psychol. Life Sci.* 19, 529–552.

Peterson, R. A. (2001). On the use of college students in social science research: insights from a second-order meta-analysis. *J. Consum. Res.* 28, 450–461. doi: 10.1086/323732

Ployhart, R. E., and Vandenberg, R. J. (2010). Longitudinal research: the theory, design, and analysis of change. *J. Manag.* 36, 94–120. doi: 10.1177/0149206309352110

Ramos-Villagrasa, P., Marques-Quinteiro, P., Navarro, J., and Rico, R. (2018). Reviewing 17 years of teams as complex adaptive systems. *Small Group Res.* 49, 135–176. doi: 10.1177/1046496417713849

Ramos-Villagrasa, P. J., Navarro, J., and García-Izquierdo, A. L. (2012). Chaotic dynamics and team effectiveness: evidence from professional basketball. *Eur. J. Work Organ. Psychol.* 21, 778–802. doi: 10.1080/1359432X.2012.669525

Reagans, R., and McEvily, B. (2003). Network structure and knowledge transfer: the effects of cohesion and range. *Adm. Sci. Q.* 48, 240–267. doi: 10.2307/3556658

Rebelo, T., Stamovlasis, D., Lourenço, P. R., Dimas, I., and Pinheiro, M. (2016). A cusp catastrophe model for team learning, team potency and team culture. *Nonlinear Dynamics Psychol. Life Sci.* 20, 537–563.

Rico, R., Hinsz, V. B., Davison, R. B., and Salas, E. (2018). Structural influences upon coordination and performance in multiteam systems. *Hum. Resour. Manage. Rev.* 28, 332–346. doi: 10.1016/j.hrmr.2017.02.001

Rico, R., Sánchez-Manzanares, M., Gil, F., and Gibson, C. (2008). Team implicit coordination processes: a team knowledge–based approach. *Acad. Manage. Rev.* 33, 163–184. doi: 10.5465/AMR.2008.27751276

Roe, R. A. (2008). Time in applied psychology: the study of" what happens" rather than" what is". *Eur. Psychol.* 13, 37–52. doi: 10.1027/1016-9040.13.1.37

Scargle, J. D. (1999). Publication bias (the "file-drawer problem") in scientific inference. arXiv:physics/9909033 [Preprint].

Schlomer, G. L., Bauman, S., and Card, N. A. (2010). Best practices for missing data management in counseling psychology. *J. Couns. Psychol.* 57, 1–10. doi: 10.1037/a0018082

Schmutz, J., Hoffmann, F., Heimberg, E., and Manser, T. (2015). Effective coordination in medical emergency teams: the moderating role of task type. *Eur. J. Work Organ. Psychol.* 24, 761–776. doi: 10.1080/1359432X.2015.1018184

Selig, J. P., and Preacher, K. J. (2009). Mediation models for longitudinal data in developmental research. *Res. Hum. Dev.* 6, 144–164. doi: 10.1080/15427600902911247

Stout, R. J., Cannon-Bowers, J. A., Salas, E., and Milanovich, D. M. (1999). Planning, shared mental models, and coordinated performance: an empirical link is established. *Hum. Factors J. Hum. Factors Ergon. Soc.* 41, 61–71. doi: 10.1518/001872099779577273

Uitdewilligen, S., Rico, R., and Waller, M. J. (2018). Fluid and stable: dynamics of team action patterns and adaptive outcomes. *J. Organ. Behav.* 39, 1113–1128. doi: 10.1002/job.2267

van de Schoot, R., Lugtig, P., and Hox, J. (2012). A checklist for testing measurement invariance. *Eur. J. Dev. Psychol.* 9, 486–492. doi: 10.1080/17405629.2012.686740

von Soest, T., and Hagtvet, K. A. (2011). Mediation analysis in a latent growth curve modeling framework. *Struct. Equ. Modeling* 18, 289–314. doi: 10.1080/10705511.2011.557344

Weiss, H. M., and Cropanzano, R. (1996). "Affective events theory: a theoretical discussion of the structure, causes and consequences of affective experiences at work," in *Research in Organizational Behavior: An Annual Series of Analytical Essays and Critical Reviews*, Vol. 18, eds B. M. Staw and L. L. Cummings (Greenwich: JAI Press), 1–74.

West, M. A., Markiewicz, L., and Dawson, J. F. (2004). *TPI–Team Performance Inventory: User Guide*. Birmingham: Aston Organization Development.

Wise, S. (2014). Can a team have too much cohesion? The dark side to network density. *Eur. Manag. J.* 32, 703–711. doi: 10.1016/j.emj.2013.12.005

Zaccaro, S. J., Gualtieri, J., and Minionis, D. (1995). Task cohesion as a facilitator of team decision making under temporal urgency. *Mil. Psychol.* 7, 77–93. doi: 10.1207/s15327876mp0702_3

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Marques-Quinteiro, Rico, Passos and Curral. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

METHODS
published: 24 April 2019
doi: 10.3389/fpsyg.2019.00863

Using State Space Grids for Modeling Temporal Team Dynamics

Annika L. Meinecke[1], Clara S. Hemshorn de Sanchez[1], Nale Lehmann-Willenbrock[1] and Claudia Buengeler[2]*

[1] Department of Industrial/Organizational Psychology, Institute of Psychology, University of Hamburg, Hamburg, Germany,
[2] Department of Human Resource Management and Organization, Institute of Business, University of Kiel, Kiel, Germany

We outline the potential of dynamics systems theory for researching team processes and highlight how state space grids, as a methodological application rooted in the dynamic systems perspective, can help build new knowledge about temporal team dynamics. Specifically, state space grids visualize the relationship between two categorical variables that are synchronized in time, allowing the (team) researcher to track and capture the emerging structure of social processes. In addition to being a visualization tool, state space grids offer various quantifications of the dynamic properties of the team system. These measures tap into both the content and the structure of the dynamic team system. We highlight the implications of the state space grid technique for team science and discuss research areas that could benefit most from the method. To illustrate the various opportunities of state space grids, we provide an application example based on coded team interaction data. Moreover, we provide a step-by-step tutorial for researchers interested in using the state space grid technique and provide an overview of current software options. We close with a discussion of how researchers and practitioners can use state space grids for team training and team development.

Keywords: team science, dynamic systems theory, state space grids, team process dynamics, interaction analysis

OPEN ACCESS

Edited by:
Michael Rosen,
Johns Hopkins Medicine,
United States

Reviewed by:
Bertolt Meyer,
Technische Universität Chemnitz,
Germany
Paul B. Paulus,
University of Texas at Arlington,
United States

****Correspondence:***
Annika L. Meinecke
annika.luisa.meinecke@uni-hamburg.de

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *30 October 2018*
Accepted: *02 April 2019*
Published: *24 April 2019*

Citation:
Meinecke AL, Hemshorn de Sanchez CS, Lehmann-Willenbrock N and Buengeler C (2019) Using State Space Grids for Modeling Temporal Team Dynamics. Front. Psychol. 10:863. doi: 10.3389/fpsyg.2019.00863

INTRODUCTION

Team researchers agree that teams are inherently dynamic in nature (e.g., Cronin et al., 2011; Herndon and Lewis, 2015; Waller et al., 2016). Teams are often referred to as complex dynamic systems that evolve and change over time as they adapt to new and changing task demands, or as members leave or join the team (Arrow et al., 2000; McGrath et al., 2000; Kozlowski and Ilgen, 2006). Because teams are comprised of independent actors that interact over time, the evolution of teams is non-linear and highly dynamic (e.g., Guastello and Liebovitch, 2009). A recent review of the literature on teams as complex and dynamic systems emphasizes the need for team research to embrace methods that can account for this complexity and dynamism at the core of team processes (Ramos-Villagrasa et al., 2018).

Yet, existing research is often based on simplified theoretical models that do not appropriately account for dynamic team processes. For example, McGrath (1964) seminal work emphasized the central role of team processes as the underlying mechanism by which team members combine their individual resources to resolve team task demands. Yet, team processes are often treated as

if they were "frozen" in a mediation box (Kozlowski, 2015), rather than accounting for the complex temporal interaction dynamics at the core of most team processes (e.g., Lehmann-Willenbrock and Allen, 2018).

In this paper, we draw from dynamic systems theory (e.g., Thelen and Smith, 1998) to address the challenge of adequately conceptualizing and operationalizing temporally embedded team processes. Specifically, we propose to study how teams evolve and mature in organizations by showcasing how state space grids (SSGs, Lewis et al., 1999; Hollenstein, 2013) as a methodological application rooted in dynamics system theory can capture and advance our understanding of complex team temporal dynamics. SSGs were originally used by developmental psychologists to study how developmental states occur in real time and how, over time, interpersonal patterns form and stabilize (Hollenstein, 2007, 2013). We argue that team science can greatly benefit from this approach. We discuss the benefits of the dynamic systems perspective for team science and illustrate how SSGs can trigger novel insights into team evolution and maturation, address previous methodological shortcomings, and pave the way for innovative team feedback and intervention practices.

In sum, the aim of our paper is to (a) provide a discussion of how dynamic systems theory can advance our understanding of non-linear processes unfolding in groups and teams[1], (b) give an in- depth, step-by-step tutorial of how to use the SSG technique to empirically test ideas derived from dynamic systems theory, and (c) outline the benefits of SSGs for both team research and team development. To illustrate the approach, we present sample SSGs generated from coded team interactions.

DYNAMIC SYSTEMS THEORY

A dynamic system is defined as a collection of elements that change over time (Alligood et al., 1996; Thelen and Smith, 1998). As group and team researchers, we are interested in the human domain and therefore focus on groups of individuals in terms of such dynamic systems (see also McGrath et al., 2000). In doing so, we regard groups as *open* rather than closed systems because they are embedded in and interact with their surrounding environment, rather than being isolated from it (Arrow et al., 2000; Marrone, 2010). Of note, dynamic systems theory is not limited to the study of humans. It originated from the fields of physics and mathematics and was later transferred to biological and psychological research (for a more detailed discussion of the foundations and history of dynamics systems theory, see Guastello and Liebovitch, 2009 as well as Thelen and Smith, 1998). In the following, we will outline the basic assumptions underlying dynamic systems approaches and illustrate them with examples from both developmental psychology— the field of psychology in which the dynamic systems perspective is most strongly represented —and team research. We acknowledge here that our outline of dynamics systems theory comprises only its basic structure but that there is much more to explore about the dynamics systems perspective and how it can help to shed new light on how teams evolve and mature over time. We encourage interested readers to follow up with the seminal work of Arrow et al. (2000) who have described teams as complex, adaptive systems in more detail.

The central tenet of dynamic systems theory is that a system (e.g., an individual, a dyad, or a team) can only be in one state at any given moment in time, although several states are available (Thelen and Smith, 1998). For a team researcher, such states may be specific behaviors but they could also represent emotional, affective, or cognitive elements. A system is usually characterized by a certain degree of variability, meaning that it moves from state to state. The change from one state to another describes the *dynamics* of a system. These dynamics are typically messy, difficult to predict, and non-linear in nature. Despite this inherently dynamic perspective, systems do not operate randomly but tend to stabilize in certain states. Thus, over time stable and recurrent patterns emerge. This idea of self-organization or emergence (a term more familiar to team science; Kozlowski, 2015; Waller et al., 2016) "is at the heart of any dynamic systems approach" (Hollenstein, 2013, p. 3; see also Lewis, 2000).

Self-organization in dynamic systems theory is largely seen as a bottom-up process. Higher-order patterns that are characteristic for a system emerge from interactions among lower-order elements represented by individual transitions between states. This process of emergence is often spontaneous and thus challenges traditional ideas of determinism (Lewis, 2000). It is important in this context that dynamic systems theory rather functions as a meta-theoretical framework (Hollenstein, 2013). It is not bound to a specific time frame, but provides a flexible account for understanding the changes of dynamic systems. Dynamic systems can change and stabilize over the course of minutes, weeks, months, or years. Depending on the specific research question at hand and the phenomenon to be examined, a suitable time scale must be selected to observe the dynamics of the particular system. Further adding to its complexity, the dynamics systems perspective assumes that change is hierarchically nested in time (Granic, 2005). This means that patterned structures at a higher level also have a top-down effect in that they shape and constrain interactions among lower-order elements.

To make these assumptions more tangible, we can extrapolate from examples from developmental psychology (e.g., Lewis, 2000; Hollenstein, 2011). In this line of research, lower-order dynamics are often studied in real time at the moment-to-moment (micro) level. For instance, the dynamic systems perspective can help to understand how emotional development unfolds over time (for an edited volume see Lewis and Granic, 2000). At the micro level, emotional states are fast and fleeting and can change within seconds. Over the course of minutes or hours, however, they can persist and transform into more stable moods. These moods, in turn, impact real-time emotional states. It is less likely that we experience instantaneous joy and happiness when we are currently in a bad mood. Through a developmental lens, such recursive patterns can be traced even further. A multiplicity of factors, such as the environment in which we grow up or our temperament, influence which emotional experiences repeatedly

[1] In accordance with much of the existing literature, we use the terms "group" and "team" synonymously.

solidify and expand into moods. In the long run, often over the course of years, these experiences shape our personality. Personality then has further top-down effects and influences how we behave in and evaluate certain (emotional) situations (see also Hollenstein, 2013).

Transferred to team research, dynamic systems theory can help us understand how moment-to-moment interactions among team members may result in repeating and stable patterns of behavior, such as those that lead to the development of group norms (e.g., norms for turn taking during an organizational meeting). These group norms may well restrict the team members' behavior during subsequent team meetings. Thus, dynamic systems theory postulates causal processes both *within* and *between* time scales (Hollenstein, 2013). Next, we briefly outline the key terminology associated with dynamic systems theory before introducing SSGs as a method for applying dynamic systems theory to the study of team evolution and maturation.

State Space, Attractors, Repellors, and Phase Transitions

As a system transitions from one state to another it moves within a specific space. This space is defined by the range of all possible states and is referred to as the *state space* (Hollenstein, 2007). As outlined above, dynamic systems tend to stabilize such that they rarely explore or "visit" the full range of possible states in the state space. In other words, some states seem to be more attractive for the system than others. States that are visited more often, thus stable and recurrent states, are termed *attractors* (Hollenstein, 2007, 2013). It is easy for the system to rest in these states and more difficult to exit them. Returning to our emotion example, negative mood or even depression have been discussed as attractors (Johnson and Nowak, 2002). Looking at organizational teams, a team leader might constitute an attractor because the conversation among the team tends to center around him/her during an interaction episode such as a team meeting. Likewise, a team with a history of conflicts might fall back into accusatory patterns as soon as certain themes are mentioned in a meeting. The opposite of attractors are *repellors*, states that are visited less often (Hollenstein, 2007). It is more difficult for the system to reach these states and easier to leave them. As an illustration, the concepts of attractors and repellors are often represented as an undulating landscape of peaks (i.e., repellors) and valleys (i.e., attractors; Hollenstein, 2007). The behavior of the system is traceable like a trajectory or "walking path" as the system moves through the state space.

The arrangement of attractors and repellors is not set in stone. Instead, systems evolve and often adapt to changes in the environment. At certain critical points in time, the system breaks out of its usual pattern and forms new dynamics before stabilizing in a new pattern. This reconfiguration of the state space is labeled *phase transition* (Hollenstein, 2007). An example often used in developmental psychology is puberty. Puberty is characterized by a temporary increase in variability, including entirely new patterns of behavior that teenagers might exhibit. As a result, systems are less predictable during a phase transition (Hollenstein, 2013). After the transition, a new stability matures. For an organizational team, a phase transition might occur when a new team member joins the team, when the team has to take on radically different tasks, or when a major misunderstanding causes conflict among the team members.

STATE SPACE GRIDS

SSGs are one way to empirically test concepts from dynamic system theory in a very accessible manner (Hollenstein, 2007). The SSG technique allows for the visualization of real-time trajectories and provides various quantifications for the content and structures of these trajectories. In the following, we first describe the general set-up of SSGs and present key studies on the technique. Next, we introduce typical measures that can be derived from the visualization.

Visualizing Patterns of Dynamic Interactions

The SSG is a graphic representation of the state space of a dynamic system and plots the system's trajectory as it moves through the state space. Most studies that employ the SSG technique focus on just two dimensions (i.e., variables) that characterize the state space. Like a chessboard, the SSG is then "a two-dimensional plane formed by the intersection of two perpendicular dimensions or axes" (Hollenstein, 2013, p. 11). Each position on the grid can be expressed as a combination of one value on the *x*-axis and one value on the *y*-axis. SSGs can be derived from any categorical dimensions[2] as long as the values on both dimensions are mutually exclusive and exhaustive so that all possible states of the system are mapped out (Hollenstein, 2013). The scale and/or range of each dimension does not have to be equivalent which means that the state space does not have to be a perfect square (Hollenstein, 2013). It is important, however, that the two dimensions underlying the SSG can be assessed at the same point in time as each cell represents the simultaneous combination of the two values in the corresponding row and column. Thus, the event sequences for the two dimensions need to be synchronized. Any time series with at least two synchronized streams of coded categorical data is suitable for creating a SSG (Hollenstein, 2007).

SSGs as a methodological application rooted in the dynamic systems perspective were first introduced to the field of developmental psychology by Lewis et al. (1999). Today, new developments with regard to the SSG technique and the related GridWare software (see below) are headed by Tom Hollenstein at Queen's University, Kingston, Ontario. SSGs were originally developed as a novel approach to study dynamic processes in early socioemotional development. Specifically, the initial study by Lewis et al. (1999) focused on infants' attention to their mothers, measured as their angle of gaze and their simultaneous levels of distress. Infants were observed at two

[2]So far, the SSGs technique has been applied primarily to categorical data. An extension to continuously sampled signals is discussed in Hollenstein (2013).

waves, when they were 10–12 weeks old and again when they were 26–28 weeks old. Thus, the technique was originally developed to depict and measure changes in intra-individual dynamics (i.e., the individual as the system). A similar approach can be found in a recent study focusing on the relationship between mood and rumination in remitted depressed individuals (Koster et al., 2015). Granic and Lamey (2002) extended the SSG technique to parent–child interactions (for more recent examples see Ha and Granger, 2016; van Dijk et al., 2017), and most studies that followed focused on dyadic interactions. For example, SSGs have been used to describe teacher–student interactions (for an overview see Pennings and Mainhard, 2016), coach–athlete interactions (Erickson et al., 2011; Turnnidge et al., 2014), therapist–client interactions (Tomicic et al., 2015; Couto et al., 2016), or interactions in romantic couples (Butler et al., 2014; Sesemann et al., 2017). Despite this focus on dyadic systems, we believe that SSGs also provide a powerful tool to describe patterns of dynamic interactions in groups and teams. To illustrate, let us introduce a short example.

Figure 1 shows a sample SSG for a hypothetical team that is currently brainstorming new ideas. We built this sample SSG using the SSG package implemented in Interact (Mangold, 2017), a commercial software for video annotation. There is also a free software option called GridWare (Lamey et al., 2004) which can be downloaded from www.statespacegrids.org. The website also offers an overview of published studies on SSGs and thus provides an excellent starting point for group and team researchers who are interested in the technique.

The sample SSG in **Figure 1** depicts the relationship between coded talk (on the *y*-axis) and the team's energy level (on the *x*-axis). Please note that this SSG is not based on actual data but serves as an illustration. The verbal interaction was categorized using five behavioral codes, namely, support, idea expression, neutral statement, idea blocking, and criticism. The team's energy level was coded into five categories, ranging from high negativity, to neutral, to high positivity. The combination of the two dimensions results in a grid with 25 individual states. By default, the software adds an additional row (at the bottom) and column (far left).

The behavioral trajectory (i.e., the sequence of states) is plotted as it proceeds in real time. In this particular example, we coded a total of 10 consecutive events. Each circle (also called node) represents a joint occurrence, and the size of the circle denotes the duration of each particular event. The larger the circle, the longer the two corresponding codes were logged for that particular time unit. The placement of the circles within each cell is random and can be manually adjusted as needed. The red bordered circle denotes the first joint occurrence of coded talk and coded energy. The colors can be adjusted to one's preferences. This first event shows that the team started the brainstorming session with a neutral statement that was also neutral in tone. The arrows connecting the circles represent the order of the events. Hence, the second statement was coded as an idea put forward in a low positive tone, and so forth. In general, the idea and support statements in our example were accompanied by a positive energy level, whereas statements that were coded as idea blocking or criticism were associated with low to high negativity. Thus, the team in our example did not (yet) visit all the states in the SSG.

Quantifying Patterns of Dynamic Interactions

In addition to being a visualization tool, SSGs can be used to derive various measures that describe the dynamics of the observed system. Which measures are ultimately used to further

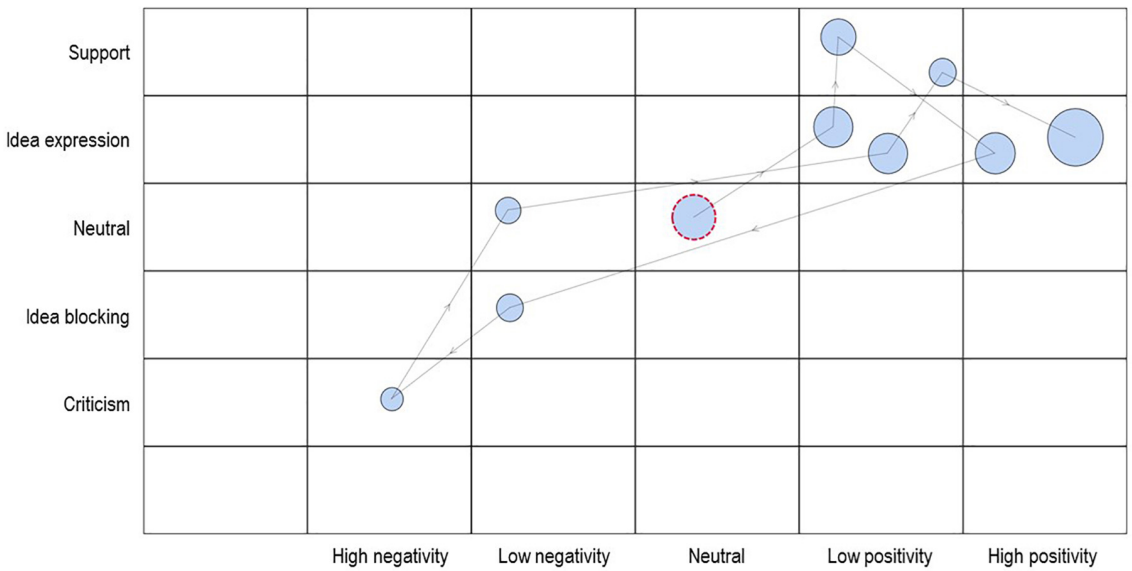

FIGURE 1 | An example of using a state space grid to display the first 10 events of a hypothetical brainstorming session. The team's energy level is plotted on the *x*-axis and coded talk is plotted on the *y*-axis.

quantify the SSG depends on the specific research questions at hand. The original GridWare software provides more measures to choose from than the SSG application in Interact, which is why we used both. In the following, we want to give an overview of those measures that are frequently turned to in SSG studies. These measures can tap both the *content* and the *structure* of the dynamic system (e.g., Granic and Hollenstein, 2003; Pennings and Mainhard, 2016).

Starting with content, the most straightforward approach is to focus on frequency measures and use this information to explore possible attractors and repellors. Thus, content measures can help to identify which states were visited most or least often. In our example above, we can see that three states were visited twice, four states were visited once, and 18 states were not visited at all. There is an important distinction between *events* and *visits* when it comes to SSG measures. Whereas events refer to any node visible in the SSG, a visit is always a transition from one cell to the next. The number of visits therefore provides information about the variability, that is the degree of state transitions, of the system. We will come back to this point when turning to the measures that capture the structure of SSGs. In our sample trajectory in **Figure 1**, with every event the system transitioned to a new cell. Therefore, we count 10 events and 10 visits. We chose this set up for simplicity but, of course, events can also occur consecutively within one cell. In such cases, the number of events is greater than the number of visits. In addition to raw frequencies, percentages may be considered to aid the comparison across different trajectories (or teams). Another way to standardize frequency measures is to divide them by the total duration of the trajectory. When SSGs are based on real-time recordings (i.e., moment-to-moment dynamics) and an adequate software solution was used to annotate the interaction data (i.e., including time stamps), researchers can obtain measures for duration in addition to frequency.

Based on how often and how long interaction was located in a specific cell, there are different ways to locate attractors and to describe their stability. While some approaches are more descriptive in nature, others require more intensive modeling. The respective procedure also depends on whether attractors are to be empirically identified bottom-up or whether they are derived from theory (Hollenstein, 2013). A simple way to describe attractors is to focus on those cells with (a) the highest number of visits, (b) the highest total duration, or (c) the highest mean duration per visit (Hollenstein, 2013). Such measures are not necessarily rigorous enough to provide a solid attractor analysis, but they are a good first step. If researchers are interested to explore which states actually have a higher probability of occurrence, then the *winnowing procedure* described by Lewis et al. (1999) might be suitable. This iterative step-by-step procedure first deletes those cells with the lowest duration. Next, a heterogeneity score is computed for each cell based on the observed and expected duration for each cell. As such, the winnowing procedure shares common ground with chi-square tests of independence. Interested readers are referred to Hollenstein (2013) who provides a detailed description of the method.

Once one or several attractors, or repellors, are identified, additional measures to describe their stability or strength can be used. The *average return time* to a specific cell or region describes the "pull" of the attractor. Shorter return times indicate that the system only temporally moves away from the attractor but then returns quickly, whereas longer return times may be an indication of a weaker attractor. Similarly, the total number of discrete visits to any other cell before returning to the attractor (i.e., *mean return visits*) describes the strength of an attractor, this time in terms of frequency and not duration.

The measures for attractor strength demonstrate that a dynamic system always wanders around the state space to some extent. In fact, the system would not be dynamic if it were "stuck" in only one particular state. Hence, measures of structure are important to describe the variability and patterns of the observed system. In the following, we want to briefly touch on the following four measures of structure, which we find especially suited for describing dynamic team interactions, namely (a) cell range, (b) total cell transitions, (c) dispersion, and (d) entropy.

Cell range is the total number of cells visited by the system. In our example in **Figure 1**, only seven out of 25 possible cells or states were visited. Hence, 72 percent (i.e., 18 cells) of the state space remains unexplored at this point in time. Of course, it is important that there is sufficient data for interpretation. Since we only included 10 data points in our example, it was physically impossible for the system to visit all states. Of the four variability or structural measures presented, cell range is the least dynamic measure.

Total cell transitions comprises the number of visits to the next cell, and therefore describes how intensely the system moves from state to state. Because the very first visit is not counted as a transition, the number of transitions between cells is expressed as the number of visits minus 1. In our example, the system always moved to a new cell with each time step. Hence, the total count of cell transitions is 9. Researchers interested in using this measure should attend to how they conceptualize transitions from cell to cell (Hollenstein, 2013). A total of 9 transitions, for instance, could have occurred between seven cells as in our example or between just two cells such that the system switched back and forth between two states. Thus, the number of cell transitions can be high even though the cell range is rather low. This also shows that in most cases it is useful not to look at certain SSG measures in isolation, but to use several measures simultaneously to describe the grid.

Dispersion is a measure that describes how much the coded events are scattered across the state space, controlling for relative duration. Its calculation is based on the number of visited cells and their duration. Mathematically, it is "the sum of the squared proportional durations across all cells, corrected for the number of cells" (Hollenstein, 2013, p. 46). The measure is inverted to reflect numbers between 0 and 1. Higher values indicate a higher variability, thus less rigid interaction. A value of zero would mean that all interaction took place in just one cell. A value of 1 would mean that interaction occurred evenly spread across all cells. In our example, dispersion reached a value of 0.84. Although the values are standardized and are in the range of 0–1, a comparison

across different SSGs is particularly useful if their underlying dimensions are the same.

Entropy is a measure of predictability and describes the level of organization of the system. In GridWare entropy can be calculated based on cell visits (i.e., visited entropy), cell transitions (i.e., transitional entropy), and duration (i.e., duration entropy). To clarify, consider the following sequence of coded behavior ABABABAB with A and B being discrete codes, such as a joint occurrence of idea expression and low positivity. This particular sequence is much easier to recreate than the following sequence, ACBFDAAB, which seems rather random. For computing entropy, a conditional probability is calculated for each cell. For example, the probability of visiting cell A is calculated by dividing the number of visits in cell A by the total number of visits. These individual probabilities are then summed up for the entire grid based on the formula by Shannon and Weaver (1949). Lower entropy values indicate a highly organized pattern, whereas high entropy denotes unpredictability. The exact formula and implementation in GridWare is described in Hollenstein (2013; see also Dishion et al., 2004). In our example, visit entropy was 1.89. The interpretation of this measure should be based on the respective study and the structure of the SSG. For example, a comparison across different teams who have worked on a similar task and whose interaction were analyzed with the same coding system would likely yield interesting insights.

Of note, the SSG technique offers a range of measures and, although tempting, these measures should not be used blindly in subsequent analyses. Instead, the choice of a specific SSG setting and accompanying measure in GridWare or Interact software should be guided by theoretical considerations.

BENEFITS AND IMPLICATIONS FOR TEAM SCIENCE

Team interactions are dynamic and can be rather messy (e.g., Cronin et al., 2011). Adopting a fine-grained behavioral approach to investigate team interactions typically generates large amounts of data that can be difficult to make sense of (e.g., Kozlowski et al., 2015). The SSG technique can address this challenge and innovate the study of team evolution and maturation processes. In the following, we first describe the strengths of the SSG approach before we outline how this technique complements existing analysis strategies.

Strengths of the SSG Approach

The strengths of the SSG approach to innovate team science broadly fall into three areas. First and foremost, the conceptual approach underlying SSGs can innovate team science by applying non-linear dynamic systems theory and changing the epistemology of teams (for a detailed discussion, see Ramos-Villagrasa et al., 2018). The opportunity afforded by SSGs of embracing the notion of teams as complex and dynamic systems and moving away from the typical linear thinking that has predominated team research (cf. Ramos-Villagrasa et al., 2018) is particularly fruitful for advancing our understanding of the evolution and maturation of teamwork and team processes. Team interactions can be chaotic and teamwork may move in spurts rather than flow evenly toward team outcomes. This is particularly true for teamwork in the face of trends toward increasing team fluidity and temporary organizing (i.e., quick changes in team composition), distributed teamwork (i.e., members collaborating from a distance and interacting and coordinating their actions in intervals), and multiple team memberships (i.e., employees finding themselves in different roles across different teams). In light of such developments, teams are discussed as "dynamic hubs of participants" rather than clearly bounded structures (Mortensen and Haas, 2018). We expect that the interactions that ensue in these dynamic hubs are even less likely to follow linear rules than in traditional teams, and SSGs can account for this possibility.

The second strength of SSGs constitutes visualizing team interaction patterns and making complex team dynamics more accessible. This can be tremendously helpful especially for exploratory research stages, for example when there is little or no prior empirical research on team dynamics and team interactions in a particular team setting. As discussed by Granic and Hollenstein (2003), SSGs can summarize complex interactional data in an intuitively appealing manner (Granic and Hollenstein, 2003; Pennings and Mainhard, 2016). Whereas the theoretical underpinnings of dynamic systems theory may seem daunting, the visualization of such system dynamics via SSGs helps team researchers grasp the characteristics of the team as an interacting system from a holistic perspective. Visualizing the complexity of team interactions may be particularly helpful for understanding team contexts that involve frequent changes or "upheaval" and that require teams to develop swift trust and rapid collaboration (i.e., quickly settling into new routines). This includes action teams (e.g., first response teams) as well as agile teams (e.g., software development teams), where behavioral interaction patterns emerge quickly and where teams are often characterized by fluidity and low stability in team boundaries (Mortensen and Haas, 2018). In those contexts, the adoption of dynamic systems theory for team science will be particularly fruitful, and SSGs as a visualization tool can help position and guide the scholarly thought process in this regard.

When utilizing SSGs as a visualization tool, it is important to decide how to best arrange the different categories along the two axes of the grid. Rearranging the categories may be very helpful for "reading" the interaction more intuitively but should align with the theoretical underpinnings of the respective study. Moreover, the use of SSGs as a visualization tool for complex team interaction dynamics also incorporates a movie function that allows the inspection of a team trajectory evolving over time (see Hollenstein, 2013). Team researchers can either explore the cumulative trajectory of an overall observed team interaction, or they can select specific time windows for shorter trajectories (e.g., for highlighting particularly eventful or critical episodes within a longer stream of team interaction). While this analysis remains qualitative, it can facilitate more dynamic theorizing about the evolution and maturation of team processes. Furthermore, the visualization of complex team dynamics via SSGs may generate innovative research hypotheses to be tested in further analyses.

The third strength of the SSG approach concerns novel opportunities for empirical research and hypothesis testing based on the quantitative measures for complex interaction patterns derived by SSG software. SSGs provide a wide array of different measures that can be compared to traditional measures or added to existing models. Measures cannot only be obtained in a cumulative fashion, as in our example above, but also for smaller time slices within a larger data set. For example, we could request the number of events per cell for every 5 min of an observed team meeting interaction and thus obtain information about the dominant speaker (or any other measure of interest) for each temporal slice of interest. Such an approach opens up new possibilities for investigating how team processes evolve at a quicker pace and within much smaller time frames than typically investigated in temporal team process research, and departs from larger-scale temporal frames for conceptualizing team emergence (e.g., Kozlowski, 2015).

Relying on the SSG technique to quantify team interaction dynamics may be especially useful in the context of infrequent or rare team interaction behaviors. When applying a quantitative behavioral observation approach, team researchers may feel inclined to neglect such behaviors given their low base rate, or choose to combine them with other behaviors in order to obtain more frequent categories (see Lehmann-Willenbrock and Allen, 2018, for a more detailed discussion of decisions to be made when coding team interactions). The SSG technique is sensitive to such low frequency behaviors, which are sometimes highly informative (e.g., when a rare behavior only occurs in successful but not in unsuccessful teams).

As a guiding reminder, team researchers looking to apply SSGs to study team interaction dynamics need to be aware and make informed decisions about how their approach to coding the observed data will affect the results regarding system dynamics that can be obtained using the SSG technique. Of note, this does not necessarily mean that SSGs are applied to evaluate entire theories, but rather refers to making conceptually sound decisions about the operationalization of relevant team constructs at the behavioral event level. Decisions about how relevant team interaction phenomena can adequately be captured in terms of observable behavioral units should be guided by conceptual arguments (cf. Lehmann-Willenbrock and Allen, 2018), which also applies to decisions about SSGs. In other words, when choosing SSGs to quantify interaction dynamics, team researchers need to be mindful when conceptualizing the state space to ensure that those phenomena or variables of interest that will later fall onto the two dimensions of the grid will be assessed at the same time. Moreover, especially when measures of duration are of interest to a researcher, clear unitizing rules are imperative (i.e., deciding when each behavioral unit within the temporal team interaction stream starts and ends).

Complementary Analyses

The SSG technique shares common ground with some other analytical strategies that aim to distil higher-level emergent patterns from lower-level interaction among individual elements. Thus, we do not want to position SSGs as the new "holy grail" of team research. To put it in the words of Hollenstein (2013, p. 108), "[SSG] are an important tool but often it takes many tools to complete the understanding of the phenomenon at hand." We have identified two techniques that, in our opinion, are useful complements to the analysis of SSGs, specifically recurrence quantification analysis (e.g., Eckmann et al., 1987; Webber and Zbilut, 2005; Knight et al., 2016) and sequence analysis (e.g., Bakeman and Quera, 2011; Herndon and Lewis, 2015; Klonek et al., 2016). In the following, we briefly compare the main similarities and differences between the SSG technique on the one hand and recurrence quantification analysis and sequence analysis on the other hand, respectively. Readers interested in an overview of additional methods for pattern recognition in team process data are referred to Poole (2018) or Ramos-Villagrasa et al. (2018).

As described earlier, SSGs are a tool for visualizing and quantifying the trajectories of categorical time-series data such as coded team interactions. Turning to team interactions during organizational meetings as an example, researchers may ask questions such as: Does team behavior A typically coincide with team behavior B? Do certain behavioral pairings occur more often than others? Is the interaction evenly distributed across the state space (i.e., flexible patterns) or "boxed" into specific corners (i.e., rigid patterns)? Is each team unique in terms of exhibiting qualitatively different patterns (e.g., distinctive trajectories resulting in idiosyncratic attractors) or can we identify similarities in interaction patterns across different teams?

Another non-linear approach based on the visualization of time-series data is recurrence quantification analysis (Eckmann et al., 1987; Webber and Zbilut, 2005). The visualizations at the heart of this approach are called *recurrence plots* (Marwan et al., 2007; Marwan, 2011). In its most classical application, a recurrence plot spans two dimensions, but shows the same time series on both axes (e.g., ABACABC, with A, B, and C denoting discrete behavioral codes). In contrast to a SSG visualization, the recurrence plot does not show specific values along the two axes, and the plot does not become denser with time as more and more events are entered. Instead, the recurrence plot shows when a specific value in the time series repeats itself (e.g., the code "A" reoccurs at positions 3 and 5) and the plot itself gets larger when the time series is longer. Whenever there is a repetition in the time series, these recurrence points are marked black in the recurrence plot (Marwan, 2011). The basic idea underlying the use of recurrence plots is that researchers can recognize repetitive sequences in the time series with the naked eye, which resembles the basic notion of SSGs. Similarly, recurrence quantification analysis offers various measures that can be obtained from the visualizations such as the percentage of recurrence (Webber and Zbilut, 2005).

Since recurrence quantification analysis typically focuses on the repetitive properties of a dynamic system within itself, this method may seem less intuitive to team researchers at first glance (but for previous applications in team science, see Ramos-Villagrasa et al., 2012; Knight et al., 2016). Moreover, recurrence quantification analysis focuses exclusively on the *structure* of a system's dynamics; implications regarding the content of the system dynamics are limited. Results of this type of analysis need to be interpreted within a precisely elaborated theoretical

context. Consequently, recurrence quantification analysis is less suitable for exploratory research stages. Sample research questions when applying recurrence quantification to coded team meeting interactions could include: does the team show structural recurrence in interaction data or are their interaction patterns chaotic? Are repetitions in behavior more apparent at the beginning or end of the meeting? Are there breakpoints during the meeting after which the interaction is more/less structured? How complex are the detected recurrence structures?

A benefit of recurrence quantification analysis concerns its ability to process continuously sampled signals (e.g., physiological data). When working with continuous measures, researcher need to specify a recurrence threshold (i.e., specifying when an event is marked as recurrent), which illustrates that the method is mathematically more demanding than an analysis based on SSGs as it includes finding optimal parameters (Marwan, 2011). In sum, we would argue that the SSG technique is to some extent more accessible for team researchers than recurrence quantification analysis, even though the two methods build on similar ideas—both conceptually and methodologically. We are not aware of any studies that use a combination of both techniques, but we certainly consider this promising (see also Hollenstein, 2013).

Another methodological approach to the study of team dynamics is to focus on and identify "sub-sequences" in coded team interactions (Poole, 2018). Approaches in this tradition explore more immediate temporal contingencies among coded events and can be subsumed under the umbrella term sequence analysis (Quera, 2018). Notably, sequence analysis is not one particular technique but rather "a toolbox of techniques" (Bakeman and Quera, 2011, p. 134). Over the years, different and increasingly advanced procedures for sequence analysis have been developed (Quera, 2018).

The types of research questions that can be explored with sequence analysis include the following: does behavior A trigger or inhibit behavior B, C, or D? Which behaviors A, B, or C increase the likelihood for behavior D? Which behaviors A, B, or C can inhibit behavior D? Most frequently in team research, studies using sequence analysis explore the extent to which team members reciprocate verbally (i.e., does behavior A trigger more of the same). For example, previous research has explored whether complaining leads to further complaining during organizational team meetings (Kauffeld and Meyers, 2009). Other research has utilized sequence analysis to test whether monitoring behaviors trigger different responses in higher- vs. lower-performing anesthesia teams (Kolbe et al., 2014). For such research questions, the researcher needs to specify a specific time lag. Time lags refer to the number of steps that separate a particular behavior from a criterion event. Lag1 refers to a coded event directly following the previous one (e.g., does code B immediately follow code A); lag2 refers to second-order transitions when a coded event is followed by the next but one coded event, and so forth (Bakeman and Quera, 2011). Lag sequential analysis can then test whether a certain sequence of events is statistically meaningful by comparing the observed transition frequencies to those expected by change. In contrast to SSGs, sequence analysis provides a statistical check for the sequential relationships found in the coded data. Although this is certainly also possible with quantifications derived from SSGs, the SSG technique in and of itself is much more descriptive in nature. In fact, this was one of the main reasons for the development of SSGs (Hollenstein, 2013). Sequence analysis is more rigid in comparison to SSGs because it requires the researcher to make specific assumptions about the expected patterns of behaviors. In addition, behavioral contingencies at higher lags are increasingly difficult to model because they require larger amounts of data (Quera, 2018). Yet, "often, meaningful responses in interpersonal interactions are not immediate" (Hollenstein, 2013, p. 109).

A more recent sequential analysis technique that addresses some of these caveats is *time-window sequential analysis* (Yoder and Tapp, 2004; Bakeman and Quera, 2011). Group researchers can use this technique to test whether a certain response occurs within a pre-defined time window such as a 5 s time-window (i.e., a behavior is contingent if we see a response within 5 s; Bakeman and Quera, 2011). From a conceptual point of view, this approach can solve some of the difficulties associated with specifying meaningful time lags. However, its practical implementation is more difficult, since time-window sequential analysis is not integrated in common observational software such as Interact (Quera, 2018).

Likewise, team researchers rarely turn to sequence analysis for exploring co-occurrences in parallel coded strings of events, although there are procedures that allow this (Quera, 2018). As a result, sequence analysis is often used in a simplified form (Herndon and Lewis, 2015). To recall, with SSGs the combination of at least two variables or dimensions is of interest. As such, the two analysis strategies could by combined by using the observed co-occurrences revealed with the aid of SSGs as a basis for a subsequent sequence analysis. In return, SSGs could be used to visualize the results obtained from sequence analysis and make the findings more tangible.

Finally, despite its many advantages and application possibilities, sequence analysis is not particularly sensitive to low frequency behaviors (for a detailed discussion of the limitations of the sequence analysis approach, see also Chiu and Khoo, 2005). Common practice is therefore to collapse fine-grained categories into larger macro codes and/or to pool the data across groups in order to base the analysis on a larger number of codes (e.g., Klonek et al., 2016). However, this approach regards groups as largely homogeneous, which has been criticized as a simplistic reductionist view on teams and team processes (Hewes and Poole, 2012).

In sum, the SSG technique has much to offer for team science. To date, SSGs have mainly been used for studying interactions in dyadic settings, outside the realm of team science (e.g., Pennings et al., 2014; Guo et al., 2017). We hope that team researchers will begin to embrace the SSG technique for enabling novel insights into the complex interactional dynamics at the core of team functioning and performance (e.g., Ramos-Villagrasa et al., 2018).

APPLICATION EXAMPLE AND TUTORIAL

To make the application of SSGs more tangible to team research and development, we will now present an example based on real team data. We provide step-by-step suggestions for using the technique and hope to highlight the various opportunities that SSGs offer.

A Step-by-Step Overview

As we have pointed out above, researchers should not begin considering SSGs in the final stages of an investigation. Rather, the decision to employ SSGs should be made early in order to be able to account for the requirements of this technique. In **Table 1** we have summarized the key steps for using SSGs in team research and development.

The first step involves defining the research aim and identifying the theoretical foundations for capturing team phenomena at the behavioral event level and specifying temporally sensitive interaction dynamics in the study context. The two chosen variables should be meaningfully related and their interaction should be grounded in theory. Most likely, the nodes or data points (i.e., the observed behavioral units) will not be randomly scattered across the state space but organized into clusters. It is advisable to find theoretical support for grouping the expected patterns of nodes into meaningful clusters. Hence, theory-based considerations should drive how a SSG is structured, and how this relates to the overarching team phenomenon that is studied. This step will ensure an early integration of the SSG technique as a methodological tool into the concept of the study.

The second step entails defining the variables of interest. Since the variables need to fulfill specific norms to be used for SSG analyses, it is imperative to account for such norms early on as well. In particular, it is important that the chosen dimensions underlying the SSG can be observed and coded in a sequential fashion (i.e., moment-to-moment). Likewise, the dimensions should be constructed in a way that they allow for mutually exclusive and exhaustive coding. It is therefore important to choose two variables that have similar granularity.

Closely related, the third step includes that both variables need to be unitized identically. For instance, if one variable was measured every 2 min (e.g., mood), the second variable (e.g., number of solutions mentioned) has to provide a data point for every 2 min as well. Hence, this aspect is important to consider at the research design stage, when making decisions regarding the operationalization of variables. The chosen software may pose additional requirements. For instance, the smallest time scale GridWare processes are seconds. Missing data should be avoided as this interrupts the interaction flow and thus the trajectory.

In the fourth step, an appropriate coding scheme can be chosen or developed. Available fine-grained coding schemes may be adjusted and summarized into broader categories to fit the purpose at hand. Note that each dimension (variable) may be coded with a different scheme (e.g., verbal and non-verbal interaction). Although it is not a theoretical requirement, for practical reasons a smaller number of coding categories, for example six to eight on each dimension, will yield a better overview and serve the purpose of applying SSGs as an analytical and/or visualization tool.

In the fifth step, once all these decisions have been taken, behavioral process data (video/audio recordings or live coding) can be gathered and coded. It is worth ensuring high-quality data through appropriate training of coders and establishing inter-rater reliability. Depending on the sample population, questions around data storage and privacy policies should be clarified before data collection and coding.

In the sixth step, once the coding is completed and visualizations are available for each team, the SSGs can be interpreted and appropriate measures for describing both the content and structure of the trajectories can be calculated. These measures can be easily exported and used for further analysis in other statistic software programs.

Finally, beyond research purposes, the coded data may be used for team development as detailed below. The visualizations, even more so than the measures, can serve as a basis for feedback.

The Data Set

Data for this application example were sampled from a recently gathered data set that has not been published to date. The data set comprises videotapes of the first (T1) and the final (T2) team meeting of a 6-week long student project at a large Dutch university. The project resembled the work of organizational consultants and required the teams to develop a managerial strategy for an organizational change project. The study was approved by the Economics and Business Ethics Committee at the University of Amsterdam. Participation in the study was voluntary, and all participants provided their written informed consent. From this pool we selected two five-person teams with roughly equal meeting durations on the basis of their productivity (high vs. low). On average, these four team meetings lasted for 55.14 min (SD = 4.08). As a proxy for productivity, we took the rate of solutions mentioned per hour. The productive team produced 19.45 solutions per hour at T1 and 21.15 solutions per hour at T2. The unproductive team produced 6.94 solutions per hour at T1 and 9.66 solutions per hour at T2. As shown in **Table 2**, the productive team consistently scored higher on positive team characteristics like reflexivity, cohesion, and meeting satisfaction and lower on team conflict measures.

Formatting the Data

We coded the observed team meeting interaction using the act4teams coding scheme (e.g., Kauffeld and Lehmann-Willenbrock, 2012; Kauffeld et al., 2018) and Interact software (Mangold, 2017). Act4teams is a mutually exclusive and exhaustive coding scheme for measuring problem-solving dynamics that occur in groups and teams. Using the act4teams coding scheme, a behavioral code is assigned to each verbal thought unit, which is typically a single sentence. In order to reduce complexity, we collapsed the 43 fine-grained act4teams codes into six broader aspects of interaction. These covered elements of interactions that were knowledge-oriented, problem-focused, structural, action-oriented, relational, and counterproductive. To ensure that the coding was exhaustive, we included an additional filler

TABLE 1 | Basic steps for applying SSGs in team research.

Basic steps	Considerations
(1) Define the (research) aim	- Clarify how the context and purpose of the study is linked to the dynamic systems perspective. - Describe the theoretical fundaments for temporally sensitive interaction dynamics. - Identify the underlying dimensions of the state space.
(2) Define phenomena and variables of interest	- Decide how the state space is constructed and define the variables of interest. - Variables must be observable simultaneously. - The variables should be mutually exclusive and exhaustive.
(3) Select unitizing rule (e.g., turn of talk)	- Units for the variables observed should be measured at the same time intervals. - Preferably, time units should not be smaller than 1 s.
(4) Choose existing coding scheme(s) or develop a new one	- Chose or develop one or several coding schemes that fit the research question. - A smaller number of categories will yield a better overview.
(5) Gather interaction data and code the data	- Record data such that the variables of interest can be measured effectively. - Train coders and establish inter-rater reliability.
(6) Visualize and quantify data in regards of the research question	- Create a SSG for each team using Interact (Mangold, 2017) or GridWare (Lamey et al., 2004) software. - Interpret the SSGs and derive adequate measures from the visualizations. - Several types of analyses can be conducted on the measures the software offers.
(7) Provide feedback to the team	- Chose a format that communicates the contents of the analysis which are relevant feedback for the target recipients.

TABLE 2 | Aggregated scores on team characteristics for each team at T1 and T2.

Team characteristic	T1		T2	
	Unproductive	Productive	Unproductive	Productive
Reflexivity[a]	3.35	4.35	2.85	4.05
Meeting satisfaction[b]	4.13	4.87	4.10	4.50
Social cohesion[c]	3.20	3.80	2.83	4.00
Task cohesion[c]	4.47	4.87	4.27	4.67
Intragroup conflict (relationship)[d]	1.45	1.05	2.00	1.05
Intragroup conflict (task)[d]	2.10	1.55	2.70	1.50

Answers were provided on a Likert scale ranging from 1 = very low to 5 = very high. [a]Schippers et al. (2007), [b]Rogelberg et al. (2010), [c]Carless and De Paola (2000), [d]Jehn (1995).

code labeled "other behavior." An overview of the simplified coding scheme including sample statements for each code is shown in **Table 3**. With each coded statement, we also recorded who the speaker was. Thus, our data format meets the requirements for SSGs explained in section "Visualizing Patterns of Dynamic Interactions." The coding leads to a multivariate time series of sequentially coded categorical data.

Again, we used the SSG application in Interact software for visualization and GridWare software to further analyze the coded team data. Each cell in the grid represents a distinct interactive state defined by the mutual occurrence of a specific speaker (x-axis) and the corresponding verbal behavior (y-axis). To visualize how the interaction unfolds over the time of a meeting, we created three plots per meeting for each of the two teams (see **Figures 2**, **3**). This is possible through a function integrated in both software applications, i.e., a time slider allows us to choose specific time ranges of interest within the recorded time. The SSG then builds up gradually. The SSG measures can also be calculated for each of the individual time intervals. The plots in **Figures 2**, **3** depict the interaction trajectory for the first 5 min, for the first 20 min, and for the entire meeting, respectively.

In the following we will discuss the grids and the quantitative measures with regard to the two teams in a more generalized way and point out benefits for both team research and team development where relevant.

Visual Inspection

Figure 2 shows the developing SSG for the two teams during their initial meeting. At first inspection of the entire meetings, we can observe clear differences between them. Starting with the columns (i.e., speakers), we can see an interesting difference concerning the length and distribution of speaker turns. First, there is a clearer pattern of cells that are visited more often than others in the productive team compared to the unproductive team. Second, more circles in the productive team are larger which indicates longer lasting contributions. Third, the distribution of circles across columns (speakers) in general and that of large circles in

TABLE 3 | Behavioral categories, descriptions, and sample statements.

Behavioral category	Description	Examples
Knowledge-oriented	Sharing organizational knowledge, referring to experts, and asking questions about opinions, content, or experience.	"Well, I format it like this . . .", "The guidelines are on blackboard.", We should ask Marisa about that."
Problem solving	Identifying, describing, and analyzing problems and solutions.	"We have not yet clarified the concept.", "We have to narrow our focus.", "We should stick to the marking guidelines."
Structural	Structuring the conversation by clarifying, summarizing content as well as structuring the procedure in terms of goals and priorities, time management and task distribution.	"So in sum, we have to start with this point.", "Let me write that down.", "This is a key aspect.", "We still have 15 min."
Action-oriented	Showing interest in change and new ideas as well as taking responsibility and planning concrete steps.	"I am curious about the results.", "That will bring us ahead.", "Okay, I will research that.", "I will do that next week then."
Relational	Positive socio-emotional behavior such as humor, involving and supporting other team members as well as appreciating their contributions.	"If that's okay with you, Jim.", "Yes, exactly.", "Hmm, yes.", "I have understood that."
Counterproductive	Behavior which disrupts the productivity of the team such as complaining, denying responsibility or side conversations and self-promotion.	"If everyone did it my way . . .", "We will wait and see.", "What if that ends up nowhere?", "Mark should have prepared that."
Other	Behavior which does not fit in any of the previous categories (e.g., pauses, incomplete or incomprehensible sentences).	

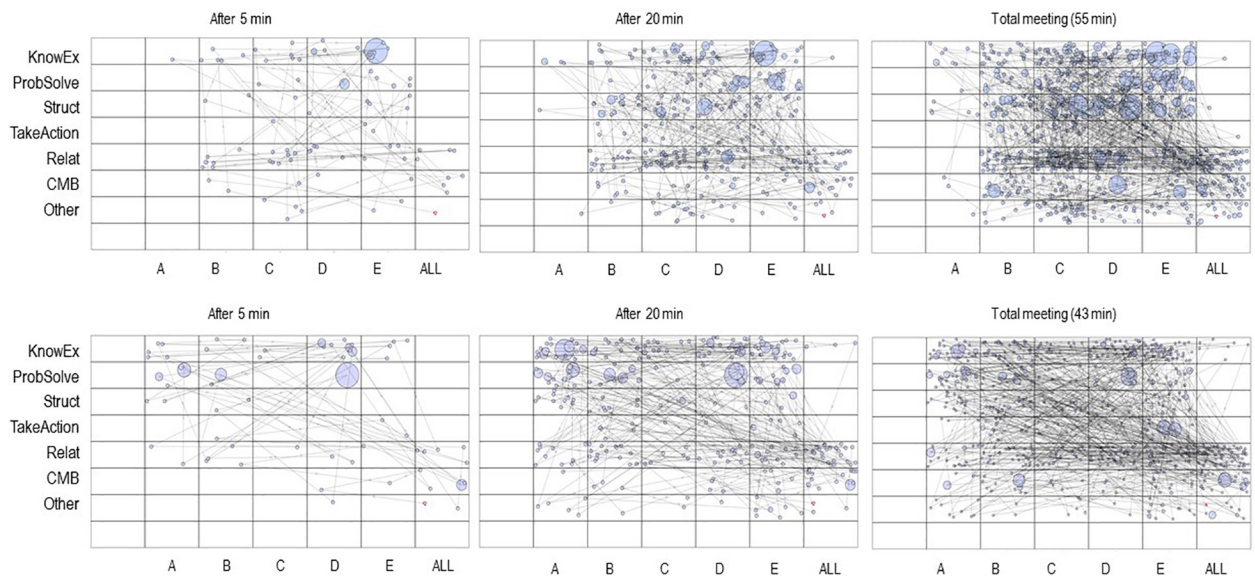

FIGURE 2 | State space grids (SSGs) representing verbal team interactions for a productive and an unproductive team at three time points for the first meeting. The **(top)** three panels show the SSGs of the productive team. The **(bottom)** three panels show the SSGs of the unproductive team. A, B, C, D, and E label each of the five team members per team. The size of the circles denotes the duration of each event. KnowEx, knowledge exchange; ProbSolve, problem solving; Struct, structuring; TakeAction, taking initiative; Relat, relational; CMB, counterproductive meeting behavior; Other, verbal behaviors that do not fit any of the six functional categories.

particular reveals that in the productive team speakers do not seem to have an equal share in the amount and length of their contributions. Some (speakers D and E) dominate the interaction and others (speaker A) are rather quiet. In the unproductive team the differences between speakers are more difficult to characterize. It seems that the conversational floor is more equally shared.

Turning to the rows and looking at the functional interaction categories, more differences arise. In the productive team, the distribution of circles in the rows shows that some are visited more frequently than others. For instance, cells on the structural level (e.g., clarifying, prioritizing, and time management statements) are visited more often than cells on the action-oriented level (e.g., interest in change and action

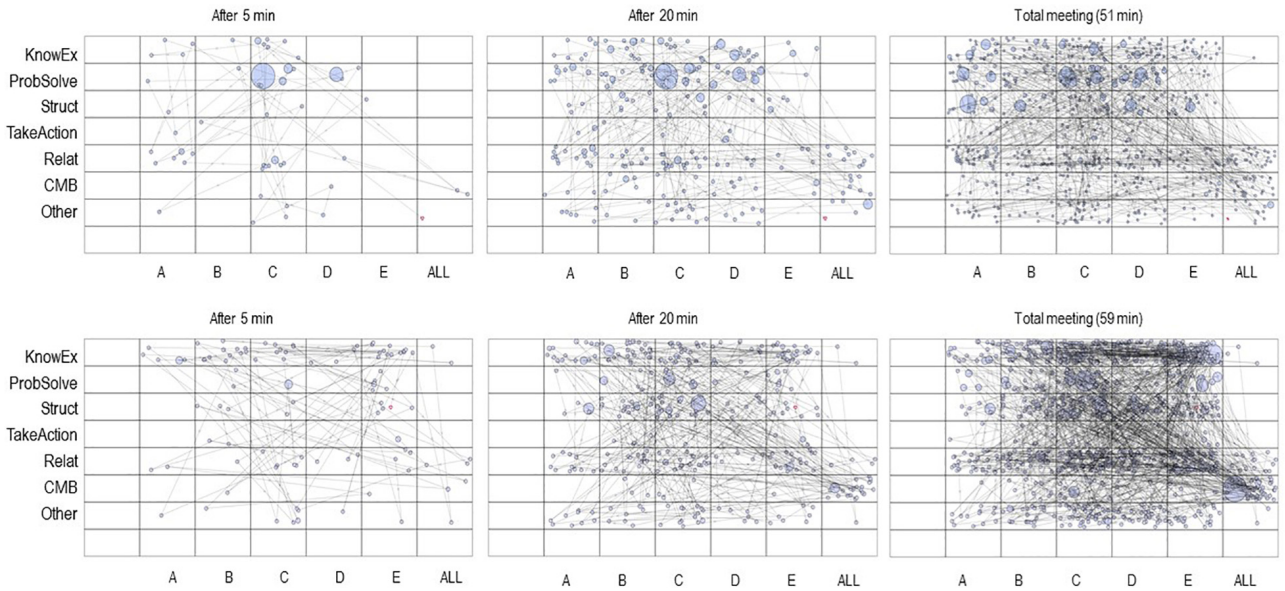

FIGURE 3 | State space grids (SSGs) representing verbal team interactions for a productive and an unproductive team at three time points for the last meeting. These are the same teams as in **Figure 2**. The **(top)** three panels show the SSGs of the productive team. The bottom three panels show the SSGs of the unproductive team. A, B, C, D, and E label each of the five team members per team. The size of the circles denotes the duration of each event. KnowEx, knowledge exchange; ProbSolve, problem solving; Struct, structuring; TakeAction, taking initiative; Relat, relational; CMB, counterproductive meeting behavior; Other, verbal behaviors that do not fit any of the six functional categories.

planning). Again, the unproductive team lacks such a clear trend. Finally, in the productive team we see a dark horizontal shade across the relational level. The shade indicates intensive interaction within that level, that is relational contributions are often followed by other relational contributions. These observations are relatively rough but they provide an overview of the interaction and thus an accessible form of feedback that can be insightful for team leaders and team members themselves (e.g., Who dominates the conversation? Who tends to structure the meeting? Who takes action? What contributions occur at what point during the meeting?). Before turning to the quantification of these observations, we will briefly examine the plots that represent earlier interaction stages within the same meetings. After 5 min, in both teams one individual seems to dominate the interaction: in the productive team, member E makes a number of contributions and a particularly lengthy knowledge-oriented one. This active role seems to remain stable across the meeting. In the unproductive team, after 5 min, member D has a similar role with a prominent problem-solving contribution. D, however, does not remain dominant throughout the meeting. Further, in this first grid the productive team shows more relational interaction compared to the unproductive team. This pattern intensifies throughout the meeting. The unproductive team, however, shows pronounced interaction on the knowledge-oriented level after 5 min that increases over time. To conclude, the two teams show specific and different trends from the beginning, and these may explain higher or lower productivity. Such conclusions highlight the potential of identifying dysfunctional processes early on during the meeting to be able to correct them guiding the team into more productive dynamics.

Figure 3 represents the equivalent interaction trajectories for the final meeting. The patterns for each team look rather different compared to the patterns for the first meeting. For instance, observing the final grid for the productive team, it is less easy to identify a dominant speaker, members seem more equally involved in the interaction compared to the first meeting. Especially team member A who was very quiet at T1 is now fully integrated in the interaction at T2. Circles in the top three rows are larger than in the bottom rows. Thus, knowledge-oriented, structural, and problem-solving contributions take up more time than other types of contributions in the productive team. The unproductive team shows two dark horizontal shadows, one on the top row suggesting an intensive exchange of knowledge-oriented contributions, and one on the relational level indicating strong positive socio-emotional exchange.

Quantitative Inspection

For many of these observations we can obtain quantitative measures. These help to analyze the content and structure of the interaction within and across grids. In practical terms, it means that we could establish dominant speakers, dominant interaction categories or characterize speakers with regard to their types of interactive contributions. In addition, we can quantify if the interaction was rigid or flexible such that structural patterns in the trajectory can be identified. For example, if we want to know who of the speakers dominated the interaction we can look for the number of events that we find within that speaker's column or we might look at the proportion of the total time taken up by the events of that speaker. Taking the example of the productive team at T1 (**Figure 2**) makes clear how critical it is to

determine these measures beforehand and rooting this decision in theoretical grounds: considering the number of events per speaker yields member C as the dominant individual (226 events) while we can record much less events for speaker D (141 events) and speaker E (153 events) which we had identified as dominant through our visual inspection. Considering the proportion of the total time per speaker results in a different conclusion: the contributions of the three speakers are rather similar, although speaker E slightly dominates the conversational floor (C = 23.5%, D = 23.6%, and E = 27.3%). Overall, the standard deviation for these percentages was 9.23. Looking at the unproductive team, the standard deviation for the proportion of the total time per speaker was 5.27. This supports our preliminary conclusion about a more even distribution of speaker contributions in the unproductive team at T1. Still, interesting differences exist. Specifically, speaker E's contributions composed 23.2% of the overall conversation whereas speaker C only contributed 7.1%.

Turning to measures of structure, findings reveal that all teams rather exhibit flexible interaction. The teams explored large parts of the grids with an average cell range of 38.75. Likewise, and because all team members did contribute to the discussion, the values for dispersion ranged between 0.97 and 0.98. Values for visit entropy were in the range of 3.22–3.49. Taken together, these values indicate a highly variable interaction style and show that interaction is rather difficult to predict. Contrary to other studies with SSGs (e.g., van Dijk et al., 2017), our coded team data was not boxed into a specific corner of the SSG. This is not necessarily characteristic for team interaction patterns in general but is, in part, due to how we defined the dimensions in our particular example with speakers on one axis and coded talk on the other.

BENEFITS AND IMPLICATIONS FOR TEAM TRAINING AND DEVELOPMENT

We would like to conclude this article with suggestions and ideas for the practical application of SGGs. Of note, these suggestions require future empirical work to evaluate their actual utility for team training and development. Yet, overall, we foresee multiple benefits of the application of SSGs in the context of team training and development, facilitating team maturation and evolution over time. First of all, getting teams to consider their team as a system of interactions, rather than a collection of people, may inspire novel understanding and insights regarding interdependencies and team dynamics. However, such a perspective can be quite complex and requires a holistic picture of the team interaction space. Visualizing this holistic picture via SSGs and presenting the behavioral feedback to the team can likely serve as a development trigger in this regard (cf. Lehmann-Willenbrock and Kauffeld, 2010). In the following, we point out specific ways in which SSGs might be used for effective delivery and transfer of training and development, along with recommendations for differing team contexts.

Training is considered effective when it produces changes in cognitive, affective, and/or skill-based outcomes (Salas and Cannon-Bowers, 2001), and leads to transfer of learning to the work context (Blume et al., 2010). For instance, a team diversity training may be aimed at enhancing the willingness to cooperate in diverse teams (e.g., affective changes), increasing knowledge regarding the potential benefits and pitfalls of diversity for teamwork (cognitive changes), providing the skills to more effectively utilize the heterogeneity of ideas and perspectives present in diverse teams (skill-based changes), leading to measurable performance improvements (e.g., Homan et al., 2015). In contrast to team training, team development (e.g., team coaching or developmental assignments) tends to be broader in scope and has a longer-time perspective. The skills to be acquired also typically go beyond those required for effectively accomplishing current tasks, jobs, and/or roles (Aguinis and Kraiger, 2009). Yet, boundaries between training and development are fluid, and both show considerable overlap in the principles followed to ensure effectiveness. Therefore, unless specified otherwise, we use both terms interchangeably and assume that both formats can benefit from SSGs in similar ways.

Training and development strategies typically follow several principles to ensure effectiveness (e.g., Salas and Cannon-Bowers, 2001). These entail presenting concepts and information relevant to the participant; showcasing the knowledge, skills, and abilities (KSAs) to be learnt; allowing for practicing the KSAs; and supplying participants with feedback during practicing and on improvements made over time. We believe that the SSG technique is particularly useful to support the feedback element of effective training and development.

The SSGs allow for detailed and visually appealing feedback based on actual behavior. This feedback can support teams in diagnosing the state they are in terms of team processes (e.g., knowledge sharing and utilization), in reflecting on emergent states (e.g., relational conflict), and in improving on important team processes. For instance, teams could receive feedback on their status quo as well as how their status quo has changed over the course of a training or developmental activity. Scholars have argued that feedback tools with a higher temporal resolution are especially suitable for providing developmental feedback (e.g., Rosen and Dietz, 2017). An important advantage of SSGs is that they allow teams and those involved in team training and development (e.g., leaders, trainers, and coaches) to gain an easily accessible overview of micro-level team interaction data that otherwise would be perceived as messy and difficult to grasp. The software's "movie function," as described earlier, may further support such practicing and feedback over time, as it adds further visual stimulation to other established forms of presentation (Myer et al., 2013). In addition, as SSGs can be administered repeatedly, (lack of) improvements could be detected, allowing teams to redirect or strengthen efforts if needed.

As SSGs are based on actual behavior, using this technique for feedback purposes might help circumvent validity and fairness issues. Such issues may arise when feedback is based on attributions or interpretations of behaviors, or of attitudes and underlying traits (e.g., by means of a rating scale completed by one's supervisor or team members, or by means of a supervisor's forced ranking of members in a team). Furthermore, feedback on relatively stable dimensions (e.g., intellectual ability) does not offer guidance regarding how to improve one's behavior. Comprehensible feedback based on actual behavior,

however, increases the likelihood that feedback leads to improved performance (e.g., Bandura, 1986; Kluger and DeNisi, 1996; Roter et al., 2004).

Besides their role in feedback, SSGs may be used to demonstrate the KSAs to be learnt during training and development, and facilitate subsequent practicing. For example, for more standardized procedures, teams may watch a video-based example of both an ineffective and effective team interaction. This demonstration could be accompanied by SSGs reflecting the respective patterns of observed interactions in the effective and ineffective example. The trainer or coach could then discuss concrete steps to bring the ineffectively interacting team closer to the effectively interacting team. Alternatively, team members could identify ways to approximate the effectively interacting team's profile. Yet, "it is important to remember that all teams are not equal" (Salas et al., 2017, p. 21). Especially in complex situations, the results of a SSG analysis of a successful team should not necessarily serve as a model for other teams (i.e., "one size fits all"). In such cases, it is particularly important that the trainer or coach stimulates reflection, so that the team members themselves can decide which elements can serve as a model for their own teamwork. Building a shared understanding of successful team interaction patterns is key to make sure that all team members equally benefit from team training with SSGs. This brings us to our next point, i.e., using SSG for team development.

Compared to team training, team development may entail a longer and less formalized process, allowing for more profound and longer-lasting maturation and evolution processes in teams. Less emphasis is given on how a team compares to other teams (e.g., by comparing the team's current SSG with the average SSG in the department, organization, or branch). Rather, development is concerned with the team's growth over time (e.g., Aguinis and Kraiger, 2009). We expect SSGs to be helpful in stimulating this growth, as the technique allows for observing the same aspects of a team's interaction at different points in time. These points in time may demarcate different "life stages" such as at team formation and in the middle and end of a project (cf. Tuckman, 1965; Gersick, 1988) or phases in a team's performance cycle (e.g., action versus transition phases; Marks et al., 2001). Depending on the exact purpose, it might be useful to employ the same or different state spaces at different points in time. To observe development on a given behavioral pattern, using the same state space is likely to be most suitable. To understand whether teams appropriately deal with the unique demands that differing stages or phases impose, using phase- or stage-specific state spaces might be more insightful. Teams might also seek to improve their phase-specific behavior over time (e.g., by increasing reflexivity in transition phases and improving on coordination in action phases). In this case, using SSGs repeatedly across multiple performance cycles may prove most conducive to continuous learning.

Finally, certain types of teams may particularly benefit from using SSGs as a feedback and development tool. As our application example shows, there are visible differences in the interaction patterns not only between teams but also across different stages in the team's life cycle (e.g., as determined by the duration of a project). Identifying characteristic patterns for team processes and emergent states embedded in certain stages of a project could help evaluate team processes in a standardized way. This could be especially interesting in and applicable to the context of SCRUM teams. While their project phases are relatively short and contents may vary according to project, the general procedures employed in SCRUM teams follow similar patterns across projects (Schwaber, 1997; Rising and Janoff, 2000). Furthermore, teams undergoing intense training (e.g., in the form of simulations) before entering the performance stage such a crisis or emergency teams, aviation or astronautic crews, or firefighter and special force units may be particularly attuned to benefit from the fine-grained, behavior-based feedback opportunities of the SSG technique. Systematically studying SSGs obtained during training and development in these team contexts may afford the opportunity to extract knowledge on more generic patterns of effective behavior across types of teams.

ETHICS STATEMENT

The study was approved by the Economics and Business Ethics Committee at the University of Amsterdam. Participation in the study was voluntary, and all participants provided their written informed consent.

AUTHOR CONTRIBUTIONS

AM developed the original idea for the manuscript, took the lead in writing, and performed the analyses. CH contributed to writing the manuscript and aided in data analysis and interpretation. NL-W and CB collected the data, critically revised the manuscript for intellectual content, and contributed to writing the manuscript. All authors approved the manuscript to be published.

REFERENCES

Aguinis, H., and Kraiger, K. (2009). Benefits of training and development for individuals and teams, organizations, and society. *Ann. Rev. Psychol.* 60, 451–474. doi: 10.1146/annurev.psych.60.110707.163505

Alligood, K. T., Sauer, T. D., and Yorke, J. A. (1996). *Chaos: An Introduction to Dynamical Systems*. New York, NY: Springer.

Arrow, H., McGrath, J. E., and Berdahl, J. L. (2000). *Small Groups as Complex Systems: Formation, Coordination, Development, and Adaptation*. Thousand Oaks, CA: Sage.

Bakeman, R., and Quera, V. (2011). *Sequential Analysis and Observational Methods for the Behavioral Sciences*. New York, NY: Cambridge University Press.

Bandura, A. (1986). *Social Foundations of Thought and Action: A Social Cognitive Theory*. Englewood Cliffs, NJ: Prentice-Hall.

Blume, B. D., Ford, J. K., Baldwin, T. T., and Huang, J. L. (2010). Transfer of training: a meta-analytic review. *J. Manag.* 36, 1065–1105. doi: 10.1177/0149206309352880

Butler, E. A., Hollenstein, T., Shoham, V., and Rohrbaugh, N. (2014). A dynamic state-space analysis of interpersonal emotion regulation in couples who smoke. *J. Soc. Pers. Relationsh.* 31, 907–927. doi: 10.1177/0265407513508732

Carless, S. A., and De Paola, C. (2000). The measurement of cohesion in work teams. *Small Group Res.* 31, 71–88. doi: 10.1177/104649640003100104

Chiu, M. M., and Khoo, L. (2005). A new method for analyzing sequential processes. *Small Group Res.* 36, 600–631. doi: 10.1177/1046496405279309

Couto, A. B., Barbosa, E., Silva, S., Bento, T., Teixeira, A. S., Salgado, J., et al. (2016). Client's immersed and distanced speech and therapist's interventions in emotion-focused therapy for depression: an intensive analysis of a case study. *Res. Psychother.* 19, 136–149. doi: 10.4081/ripppo.2016.205

Cronin, M. A., Weingart, L. R., and Todorova, G. (2011). Dynamics in groups: are we there yet? *Acad. Manag. Ann.* 5, 571–612. doi: 10.1080/19416520.2011.590297

Dishion, T. J., Nelson, S. E., Winter, C. E., and Bullock, B. M. (2004). Adolescent friendship as a dynamic system: entropy and deviance in the etiology and course of male antisocial behavior. *J. Abnorm. Child Psychol.* 32, 651–663. doi: 10.1023/B:JACP.0000047213.31812.21

Eckmann, J.-P., Oliffson Kamphorst, S., and Ruelle, D. (1987). Recurrence plots of dynamical systems. *Europhys. Lett.* 4, 973–977. doi: 10.1209/0295-5075/4/9/004

Erickson, K., Côté, J., Hollenstein, T., and Deakin, J. (2011). Examining coach athlete interactions using state space grids: an observational analysis in competitive youth sport. *Psychol. Sport Exerc.* 12, 645–654. doi: 10.1016/j.psychsport.2011.06.006

Gersick, C. J. G. (1988). Time and transition in work teams: toward a new model of group development. *Acad. Manag. J.* 31, 9–41. doi: 10.2307/256496

Granic, I. (2005). Timing is everything: developmental psychopathology from a dynamic systems perspective. *Dev. Rev.* 25, 386–407. doi: 10.1016/j.dr.2005.10.005

Granic, I., and Hollenstein, T. (2003). Dynamic systems methods for models of developmental psychopathology. *Dev. Psychopathol.* 15, 641–669. doi: 10.1017/s0954579403000324

Granic, I., and Lamey, A. V. (2002). Combining dynamic systems and multivariate analyses to compare the mother-child interactions of externalizing subtypes. *J. Abnorm.l Child Psychol.* 30, 265–283. doi: 10.1023/A:1015106913866

Guastello, S. J., and Liebovitch, L. S. (2009). "Introduction to nonlinear dynamics and complexity," in *Chaos and Complexity in Psychology: The Theory of Nonlinear Dynamic Systems*, eds S. J. Guastello, M. Koopmans, and D. Pincus (New York, NY: Cambridge University Press), 1–40. doi: 10.1017/cbo9781139058544.002

Guo, Y., Garfin, D. R., Ly, A., and Goldberg, W. A. (2017). Emotion coregulation in mother-child dyads: a dynamic systems analysis of children with and without autism spectrum disorder. *J. Abnorm. Child Psychol.* 45, 1369–1383. doi: 10.1007/s10802-016-0234-9

Ha, T., and Granger, D. A. (2016). Family relations, stress, and vulnerability: biobehavioral implications for prevention and practice. *Fam. Relat.* 65, 9–23. doi: 10.1111/fare.12173

Herndon, B., and Lewis, K. (2015). Applying sequence methods to the study of team temporal dynamics. *Organ. Psychol. Rev.* 5, 318–332. doi: 10.1177/2041386614538276

Hewes, D. E., and Poole, M. S. (2012). "The analysis of group interaction processes," in *Research Methods for Studying Groups and Teams: A Guide to Approaches, Tools, and Technologies*, eds A. B. Hollingshead and M. S. Poole (New York, NY: Routledge), 358–385.

Hollenstein, T. (2007). State space grids: analyzing dynamics across development. *Int. J. Behav. Dev.* 31, 384–396. doi: 10.1177/0165025407077765

Hollenstein, T. (2011). Twenty years of dynamic systems approaches to development: significant contributions, challenges, and future directions. *Child Dev. Persp.* 5, 256–259. doi: 10.1111/j.1750-8606.2011.00210.x

Hollenstein, T. (2013). *State Space Grids: Depicting Dynamics Across Development*. New York, NY: Springer.

Homan, A. C., Buengeler, C., Eckhoff, R. A., van Ginkel, W. P., and Voelpel, S. C. (2015). The interplay of diversity training and diversity beliefs on team creativity in nationality diverse teams. *J. Appl. Psychol.* 100, 1456–1467. doi: 10.1037/apl0000013

Jehn, K. A. (1995). A multimethod examination of the benefits and detriments of intragroup conflict. *Administ. Sci. Quart.* 40, 256–282. doi: 10.2307/2393638

Johnson, S. L., and Nowak, A. (2002). Dynamical patterns in bipolar depression. *Pers. Soc. Psychol. Rev.* 6, 380–387. doi: 10.1207/S15327957PSPR0604_12

Kauffeld, S., and Lehmann-Willenbrock, N. (2012). Meetings matter: effects of team meetings on team and organizational success. *Small Group Res.* 43, 130–158. doi: 10.1177/1046496411429599

Kauffeld, S., Lehmann-Willenbrock, N., and Meinecke, A. L. (2018). "The Advanced Interaction Analysis for Teams (act4teams) coding scheme," in *The Cambridge Handbook of Group Interaction Analysis*, eds E. Brauner, M. Boos, and M. Kolbe (New York, NY: Cambridge University Press), 422–431. doi: 10.1017/9781316286302.022

Kauffeld, S., and Meyers, R. A. (2009). Compliant and solution-oriented circles: interaction patterns in work group discussions. *Eur. J. Work Organ. Psychol.* 18, 267–294. doi: 10.1080/13594320701693209

Klonek, F. E., Quera, V., Burba, M., and Kauffeld, S. (2016). Group interactions and time: using sequential analysis to study group dynamics in project meetings. *Group Dyn.* 20, 209–222. doi: 10.1037/gdn0000052

Kluger, A. N., and DeNisi, A. (1996). The effects of feedback interventions on performance: a historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychol. Bull.* 119, 254–284. doi: 10.1037/0033-2909.119.2.254

Knight, A. P., Kennedy, D. M., and McComb, S. A. (2016). Using recurrence analysis to examine group dynamics. *Group Dyn.* 20, 223–241. doi: 10.1037/gdn0000046

Kolbe, M., Grote, G., Waller, M. J., Wacker, J., Grande, B., Burtscher, M. J., et al. (2014). Monitoring and talking to the room: autochthonous coordination patterns in team interaction and performance. *J. Appl. Psychol.* 99, 1254–1267. doi: 10.1037/a0037877

Koster, E. H. W., Fang, L., Marchetti, I., Ebner-Priemer, U., Kirsch, P., Huffzinger, S., et al. (2015). Examining the relation between affect and rumination in remitted depressed individuals: a dynamic systems analysis. *Clin. Psychol. Sci.* 3, 619–627. doi: 10.1177/2167702615578129

Kozlowski, S. W. J., Chao, G. T., Chang, C.-H., and Fernandez, R. (2015). "Team dynamics: using "big data" to advance the science of team effectiveness", in *Big Data at Work: The Data Science Revolution and Organizational Psychology*, eds S. Tonidandel, E. King, and J. Cortina (New York, NY: Routledge Academic), 272–309.

Kozlowski, S. W. J. (2015). Advancing research on team process dynamics: theoretical, methodological, and measurement considerations. *Organ. Psychol. Rev.* 5, 270–299. doi: 10.1177/2041386614533586

Kozlowski, S. W. J., and Ilgen, D. R. (2006). Enhancing the effectiveness of work groups and teams. *Psychol. Sci. Publ.c Inter.* 7, 77–124. doi: 10.1111/j.1529-1006.2006.00030.x

Lamey, A., Hollenstein, T., Lewis, M. D., and Granic, I. (2004). *GridWare (Version 1.1) [Computer software]*. Available at: http://statespacegrids.org (accessed August 28, 2018).

Lehmann-Willenbrock, N., and Allen, J. A. (2018). Modeling temporal interaction dynamics in organizational settings. *J. Bus. Psychol.* 33, 325–344. doi: 10.1007/s10869-017-9506-9

Lehmann-Willenbrock, N., and Kauffeld, S. (2010). "The downside of communication: Complaining cycles in group discussions," in *The Handbook For Working With Difficult Groups: How They Are Difficult, Why They Are Difficult, What You Can Do*, ed. S. Schuman (San Francisco, CA: Jossey-Bass/Wiley), 33–54.

Lewis, M. D. (2000). The promise of dynamic systems approaches for an integrated account of human development. *Child Dev.* 71, 36–43. doi: 10.1111/1467-8624.00116

Lewis, M. D., and Granic, I. (2000). *Emotion, Development, And Self-Organization: Dynamic Systems Approaches To Emotional Development*. New York, NY: Cambridge University Press.

Lewis, M. D., Lamey, A. V., and Douglas, L. (1999). A new dynamic systems method for the analysis of early socioemotional development. *Dev. Sci.* 2, 457–475. doi: 10.1111/1467-7687.00090

Mangold, A. (2017). *INTERACT (Lab Suite Version 2017) [Computer software]. Mangold International GmbH*. www.mangold-international.com (accessed March 1, 2018).

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manag. Rev.* 26, 356–376. doi: 10.2307/259182

Marrone, J. A. (2010). Team boundary spanning: a multilevel review of past research and proposals for the future. *J. Manag.* 36, 911–940. doi: 10.1177/0149206309353945

Marwan, N. (2011). How to avoid potential pitfalls in recurrence plot based data analysis. *Int. J. Bifurc. Chaos* 21, 1003–1017. doi: 10.1142/S0218127411029008

Marwan, N., Romano, M. C., Thiel, M., and Kurths, J. (2007). Recurrence plots for the analysis of complex systems. *Phys. Rep.* 438, 237–329. doi: 10.1016/j.physrep.2006.11.001

McGrath, J. E. (1964). *Social Psychology: A Brief Introduction*. New York, NY: Holt, Rinehart, & Winston.

McGrath, J. E., Arrow, H., and Berdahl, J. L. (2000). The study of groups: past, present, and future. *Pers. Soc. Psychol. Rev.* 4, 95–105. doi: 10.1207/S15327957PSPR0401_8

Mortensen, M., and Haas, M. R. (2018). Rethinking teams: from bounded membership to dynamic participation. *Organ. Sci.* 29, 341–355. doi: 10.1287/orsc.2017.1198

Myer, G. D., Stroube, B. W., DiCesare, C. A., Brent, J. L., Ford, K. R., Heidt, R. S., et al. (2013). Augmented feedback supports skill transfer and reduces high-risk injury landing mechanics: a double-blind, randomized controlled laboratory study. *Am. J. Sports Med.* 41, 669–677. doi: 10.1177/0363546512472977

Pennings, H. J., and Mainhard, T. (2016). "Analyzing teacher–student interactions with state space grids," in *Complex Dynamical Systems in Education: Concepts, Methods and Applications*, eds M. Koopmans and D. Stamovlasis (Basel: Springer), 233–271. doi: 10.1007/978-3-319-27577-2_12

Pennings, H. J. M., van Tartwijk, J., Wubbels, T., Claessens, L. C. A., van der Want, A. C., and Brekelmans, M. (2014). Real-time teacher–student interactions: a dynamic systems approach. *Teach. Teach. Educ.* 37, 183–193. doi: 10.1016/j.tate.2013.07.016

Poole, M. S. (2018). "Coding and analyzing multiple levels," in *The Cambridge Handbook of Group Interaction Analysis*, eds E. Brauner, M. Boos, and M. Kolbe (New York, NY: Cambridge University Press), 370–386. doi: 10.1017/9781316286302.019

Quera, V. (2018). "Analysis of interaction sequences," in *The Cambridge Handbook of Group Interaction Analysis*, eds E. Brauner, M. Boos, and M. Kolbe (New York, NY: Cambridge University Press), 295–322. doi: 10.1017/9781316286302.016

Ramos-Villagrasa, P. J., Marques-Quinteiro, P., Navarro, J., and Rico, R. (2018). Teams as complex adaptive systems: reviewing 17 years of research. *Small Group Res.* 49, 135–176. doi: 10.1177/1046496417713849

Ramos-Villagrasa, P. J., Navarro, J., and García-Izquierdo, A. L. (2012). Chaotic dynamics and team effectiveness: evidence from professional basketball. *Eur. J. Work Organ. Psychol.* 21, 778–802. doi: 10.1080/1359432X.2012.669525

Rising, L., and Janoff, N. S. (2000). The scrum software development process for small teams. *IEEE softw.* 17, 26–32. doi: 10.1109/52.854065

Rogelberg, S. G., Allen, J. A., Shanock, L., Scott, C., and Shuffler, M. (2010). Employee satisfaction with meetings: a contemporary facet of job satisfaction. *Hum. Res. Manag.* 49, 149–172. doi: 10.1002/hrm.20339

Rosen, M. A., and Dietz, A. S. (2017). "Team performance measurement," in *The Wiley Blackwell Handbook of the Psychology of Team Working and Collaborative Processes*, eds E. Salas, R. Rico, and J. Passmore (Hoboken, NJ: Wiley-Blackwell), 481–502.

Roter, D. L., Larson, S., Shinitzky, H., Chernoff, R., Serwint, J. R., Adamao, G., et al. (2004). Use of an innovative video feedback technique to enhance communication skills training. *Med. Educ.* 38, 145–157. doi: 10.1046/j.1365-2923.2004.01754.x

Salas, E., and Cannon-Bowers, J. A. (2001). The science of training: a decade of progress. *Ann. Rev. Psychol.* 52, 471–499. doi: 10.1146/annurev.psych.52.1.471

Salas, E., Reyes, D. L., and Woods, A. L. (2017). "The assessment of team performance: Observations and needs," in *Innovative Assessment of Collaboration. Methodology of Educational Measurement and Assessment*, eds A. A. von Davier, M. Zhu, and P. C. Kyllonen (Cham: Springer), 21–36. doi: 10.1007/978-3-319-33261-1_2

Schippers, M. C., Den Hartog, D. N., and Koopman, P. L. (2007). Reflexivity in teams: a measure and correlates. *Appl. Psychol. Int. Rev.* 56, 189–211. doi: 10.1111/j.1464-0597.2006.00250.x

Schwaber, K. (1997). "Scrum development process," in *Proceedings of the Business Object Design and Implementation. OOPSLA '95 Workshop*. eds J. Sutherland, D. Patel, C. Casanave, J. Miller, and G. Hollowell (London, UK: Springer), 117–134. doi: 10.1007/978-1-4471-0947-1_11

Sesemann, E. M., Kruse, J., Gardner, B. C., Broadbent, C. L., and Spencer, T. A. (2017). Observed attachment and self-report affect within romantic relationships. *J. Couple Relationsh.p Ther.* 16, 102–121. doi: 10.1080/15332691.2016.1238794

Shannon, C. E., and Weaver, W. (1949). *The Mathematical Theory of Communication*. Urbana, IL: University of Illinois Press.

Thelen, E., and Smith, L. B. (1998). "Dynamic systems theories," in *Handbook of Child Psychology*, eds W. Damon, R. M. Lerner, and N. Eisenberg (New York, NY: Wiley), 563–634.

Tomicic, A., Martínez, C., Pérez, J. C., Hollenstein, T., Angulo, S., Gerstmann, A., et al. (2015). Discourse-voice regulatory strategies in the psychotherapeutic interaction: a state-space dynamics analysis. *Front. Psychol.* 6:378. doi: 10.3389/fpsyg.2015.00378

Tuckman, B. W. (1965). Developmental sequence in small groups. *Psychol. Bull.* 63, 384–399. doi: 10.1037/h0022100

Turnnidge, J., Cote, J., Hollenstein, T., and Deakin, J. (2014). A direct observation of the dynamic content and structure of coach-athlete interactions in a model sport program. *J. Appl. Sport Psychol.* 26, 225–240. doi: 10.1080/10413200.2013.821637

van Dijk, R., Deković, M., Bunte, T. L., Schoemaker, K., Zondervan-Zwijnenburg, M., Espy, K. A., et al. (2017). Mother-child interactions and externalizing behavior problems in preschoolers over time: inhibitory control as a mediator. *J. Abnorm. Child Psychol.* 45, 1503–1517. doi: 10.1007/s10802-016-0258-1

Waller, M. J., Okhuysen, G. A., and Saghafian, M. (2016). Conceptualizing emergent states: a strategy to advance the study of group dynamics. *Acad. Manag. Ann.* 10, 561–598. doi: 10.1080/19416520.2016.1120958

Webber, C. L., and Zbilut, J. P. (2005). "Recurrence quantification analysis of nonlinear dynamical systems," in *Tutorials in Contemporary Nonlinear Methods for the Behavioral Sciences*, eds M. A. Riley and G. C. Van Orden (Arlington, VA: National Science Foundation), 26–94.

Yoder, P. J., and Tapp, J. (2004). Empirical guidance for time-window sequential analysis of single cases. *J. Behav. Educ.* 13, 227–246. doi: 10.1023/B:JOBE.0000044733.03220.a9

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Meinecke, Hemshorn de Sanchez, Lehmann-Willenbrock and Buengeler. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

ORIGINAL RESEARCH
published: 03 May 2019
doi: 10.3389/fpsyg.2019.00992

The Emergence of Group Potency and Its Implications for Team Effectiveness

Hayden J. R. Woodley[1]†, Matthew J. W. McLarnon[2]† and Thomas A. O'Neill[3]*

[1] Faculty of Business, University of Prince Edward Island, Charlottetown, PE, Canada, [2] Department of Psychology, Oakland University, Rochester, MI, United States, [3] Department of Psychology, University of Calgary, Calgary, AB, Canada

Much of the previous research on the emergence of team-level constructs has overlooked their inherently dynamic nature by relying on static, cross-sectional approaches. Although theoretical arguments regarding emergent states have underscored the importance of considering time, minimal work has examined the dynamics of emergent states. In the present research, we address this limitation by investigating the dynamic nature of group potency, a crucial emergent state, over time. Theory around the "better-than-average" effect (i.e., an individual's tendency to think he/she is better than the average person) suggests that individuals may have elevated expectations of their group's early potency, but may decrease over time as team members interact gain a more realistic perspective of their group's potential. In addition, as members gain experience with each other, they will develop a shared understanding of their team's attributes. The current study used latent growth and consensus emergence modeling to examine how potency changes over time, and its relation with team effectiveness. Further, in accordance with the input-process-output framework, we investigated how group potency mediated the relations between team-level compositions of conscientiousness and extraversion and team effectiveness. We collected data at three time points throughout an engineering design course from 337 first-year engineering students that comprised 77 project teams. Results indicated that group potency decreased over time in a linear trend, and that group consensus increased over time. We also found that teams' initial potency was a significant predictor of team effectiveness, but that change in potency was not related to team effectiveness. Finally, we found that the indirect effect linking conscientiousness to effectiveness, through initial potency, was supported. Overall, the current study offers a unique understanding of the emergence of group potency, and facilitate a number theoretical and practical implications, which are discussed.

Keywords: group potency, emergence, team effectiveness, conscientiousness, extraversion

OPEN ACCESS

Edited by:
Eduardo Salas,
Rice University, United States

Reviewed by:
Ishani Aggarwal,
Brazilian School of Public and Business Administration, Brazil
Gary Pheiffer,
University of Hertfordshire, United Kingdom

****Correspondence:***
Hayden J. R. Woodley
hwoodley@upei.ca

† These authors have contributed equally to this work as first authors

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *01 November 2018*
Accepted: *15 April 2019*
Published: *03 May 2019*

Citation:
Woodley HJR, McLarnon MJW and O'Neill TA (2019) The Emergence of Group Potency and Its Implications for Team Effectiveness. Front. Psychol. 10:992. doi: 10.3389/fpsyg.2019.00992

INTRODUCTION

According to the input-process-outcome (IPO) framework (McGrath, 1964) and related models (e.g., the input-mediator-output-input [IMOI] model; Ilgen et al., 2005), emergent states are integral to understanding the effectiveness of teams. In this light, extensive research has been conducted in effort to improve our understanding of how emergent states influence team

effectiveness (Kozlowski and Ilgen, 2006). Marks et al. (2001) defined emergent states as, "constructs that characterize properties of the team that are typically dynamic in nature and vary as a function of team context, inputs, processes, and outcomes" (p. 357). Examples of emergent states include collective efficacy, group potency, and cohesion. Overall, meta-analyses have found that the previously mentioned emergent states are positively related to team effectiveness (e.g., Gully et al., 2002; Beal et al., 2003; Stajkovic et al., 2009, respectively). Although these findings have been influential in building our understanding of team effectiveness, little research has investigated the temporal, dynamic aspects of emergent states (Kozlowski et al., 2016; Waller et al., 2016). Ilgen et al. (2005) argued that time plays an important role in understanding the emergence of states in teams, and without more direct insight into the temporal nature of emergent team processes, theoretical advancements, and practical recommendations will be limited (see also Collins et al., 2016; Salas et al., 2017a,b). To address this issue, the current investigation sought to examine: (1) how group potency, a critical emergent state, changes over time, (2) the relation between the dynamics of potency and team effectiveness, and (3) the mediating effect the dynamics of potency have on the relation between inputs (i.e., team-level personality) and team effectiveness.

In this research, data were gathered from student engineering project teams over multiple time points during an academic course. We then used latent growth and consensus emergence modeling to examine the dynamic nature and emergent properties of group potency. Throughout, we use the term *dynamic* to reflect the separate factors of the initial starting point of teams' potency, the rate of change in potency over time, and also the emergence of the construct (see Ployhart and Vandenberg, 2010; Wang et al., 2016). Further, we investigated the role of team-level input variables (i.e., team-level conscientiousness and extraversion) as predictors of the dynamicity of group potency. Additionally, we examined whether the dynamics of group potency mediated the relations for both conscientiousness and extraversion on team effectiveness.

In the following sections, we utilize conservation of resources (COR) theory to discuss the importance of group potency as a team-level resource that influences team effectiveness, in accordance within the broad IPO and IMOI frameworks. In addition, we invoke COR to support our theoretical rationale for how potency changes over time, and how this change predicts team effectiveness. Then, we theorize that specific personality traits (i.e., conscientiousness and extraversion) are both antecedents (i.e., inputs) and resources that contribute to the process of group potency dynamics and the prediction of team effectiveness.

GROUP POTENCY

Group potency is one of the most frequently investigated emergent states and team processes associated with effective teamwork (LePine et al., 2008), and recent research suggest this trend is going to continue (e.g., O'Neill et al., 2016; Schaubroeck et al., 2016, among others). Although it has been described in different forms previously (see Stajkovic et al., 2009), we adhere to its conventional definition as a team's generalized confidence in its ability to perform across a variety of situations (see Guzzo et al., 1993). Potency differs from efficacy, in that "efficacy represents a shared, task-specific expectation that the team can accomplish its goals, whereas potency is a more generalized sense of competence" (Kozlowski, 2018, p. 208). To date, two meta-analyses have investigated the relations between group potency and team performance (Gully et al., 2002; Stajkovic et al., 2009), with both reporting that group potency is positively related to team performance, $\rho = 0.35$ and 0.29, respectively.

Nevertheless, these meta-analyses are based on research that has used static, cross-sectional approaches (Marks et al., 2001), which unfortunately may not adequately address the inherently dynamic nature of group potency. As such, the dynamic aspects of group potency, which we expand on subsequently, have been relatively ignored by past research (Kozlowski and Ilgen, 2006; cf. Collins and Parker, 2010; Collins et al., 2016; Salas et al., 2017a,b). There are two potential reasons for this: (1) gathering longitudinal data with teams can be difficult because team membership and/or project assignments may change over time (see McClurg et al., 2017), and (2) the analytical approaches for investigating emergence and growth had not developed until recently (see Collins et al., 2016; Lang et al., 2018). In this research, we address these methodological challenges and present a novel investigation into the dynamics of group potency over time.

EMERGENCE

The concept of emergence in multilevel phenomena (e.g., teams) has been the focus of recent theoretical discussions (see Kozlowski et al., 2013; Waller et al., 2016; Grossman et al., 2017). Here, we establish a theoretical model for the emergence and dynamics involved with group potency. Kozlowski and Klein (2000) defined an emergent state as a characteristic of a team that "is amplified by their interactions, and manifested as a higher-level, collective phenomenon" (p. 55). An emergent state, therefore, is a dynamic construct, which theoretically changes or emerges over time (Kozlowski and Ilgen, 2006). We adopt this as the basis for our investigation because it makes an important distinction that other definitions do not address (e.g., Marks et al., 2001). In Kozlowski and Klein (2000) definition, emergence is not a singular attribute; rather there are two distinct underlying processes that develop as a result of group interactions: (1) amplification, and (2) consensus. Amplification refers to the growth aspect, or in broader terms, reflects the notion of changing levels over time, of a construct. Consensus refers to the emergence of a collective phenomenon from the shared perceptions of individual members. Broadly speaking, the literature on emergent states has ignored the dynamic nature of both amplification and consensus (Cronin et al., 2011; Kozlowski et al., 2016). In particular, the vast majority of previous research has used cross-sectional data, which is poorly

suited to examining the role time plays in both amplification and consensus processes (Cronin et al., 2011; Roe et al., 2012; Vantilborgh et al., 2018). Emergent states should demonstrate changes in level and consensus over time, and result from team interactions and collective experiences that lead to increasingly shared perceptions and consensus between individual members (Kozlowski and Klein, 2000; Marks et al., 2001; Kozlowski et al., 2013; Kozlowski, 2018).

Group Potency Levels Across Time

For group potency – and other emergent states – to develop, team members need time and a reason to interact and develop an understanding of "who they are" as a group (Marks et al., 2001; Kozlowski, 2018). This suggests that potentially, at first, teams would be less confident in their ability to perform because they do not have enough experience with each other to develop a shared understanding of their collective ability. Then, conceivably, as team members interact over time they will gain insight into each member's work habits and abilities, leading to increases in collective confidence. This perspective, however, rests on the assumption that team members enter teams without any pre-existing expectations. It seems more likely that team members enter their teams with high expectations, optimism, and confidence, especially without evidence to suggest otherwise. In support of the latter, Allen and O'Neill (2015b) theorized that the early agreement they found among team members on ratings of emergent states (e.g., group potency) might be attributed to an early positivity bias. They reasoned that this bias may lead to inflated perceptions of potency early in teams' lifecycle, indicating a strong need to consider the role of time in investigating team processes. Unfortunately, limited research has been conducted on the dynamic nature of group potency. One study, however, by Lester et al. (2002) measured group potency at two time points, and using differences scores found that group potency *decreased* over time. Although difference scores have several methodological shortcomings (see Edwards, 2001, for a review), this finding is not overly surprising. In fact, research on the "better-than-average" effect (e.g., Svenson, 1981) – a common social comparison bias – would suggest that team members' initial expectations of their team's collective general ability might be inflated. The better-than-average effect has also been found to be stronger when the comparison target is ambiguous (Alicke et al., 1995), as in a newly formed team might be, and is positively related to over-confidence in one's individual ability (Larrick et al., 2007). It may therefore stand to reason that confidence in one's team may occur early in a team's lifecycle. Yet, as members may rate their team artificially high early on in their tenure (Lester et al., 2002), scores will tend to decrease over time as members interact with each other and face ongoing challenges with the task that may reduce their potency resources that are available for subsequent performance episodes. Continuing interactions and experience with the task may facilitate more realistic perceptions of how the team can reasonably be expected to perform (i.e., a demonstrating a decreasing trend over time), in conjunction with increasing consensus across members. Together, this underscores the emergent and dynamic nature of potency. Based on this theorizing, the following is hypothesized:

Hypothesis 1: Perceptions of group potency will decrease over time.

To be clear, we suggest that the downward trend of group potency would be approximated well by a linear trajectory (see Ployhart and Vandenberg, 2010). Rather than a series of discrete step-wise drops, or patterns of punctuated change, we anticipate an incremental series of changes over time. Particularly, as teams meet on a set schedule during their lifecycle (i.e., three times a week during course and laboratory sessions) interacting with each other may lead to gradual changes in perceptions of group potency. Thus, rather than sudden, dramatic changes (i.e., discontinuous, non-linear change) in perceptions of group potency, teams will demonstrate a consistent, linear, downward pattern over time.

Group Potency Over Time and Implications for Team Effectiveness

To improve our understanding of the dynamic nature of group potency, it is crucial to investigate its criterion-related validity and examine how group potency relates to team effectiveness. Meta-analytic research at both the individual- (e.g., Stajkovic and Luthans, 1998) and team-level (Gully et al., 2002; Stajkovic et al., 2009) suggests strong, positive relations with performance. However, these results, as previously mentioned, are based on static research methods and do not take into consideration changes over time.

Within a time-limited project, group potency may function as a team-level resource that takes time to coalesce through consensus, but can be drawn upon by the team to influence effectiveness and the achievement of team tasks and goals. According to the COR theory, resources play an important role in understanding behavioral outcomes (e.g., performance; Halbesleben and Bowler, 2007). Halbesleben et al. (2014) defined resources as "anything perceived by the individual to help attain his or her goal" (p. 1338). Although defined at the individual level, this definition could easily be translated to the team context by defining a team resource as anything perceived by the members that can help the team attain its goal(s). This definition allows group potency to be considered a team-level resource that can be used to optimally influence team effectiveness (see Guzzo et al., 1993; Gully et al., 2002; Stajkovic et al., 2009). In this light, there are two key components of COR to consider: (1) initial resource losses lead to future resource losses, and (2) a greater amount of a resource can reduce the vulnerability to resource losses (Hobfoll, 2001, 2011), as in a buffering effect. Concerning initial resource loss, Hobfoll et al. (2018) argued that resource loss begets stress, which leads to further resource loss. In support of this theorizing, research by Demerouti et al. (2004) demonstrated that resource loss (due to work pressure) leads to increased stress (i.e., work-life role conflict) in individuals, which then leads to further resource loss (i.e., exhaustion). Demerouti et al. (2004) referred to this phenomenon as a "loss spiral," which has also been reported by De Cuyper et al. (2012) and Whitman et al. (2014). Consistent with these findings, we anticipate that teams that are unable to conserve their potency resources over time will lose further resources over time, and experience worse

team effectiveness. Concerning the buffering effect, Hobfoll et al. (2018) argued that individuals who have more resources are less likely to lose resources and are more likely to gain resources. For example, Hakanen et al. (2008) found that individuals with greater job resources were more engaged in their work, which led to increased innovativeness in their work group. Chen et al. (2009) also found that by boosting individuals' resources through training, they were more likely to adapt to changing work contexts and were less likely to experience resource loss (i.e., exhaustion). We therefore propose that teams that start with higher potency (i.e., initially have more potency resources than other teams) will perform better than teams that have lower initial potency. Together, we therefore hypothesize the following:

Hypothesis 2: Changes in group potency (i.e., *the downward trend described by Hypothesis 1*) *will be negatively related to team effectiveness.*
Hypothesis 3: Initial group potency will be positively related to team effectiveness.

Group Potency Consensus Over Time

Emergent states, as previously defined, describe the development of a collective phenomenon from the sharedness of individual members' perceptions of a team-level attribute. Emergent states therefore exist as constructs at the collective level (e.g., team, group, unit, and organization), underscoring their theoretical foundations based on differing composition frameworks. Detailed considerations of composition models is available elsewhere (e.g., Chan, 1998; Kozlowski and Klein, 2000); however, we note here that research on emergent states (e.g., group potency) requires that a level of consensus (i.e., agreement or sharedness), which is based on a theoretically appropriate composition model, be demonstrated. Emergent state research has generally relied on r_{wg}, intraclass correlations (ICCs), and other agreement statistics (see LeBreton and Senter, 2008, for a review) as indices of consensus. Kozlowski et al. (2013) noted that although these statistical approaches for assessing agreement have been used in both cross-sectional and longitudinal research to demonstrate emergence, their use has predominantly been restricted to static interpretations (even when averaged across time in longitudinal research), and therefore ignores the temporal aspect of emergence. More specifically, in both cross-sectional and longitudinal data, these consensus statistics have been used to demonstrate that emergence has taken place, but only provide a snapshot of sharedness, thereby ignoring the dynamicity of the emergence process. For example, in cross-sectional research, after demonstrating some level of consensus, researchers are left to *assume* a team-level phenomenon has emerged, without actually assessing the pattern of *change in consensus* that may more accurately represent the emergence process (O'Neill and Allen, 2012; Allen and O'Neill, 2015a). Although this is informative from a descriptive standpoint, interpreting isolated ICC estimates may not provide a strict test of whether emergence has occurred. To address this issue, Lang et al. (2018) introduced the consensus emergence model, which allows researchers to examine change in consensus over time, a key component of the emergence process. The current investigation used this methodology to provide an assessment of group potency emergence over time.

As a collective phenomenon, group potency fits into Chan (1998) referent-shift consensus model. Group potency, therefore, requires consensus amongst group members to demonstrate the collective or shared aspect of the construct. Commensurate with Kozlowski et al. (2013) theorizing on emergent processes, group members need time to interact with each other and engage with the task to develop a shared understanding of the team-level phenomenon. Initially, group members' perceptions of their potency will be based on minimal information as they have had limited time interacting. As a result, initial ratings of group potency will be more indicative of individual members' perceptions rather than shared perceptions. It can therefore be theorized that agreement between group members will increase over time. Accordingly, we forward the following hypothesis:

Hypothesis 4: Consensus on group potency will increase over time.

ANTECEDENTS OF GROUP POTENCY'S DYNAMIC NATURE

According to the IPO framework, inputs play an important role in the development of team processes. Inputs are conditions or characteristics of team members that exist prior to the team interacting and performing together, including – but not limited to – personality, and other dispositional characteristics. Inputs can therefore be considered as antecedents to emergent states, such as group potency. We selected conscientiousness and extraversion as two input variables (i.e., resources) that will contribute to group potency (i.e., a resource gain). Our rationale for selecting conscientiousness and extraversion is two fold. First, meta-analytic research by Ng and Feldman (2014), structured around COR theory, demonstrated that both conscientiousness, and extraversion contribute to resource gains (e.g., salary attainment). Second, meta-analytic research by Bell (2007) found that team-level conscientiousness and extraversion were positively related to team effectiveness (ρ = 0.14 and ρ = 0.10, respectively). Although the latter supports the direct relation between our selected inputs and team effectiveness, there is a dearth of research investigating the full IPO framework and the implied indirect effects of *how* the inherently dynamic nature of team processes and resources (e.g., group potency) transmit the effects of input resources to outputs. LePine et al. (2011) described the issues involved with this piecemeal approach of only assessing the input-output, or process-output relations, for example, rather than a more theoretically aligned model of input → process → output. Further, LePine et al. (2011) noted that more advanced research designs and analyses should be forwarded to improve understanding of the complete framework (see also Pitariu and Ployhart, 2010). Finally, Mathieu et al. (2014) pointed out that team personality composition might not just be relevant for static teamwork variables but also their change over time.

In the current research, we investigated the full IPO framework by incorporating team-level conscientiousness and extraversion as inputs (i.e., antecedent resources), initial levels and change in group potency as process variables (i.e., team process resources), and team effectiveness as an output. Together, indirect relations are described with group potency's dynamics mediating the relations between team-level personality and team effectiveness.

Conscientiousness

Individuals with high conscientiousness are characterized by being hardworking and achievement-oriented (Goldberg, 1990). Further, conscientious individuals tend to be confident (Chen et al., 2004; Ebstrup et al., 2011), and likely behave in a manner that is conducive to operating in a team environment (e.g., O'Neill and Allen, 2011). Even further, as noted, Bell's (2007) meta-analysis found that team-level mean conscientiousness was positively related to team performance. Thus, past research has illustrated positive relations between team-level conscientiousness and both group potency and team effectiveness.

We again draw upon COR theory, and apply a resource-based perspective to propose how team-level conscientiousness relates to the dynamics of group potency and team effectiveness. Another key proposition of COR is that initial resources can combine to positively influence the achievement of desired outcomes, and can help produce gains in resources, or alternatively, can provide additional resources to help maintain resources levels that may otherwise become depleted over time. Hobfoll (2011) argued that resources should be considered as "caravans," in which the combined functioning of resources best facilitates achieving desired outcomes (e.g., meeting goals, coping with stress). Based on the importance of team-level conscientiousness, we argue that team-level conscientiousness can function as a team "input" resource that can lead to gains in (i.e., higher) initial group potency. For instance, groups that see themselves as more collectively hard working will likely see themselves as having higher initial confidence in their ability to achieve the team's goals, because they know they will persist even when the task difficulty increases. In addition, increased team-level conscientiousness may provide another resource to the team to protect against loss of potency resources over time. Thus, teams with higher levels of conscientiousness will be able to better conserve their potency resources over time. This, in turn, will lead to increased team effectiveness. Thus:

> *Hypothesis 5a: The initial level of group potency will mediate the relation between conscientiousness and team effectiveness.*
> *Hypothesis 5b: The rate of change of group potency will mediate the relation between conscientiousness and team effectiveness.*

Extraversion

Highly extraverted individuals tend to be talkative and sociable (Goldberg, 1990). Research on team-level extraversion has generally revealed positive relations with team performance (Bell, 2007), as it may facilitate positive interpersonal interactions between team members (Barry and Stewart, 1997). Further, extraverts tend to have higher confidence in their ability to work in a self-managed group (Thoms et al., 1996), suggesting a positive relation between team-level extraversion and group potency. Finally, extraversion involves facets related to energy, activity, and excitement seeking (Hastings and O'Neill, 2009), all of which would encourage strong willingness to engage in the work and exploration required for team success.

Similar to team-level conscientiousness, team-level extraversion can be considered a resource that is brought to the team by its individual members and functions as an input for team processes (i.e., group potency). Thus, considering team-level extraversion as a team resource, it may lead to increased initial group potency and help teams preserve their group potency over time. This will permit teams to conserve and maintain their potency resources during its lifecycle, potentially leading to increased team effectiveness. Based on this theorizing, the following is hypothesized:

> *Hypothesis 6a: The initial level of group potency will mediate the relation between extraversion and team effectiveness.*
> *Hypothesis 6b: The rate of change of group potency will mediate the relation between extraversion and team effectiveness.*

MATERIALS AND METHODS

Participants and Procedure

This study was reviewed and approved by Western University's Non-Medical Research Ethics Board and participants provided written informed consent prior to participating. Participants were 337 first-year engineering students. The majority of participants (81%) were male, and ranged in age from 16 to 33 years (M = 18.5, SD = 1.9). Participants were randomly assigned to one of 77 project teams, which consisted of either four (62% of teams) or five (38%) members. Each team had two small design projects (taking place over 2 months each) and one large design project (taking place over 4 months) to complete over the course of an academic year. For the large design project, students were required to create a prototype of a device that individuals with a disability could use to improve their well-being.

Survey data were collected at five different time points throughout the academic year. Conscientiousness and extraversion data was collected on the first day of class before students were assigned into their project teams (i.e., Time 1). Group potency data was collected at three subsequent time points: 2 months (Time 2), 5 months (Time 3), and 8 months (Time 4) after the start of the semester. Grades on the large design project were collected at the conclusion of the semester (i.e., Time 5) and serve as our measure of team effectiveness.

Measures

Conscientiousness

Conscientiousness was measured with ten items from the International Personality Item Pool (IPIP; Goldberg et al., 2006;

α = 0.81). The IPIP items correlate highly with Costa and McCrae's (1992) NEO-PI-R. There were five positively worded and five negatively worded items. A sample item is "I am always prepared." Participants responded to these items on a five-point Likert-type agreement scale (1, strongly disagree; 5, strongly agree).

Extraversion

Extraversion was also measured with ten items from the IPIP (Goldberg et al., 2006; α = 0.86) that correlate highly with the NEO-PI-R. There were five positively worded and five negatively worded items. A sample item is "I feel comfortable around people." Participants responded to these items on a five-point Likert-type agreement scale (1, strongly disagree; 5, strongly agree).

Group Potency

Group potency was measured with seven items from Guzzo et al. (1993), which measure a team's confidence in their general ability to be effective. A sample item is "No task is too tough for this team." Participants responded to these items on a five-point Likert-type agreement scale (1, strongly disagree; 5, strongly agree). Sosik et al. (1997) found that these group potency items have strong internal consistency with a Cronbach's α ranging from 0.87 to 0.98 across three time points.

Team Effectiveness

Associated with the large design project, teams submitted a comprehensive written report that was typically about 100 pages in length. The report contained a variety of detailed information pertaining to the project including, design sketches, mathematical models, and implications for practice. Team reports were rated based on their overall quality by experienced course instructors, who were blind to this study's objectives, and grades were assigned to the team as a whole (i.e., no unique grades were assigned to individual members). Each rater rated a unique subset of the reports (see O'Neill et al., 2018).

Analytical Procedure

Using M*plus* 7.4 (Muthén and Muthén, 2012, 2015) throughout for our focal analyses, we implemented a sequential model testing procedure to conduct (1) longitudinal measurement invariance analyses, (2) latent growth modeling, and (3) consensus emergence modeling (Lang et al., 2018). The full model assessed is illustrated in **Figure 1**. Examinations of change over time requires measurement invariance to ensure that a measure functions and means the same thing over time, and to facilitate meaningful longitudinal inferences (Ployhart and Vandenberg, 2010). Longitudinal measurement invariance assesses the stability of a scale's measurement model over time, and without this support misleading interpretations may result, akin to comparing apples to oranges over time (Chen and West, 2008). Demonstrating invariance requires several analytical steps, which include: (a) configural invariance, (b) metric invariance, (c) scalar invariance, and (d) strict invariance. Ployhart and Vandenberg (2010) noted that configural, metric, and scalar invariance are sufficient for longitudinal invariance, yet strict invariance was also investigated as it can provide additional insight into the structure and function of a scale (McLarnon and Carswell, 2013). The configural invariance model assesses whether the same pattern of factor loadings holds over time. For determining configural invariance, we – in part – assumed support because all seven potency items, which measure a single factor, were assessed at each time point. In addition, we also considered indicators of model-data fit rendered by the comparative fit index (CFI) and root mean square error of approximation (RMSEA). CFI values > 0.95 and RMSEA values <0.08 can be taken as evidence for acceptable model fit (e.g., Hu and Bentler, 1999). Building on the configural invariance model, metric invariance then constrains respective factor loadings to equality, scalar invariance places additional equality constraints on respective intercepts, and strict invariance places equality constraints on respective item residuals. To assess plausibility of each of these sets of invariance constraints, the $\Delta\chi^2$ test can be used because each set of constraints imposed represent a nested model. However, as $\Delta\chi^2$ may be overly sensitive to sample size, changes in the CFI of less than 0.010 and/or changes in the RMSEA of less than 0.015 can support invariance in each step (Chen, 2007). In each longitudinal invariance analysis, autocorrelated residuals were specified between respective items (Little, 2013).

Our invariance analyses used individual-level data in order to achieve a balance between sample size and model complexity. However, to account for the nested nature of our data (i.e., individuals within teams), we used robust maximum likelihood estimation, implemented as M*plus*' MLR estimator, in conjunction with the TYPE = COMPLEX specification to furnish model fit indices and standard errors that were robust to non-independence (Muthén and Muthén, 2012; McNeish et al., 2017). Given the use of the MLR estimator, $\Delta\chi^2$ nested model comparisons were facilitated through Satorra and Bentler's (2001) scaled $\Delta\chi^2$ statistic.

An additional wrinkle in estimating the longitudinal invariance models concerns the correct specification of the longitudinal null model (Little, 2013), which is used in the derivation of the CFI. If the null model is incorrect, the CFIs used to judge invariance may also be biased and may result in erroneous inferences. As discussed by Widaman and Thompson (2003), the correct longitudinal null model should specify zero covariances between any indicators (as in the typical null model), but equal variances and equal means for respective indicators across time points. As such, our use of the CFI was based on the corrected longitudinal null model.

Then, using latent growth modeling (Chan, 2002), and the aggregated potency scores, we examined the dynamics involved with group potency. First, we estimated an unconditional model to estimate the mean and variability around the latent intercept and slope of group potency. The latent growth model was specified in a typical fashion with the factor loadings for the latent intercepts all fixed at 1.00, and the factor loadings for the latent slope were fixed at zero, 1.00, and 2.00, for each of the measures (i.e., Time 2, 3, and 4; see above), respectively. The parameterization for the slope follows from equal time spacing between Times 2 and 3, and Times 3 and 4, as both reflected 3-month time lags. We then incorporated team effectiveness, as a simultaneous outcome of both the latent intercept and

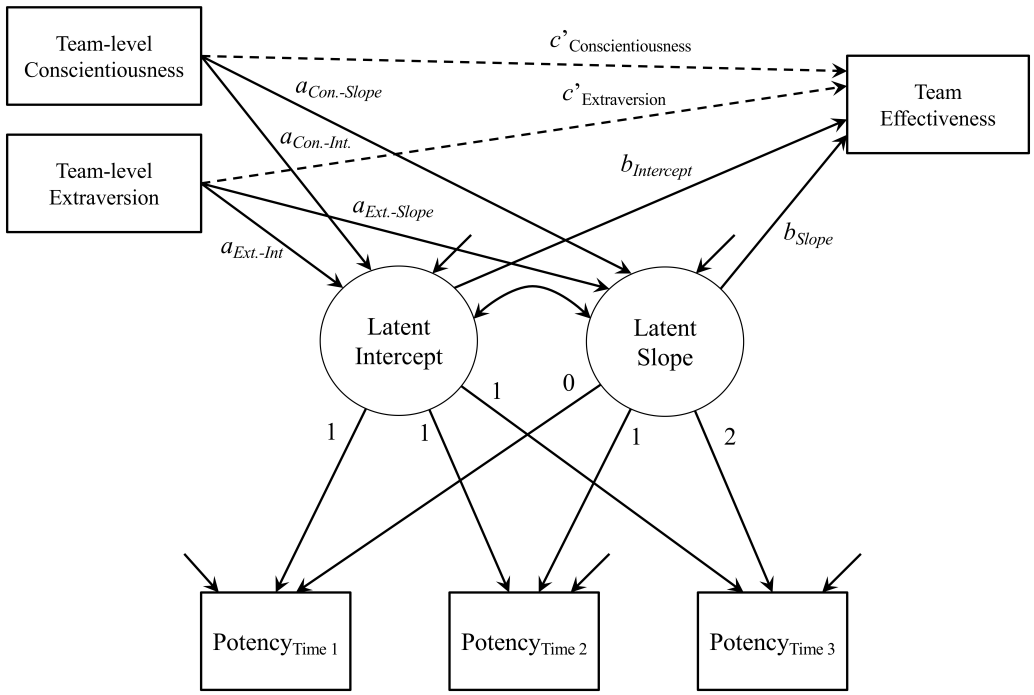

FIGURE 1 | Focal analytical model. Numeric factor loadings for LGM presented. Direct effects, c'paths, and shown in dashed lines. Indirect effects, comprising respective *a* and *b* paths and associated $a_j \times b_j$ effects, and shown in solid lines.

slope, and the personality predictors to assess the indirect effects. Using bias-corrected bootstrapping, with 10,000 samples, indirect effects were deemed significant if their 95% confidence intervals (CIs) excluded zero. Notably, the personality predictors used the mean-aggregation of scores from each individual member and as mean-aggregated personality is not a shared-unit property of a team (Kozlowski and Klein, 2000) justifying aggregation (via ICCs, etc) is therefore not required (e.g., O'Neill and Allen, 2011).

Finally, we used Lang et al.'s (2018) multilevel procedure to examine consensus emergence of group potency. This allowed us to assess emergence of the group-level potency construct from the sharedness, or more specifically the increasing degree of sharedness, of individual members' ratings over time.

RESULTS

Table 1 presents the team-level correlation matrix, the intraclass correlation estimates [ICC(1) and ICC(2)] for group potency at each time point, and Cronbach's alpha internal consistency estimates. Notably, the ICC estimates increased slightly over time, indicating a growing proportion of variance in group potency that could be attributed to the team-level rather than the individual-level. This suggests increasing consensus in perceptions of team potency over time and stronger emergence. We revisit this pattern to more formally substantiate the emergence of group potency and provide a test of Hypothesis 4.

Table 2 presents the results of the longitudinal measurement invariance analyses. The configural invariance model demonstrated adequate fit, CFI = 0.95 and RMSEA = 0.06. Adding equality constraints on the factor loadings resulted in ΔCFI = −0.001 and ΔRMSEA = −0.002, supporting metric invariance. This suggests that the potency measure retains a similar meaning across occasions. The scalar invariance model resulted in a ΔCFI = −0.003 and ΔRMSEA < 0.0004 versus the metric invariance model. This lends support to scalar invariance, which suggests that the potency measure functions similarly over time. As a final stage in the invariance analyses, additional equality constraints were placed on respective item residuals to assess strict invariance. This model resulted in ΔCFI = 0.003 and ΔRMSEA = −0.004, supporting strict invariance, and suggests that each item had equivalent reliability over time. Together, these invariance analyses suggest equivalence of group potency over time, facilitating our focal latent growth models.

Given the ICCs provided support for aggregating group potency to the team-level, we averaged individual members' group potency scores within each team, and used the aggregated scores to estimate our latent growth model. The unconditional growth model demonstrated adequate fit to the data, $\chi^2(1) = 0.73$, $p = 0.39$, CFI = 1.00, RMSEA = 0.00. With respect to Hypothesis 1, the mean of the latent slope was of central interest, which was estimated as -0.07, $p < 0.05$. This supported Hypothesis 1, suggesting that group potency *decreased* over time (by 0.07 units at each time point). The estimate of the latent intercept was 4.06, $p < 0.01$, and the variances for the latent intercept and slope were 0.20, $p < 0.01$, and 0.04, $p < 0.05$, respectively. The correlation between the latent intercept and slope was -0.14, $p = 0.59$. Interestingly, freeing the slope's factor loading for the

TABLE 1 | Team-level Descriptives and Intercorrelations.

	M	*SD*	*ICC(1)*	*ICC(2)*	*1*	*2*	*3*	*4*	*5*	*6*
1. Conscientiousness	3.66	0.26	–	–	(0.73)					
2. Extraversion	3.49	0.26	–	–	–0.00	(0.77)				
3. Potency, Time 1	4.06	0.37	0.27	0.60	0.13	0.22	(0.90)			
4. Potency, Time 2	4.06	0.52	0.35	0.65	0.24*	–0.06	0.41**	(0.93)		
5. Potency, Time 3	3.97	0.62	0.37	0.67	0.30**	0.00	0.30**	0.62**	(0.94)	
6. Team effectiveness	82.28	11.01	–	–	0.14	–0.16	0.14	0.35**	0.32**	–

*n = 77. ICCs not applicable to conscientiousness, extraversion, or team effectiveness measures. Individual-level Cronbach's α estimates given in parentheses on diagonal; Team Effectiveness was a single score (grade), therefore reliability could not be estimated. **p < 0.01, *p < 0.05.*

TABLE 2 | Longitudinal measurement invariance analyses.

	χ^2	χ^2c	*df*	*#fp*	CFI	RMSEA	$\Delta\chi^2$	$\Delta\chi^2$ *df*	ΔCFI	ΔRMSEA
Configural	355.46*	1.22	165	87	0.95	0.06	–	–	–	–
Metric	370.09*	1.21	177	75	0.95	0.06	13.61	12	–0.001	–0.002
Scalar	392.72*	1.20	189	63	0.95	0.06	21.12*	12	–0.003	+0.001
Strict	394.32*	1.27	203	49	0.95	0.06	13.75	14	0.003	–0.004

*χ^2c, scaling correction factor for χ^2; df, degrees of freedom; #fp, number of parameters estimated; CFI, comparative fit index (calculated using corrected longitudinal null model; Widaman and Thompson, 2003); RMSEA, root mean square error of approximation; Δχ, Satorra-Bentler scaled χ^2 difference statistic (Satorra and Bentler, 2001); $\Delta\chi^2$ df, degrees of freedom for Satorra-Bentler $\Delta\chi^2$; ΔCFI, ΔRMSEA, change in CFI and RMSEA estimates, respectively, from less restricted to more restricted models (i.e., change in CFI from configural invariance model to metric invariance model). *p < 0.05.*

second group potency measure, as in a latent basis model (Grimm et al., 2013) did not suggest an improvement in fit. Specifically, $\Delta\chi^2(1) = 0.71$, $p = 0.39$, and both the Akaike Information Criteria and Bayesian Information Criteria were higher in the latent basis model than the latent growth model. Thus, based on parsimony, we proceed with the linear latent growth model. Notably, even in the latent basis model, the trend did not deviate significantly from a linear trajectory, thus lending further credibility to Hypothesis 1, and the underlying linear, downward pattern of change in group potency. Next, incorporating team effectiveness as a simultaneous outcome of the latent intercept and slope factors also resulted in adequate model-data fit: χ^2 (2) = 1.22, p = 0.54, CFI = 1.00, RMSEA = 0.00. Specifying regressions between both intercept and slope factors and effectiveness revealed that the regression of effectiveness on the latent slope was b = 0.07, p = 0.99, but that for the latent intercept it was b = 10.23, $p < 0.01$. Thus, there was no influence of change in potency on team effectiveness, but the starting point of teams' potency was positively related to effectiveness. Accordingly, Hypothesis 2 was not supported, whereas Hypothesis 3 was supported.

To more formally assess the emergence of the group potency construct, we used Lang et al.'s (2018) consensus emergence model. This model uses longitudinal changes in the individual-level residual variances as evidence of emerging consensus. Specifically, decreasing residual variances can be taken as indicative of increasing consensus emergence, and therefore reflects more agreement about a team-level phenomenon. Indeed, in our model the estimated change in residual variance was δ = –0.11, $p < 0.05$. This suggests significantly less individual-level variance and comparably greater sharedness at the team-level over time. In other words, this negative coefficient supports the proposition that group potency demonstrated significant increases in the support for emergence over the three measurement occasions. Thus, Hypothesis 4 was supported.

Finally, we incorporated the conscientiousness and extraversion team-level predictors into the latent growth model. This also resulted acceptable model-data fit: χ^2 (4) = 3.02, p = 0.55, CFI = 1.00, RMSEA = 0.00. Neither of the indirect effects involving the latent slope had 95% CIs that excluded zero: the conscientiousness → latent slope → team effectiveness indirect effect was -0.01, 95% CI = –3.11–2.65, and the extraversion → latent slope → team effectiveness indirect effect was 0.08, 95% CI = –2.36–4.55. The indirect effect involving extraversion → latent intercept → team effectiveness was also not significant, -0.73, 95% CI = –9.34–4.65. However, the indirect effect of conscientiousness → latent intercept → effectiveness was significant, 5.57, 95% CI = 0.59–23.58. Thus, there was no evidence for the mediating role for change in potency, but instead the latent intercept transmitted the effect of conscientiousness on team effectiveness. In sum, Hypothesis 5a was supported, but Hypotheses 5b, 6a, and 6b did not receive support.

DISCUSSION

There are four intriguing findings from the current investigation that contribute to both the group potency and the multilevel emergence literatures. First, the latent growth model revealed a significant negative slope for group potency. Group potency levels therefore *decreased* over time, on average across teams. Previous research by Lester et al. (2002) also found a decrease in group potency over time; however, that study had only two time points and a much shorter time span in comparison to the current investigation (i.e., 9 weeks vs. 6 months, respectively). We

theorized that individuals would generally tend to start with high expectations of how their team would perform (Svenson, 1981). As well, due to the "better-than-average" effect when teams first get together they may experience a "honeymoon period" where they have unrealistic positive expectations of how they will do as a group (Forsyth, 2018). Over time, it is probable that the honeymoon dissolves as team members spend more time interacting, debating, dealing with internal conflicts, and other challenges associated with teamwork and the team task (O'Neill and McLarnon, 2018; O'Neill et al., 2018). In this study, we drew upon COR theory to argue that these challenges negatively affect team resources (e.g., group potency), resulting in a decrease in magnitude over time. Interestingly, similar results have been found in other research domains. For example, in examining changes in organizational commitment, an integral workplace resource, Lance et al. (2000) and Bentein and Meyer (2004) found that organizational newcomers experienced loss of this resource over time as they interacted with their new settings. Our results, and those from the domain of organizational commitment, therefore support the argument that resources can be depleted over time as individuals interact with their environment, whether the environmental context is a workplace or a team. This suggests that early team experiences (i.e., socialization) are important for establishing strong, initial group potency resources.

This paved the way for the second intriguing finding from this study: in the latent growth model, teams' initial group potency predicted overall team effectiveness. This implies that, although group potency takes time to emerge (which we discuss subsequently), early interactions might play an important role in setting a team up for future success. Although teams may have elevated potency ratings during a honeymoon period, they are still able to effectively leverage their potency resources, such that it helps explain teams' effectiveness later on during project completion (i.e., 6 months later). This finding supports Kozlowski et al. (2013) argument that it is important to assess emergent states as early in a team's lifecycle as possible. Even though group potency resources may decrease over time, early potency, and the intrateam resources it provides, may have a role in determining future strategizing, planning, and cooperation, which helps to set the stage for the future goal and task accomplishment. Thus, despite the decreasing trend experienced by teams over time, what appears to be an important component of a team's effectiveness is each team's perception of potency early on in their respective lifecycle.

The third intriguing contribution that this research provides is that we documented an increase in consensus on group potency within teams. Thus, members gained an increasingly *shared* perception of their group's potency over time. This is an important aspect of what Kozlowski et al. (2013) described generally as exemplifying the multilevel emergence process: as team members interact they will develop a stronger, shared understanding of the team's emergent properties (e.g., group potency). Historically, "sharedness" or consensus has only been investigated using cross-sectional analyses, and inferred via ICC estimates, with "high values" taken to support the occurrence of emergence. This approach, however, does not facilitate an inference of the actual process of consensus emergence, which is temporally defined. Using Lang et al.'s (2018) methodology, we were able to utilize an analytical approach that is sensitive to emergence's inherently temporal nature and provide an empirical estimate of group potency's emergence. Commensurate with Allen and O'Neill (2015b), we found support for early emergence, with Time 1 ICCs meeting acceptable levels of agreement (LeBreton and Senter, 2008). Nevertheless, our findings also suggest that agreement still increased over longer durations as team members interact and get a better understanding of "who they are" as a collective.

Although the findings of *decreasing* group potency levels and *increasing* consensus on group potency may seem in opposition, these are independent phenomena. Conceivably, consensus could emerge over any level of a construct, which could be static or dynamic in nature. Future research may be able to leverage Lang et al.'s (2018) framework and incorporate predictors of emergence, such as relationship and process conflict (O'Neill et al., 2018), psychological safety (Edmondson, 1999), intrateam communication, and peer feedback (Donia et al., 2018), among others.

The fourth important finding reflects the application of the IPO framework to test key COR principles. More specifically, two input resources – conscientiousness and extraversion – were included as antecedents of group potency's dynamic nature. We found that the relation between conscientiousness and team effectiveness was mediated by initial group potency. Contrary to our expectations, no effect was found for extraversion, or for the link between conscientiousness and team effectiveness, as mediated by the rate of change in potency level. These findings suggest that teams that comprise individuals with higher levels of conscientiousness are more likely to get off to a "good start," and utilize their collective personality composition as a resource to develop higher levels of initial group potency (another resource), thereby leading to greater team effectiveness.

Practical Implications

Stemming from these results, an important practical implication is that early team interactions need to be managed effectively to enable a strong starting point for teams' group potency. With an emphasis on early group potency, rather than the change in potency over time, teams may be able to leverage initial potency as a critical team resource and more effectively navigate hurdles encountered during project completion. Nevertheless, future research may want to also consider how the potentially negative effects of overconfidence (Goncalo et al., 2010) can be mitigated with early team experiences such as developing a team charter, engaging in informal socialization, and other activities that may assist in developing a healthy level of early group potency.

A second practical implication is that interteam differences in personality composition play an important role in developing early group potency. We found that teams that had members with higher conscientiousness were more likely to develop group potency early on, leading to increased team effectiveness. Drawing from

an integration of COR theory and the IPO framework, conscientiousness is an important resource that sets the stage for teams' early potency, which reflects another critical team resource that, in turn, influences effectiveness. Therefore, teams can utilize the resources made available by their aggregated level of conscientiousness to establish and develop group potency allowing them to be more effective. Thus, it is important to consider personality traits, like conscientiousness, when selecting members for a team (see Allen and West, 2005; Morgeson et al., 2005; O'Neill and Allen, 2011; Allen and O'Neill, 2015a).

Limitations

One of the limitations of the current study is the use of a student sample that, on average, was relatively young (18.5 years old). As well, the participants were predominantly male. It is therefore somewhat difficult to generalize the current findings to more heterogeneous work environments. Furthermore, our results may only apply to time- and project-limited teams. Teams that are tasked with multiple performance cycles may experience a different form of change in potency over time, during the completion of their projects. Future research will be needed to assess the form and function of potency in alternative types of teamwork, which may also facilitate insight into Marks et al.'s (2001) recommendation to investigate multiphasic perspectives on team processes.

A second limitation concerns the ability to apply these results to the dynamic nature that is exemplified by other emergent states. Specifically, the dynamics of potency may vary from the growth inherent with other emergent states (e.g., cohesion). Although potency may emerge after a relatively short duration, and then decline over time, cohesion (i.e., a motivational force that drives teams to stay together) may take longer to emerge as teams take time to decide whether they want to stay together. Thus, future research should be conducted using similar research methods and analytical procedures (i.e., latent growth modeling, paired with Lang et al.'s (2018) consensus emergence model) to investigate the dynamics of other emergent states.

A third limitation is that the measures marking the beginning of the potency growth trajectories were collected 2 months into teams' lifecycle. This timeframe was selected because members had limited time to interact over the first 2 months, but would have still been representative of teams' "honeymoon" levels of potency, as they had yet to receive any substantial feedback on their team effectiveness. The results of this study, however, demonstrate that potency had already begun to emerge by the beginning of the trajectory. Future research should measure and examine potency even earlier on in a team's inception (see Kozlowski et al., 2013).

Directions for Future Research

Although this research presents several unique and valuable contributions to the literature, there are a number of crucial questions future research should investigate. First and foremost is cross-validation of these findings with a larger number of more heterogeneous teams engaged in alternative projects that take place over longer (or shorter) time periods and lifecycles. Such research endeavors may highlight alternative forms of group potency change over time (i.e., non-linear, discontinuous). However, we would still likely anticipate consensus to emerge and solidify over time, though it may taper off during longer lifecycles. Though we have substantiated a linear, downward trend in group potency over time, it may also be interesting to examine whether distinct types of teams occupy differential trajectories of group potency dynamics. Specifically, leveraging growth mixture modeling, future researchers could examine nuanced trajectories of potency that may be illustrated by distinct *types* of teams (Muthén, 2001; McLarnon and O'Neill, 2018; O'Neill et al., 2018).

Additionally, future research could be dedicated toward whether similar emergent states (e.g., collective efficacy) may exhibit differential patterns of change over time. For instance, collective efficacy, as previously mentioned, is an emergent state that represents a group's confidence in their ability to perform a *specific* task, rather than the general ability to perform that is measured by group potency. Thus, as teams engaged in a specific task (e.g., a product development initiative), they could experience increasing collective efficacy as they gain task-specific knowledge, and expertise through practice – similar to how training can increase self-efficacy (Blume et al., 2010) – while also experiencing decreasing group potency as they recognize how challenging it can be to effectively function as a team, in general. Nonetheless, we believe the current research provides substantial value to the literature, and our methodological approach may assist future studies, which we eagerly await so as to equip the literature with a comprehensive understanding of form, function, predictors, and implications of group potency.

CONCLUSION

The current investigation improves our understanding of the dynamic aspect of group potency. Results demonstrated that potency decreased over time, which we attributed to a honeymoon period associated with a team's early interactions. Further, teams tended to agree more on their team's potency over time, suggesting that it takes time for the group potency construct to emerge. Even further, early group potency predicted team effectiveness, however, the change in group potency did not. This suggests that early interactions play an important role in establishing group potency, which may emerge relatively quickly, and may set the tone for future success. Finally, initial group potency mediated the relation between team-level conscientiousness and team effectiveness, suggesting that conscientiousness plays an important role in influencing the dynamics of group potency, which subsequently leads to increased team effectiveness.

ETHICS STATEMENT

This study was carried out following the protocol approved by the university's Non-Medical Research Ethics Board, which in accordance with the Declaration of Helsinki, all subjects provided written informed consent prior to participating.

AUTHOR CONTRIBUTIONS

HW developed the study idea, coordinated the data management, and wrote sections of the manuscript. MM analyzed the data and wrote sections of the manuscript. TO'N developed the study materials, coordinated the data collection, and provided the comments throughout the manuscript.

FUNDING

This work was supported by a grant from the Social Sciences and Humanities Research Council of Canada.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Natalie Allen for her comments and feedback on a previous version of this manuscript.

REFERENCES

Alicke, M. D., Klotz, M. L., Breitenbecher, D. L., Yurak, T. J., and Vredenburg, D. S. (1995). Personal contact, individuation, and the better-than-average effect. *J. Personal. Soc. Psychol.* 68, 804–825. doi: 10.1037//0022-3514.68.5.804

Allen, N. J., and O'Neill, T. A. (2015a). "Team composition and performance: considering the project team challenge," in *The Psychology and Management of Project Teams: An Interdisciplinary Perspective*, eds F. Chiocchio, E. K. Kelloway, and B. Hobbs (Oxford: Oxford University Press), 301–328.

Allen, N. J., and O'Neill, T. A. (2015b). The trajectory of emergence of shared group-level constructs. *Small Group Res.* 46, 352–390. doi: 10.1177/1046496415584973

Allen, N. J., and West, M. A. (2005). "Selection for teams," in *Handbook of Personnel Selection*, eds A. Evers, N. Anderson, and O. Voskuijl (Oxford: Blackwell Publishing), 476–494.

Barry, B., and Stewart, G. L. (1997). Composition, process, and performance in self-managed groups: the role of personality. *J. Appl. Psychol.* 82, 62–78. doi: 10.1037/0021-9010.82.1.62

Beal, D. J., Cohen, R. R., Burke, M. J., and McLendon, C. L. (2003). Cohesion and performance in groups: a meta-analytic clarification of construct relations. *J. Appl. Psychol.* 88, 989–1004. doi: 10.1037/0021-9010.88.6.989

Bell, S. T. (2007). Deep-level composition variables as predictors of team performance: a meta-analysis. *J. Appl. Psychol.* 92, 595–615. doi: 10.1037/0021-9010.92.3.595

Bentein, K., and Meyer, J. P. (2004). doi: 10.1037/0021-9010.92.3.595

Blume, B. D., Ford, J. K., Baldwin, T. T., and Huang, J. L. (2010). Transfer of training: a meta-analytic review. *J. Manage.* 36, 1065–1105. doi: 10.1177/0149206309352880

Chan, D. (1998). Functional relations among constructs in the same content domain at different levels of analysis: a typology of composition models. *J. Appl. Psychol.* 83, 234–246. doi: 10.1037//0021-9010.83.2.234

Chan, D. (2002). "Latent growth modeling," in *Measuring and Analyzing Behavior in Organizations: Advances in Measurement and Data Analysis*, eds F. Drasgow and N. Schmitt (San Francisco, CA: Jossey-Bass), 302–349.

Chen, F. F. (2007). Sensitivity of goodness of fit indexes to lack of measurement invariance. *Struct. Equat. Model.* 14, 464–504. doi: 10.1080/10705510701301834

Chen, F. F., and West, S. G. (2008). Measuring individualism and collectivism: the importance of considering differential components, reference groups, and measurement invariance. *J. Res. Personal.* 42, 259–294. doi: 10.1016/j.jrp.2007.05.006

Chen, G., Gully, S. M., and Eden, D. (2004). General self-efficacy and self-esteem: toward theoretical and empirical distinction between correlated self-evaluations. *J. Organ. Behav.* 25, 375–395. doi: 10.1002/job.251

Chen, S., Westman, M., and Eden, D. (2009). Impact of enhanced resources on anticipatory stress and adjustment to new information technology: a field-experimental test of conservation of resources theory. *J. Occup. Health Psychol.* 14:219. doi: 10.1037/a0015282

Collins, C. G., Gibson, C. B., Quigley, N. R., and Parker, S. K. (2016). Unpacking team dynamics with growth modeling: an approach to test, refine, and integrate theory. *Organ. Psychol. Rev.* 6, 63–91. doi: 10.1177/2041386614561249

Collins, C. G., and Parker, S. K. (2010). Team capability beliefs over time: distinguishing between team potency, team outcome efficacy, and team process efficacy. *J. Occup. Organ. Psychol.* 83, 1003–1023. doi: 10.1348/096317909X484271

Costa, P. T., and McCrae, R. R. (1992). Normal personality assessment in clinical practice: the NEO personality inventory. *Psychol. Assess.* 4, 5–13. doi: 10.1037//1040-3590.4.1.5

Cronin, M. A., Weingart, L. R., and Todorova, G. (2011). Dynamics in groups: are we there yet? *Acad. Manage. Ann.* 5, 571–612. doi: 10.1080/19416520.2011.590297

De Cuyper, N., Mäkikangas, A., Kinnunen, U., Mauno, S., and De Witte, H. (2012). Cross-lagged associations between perceived external employability, job insecurity, and exhaustion: testing gain and loss spirals according to the conservation of resources theory. *J. Organ. Behav.* 33, 770–788. doi: 10.1002/job.1800

Demerouti, E., Bakker, A. B., and Bulters, A. J. (2004). The loss spiral of work pressure, work–home interference and exhaustion: reciprocal relations in a three-wave study. *J. Vocat. Behav.* 64, 131–149. doi: 10.1016/S0001-8791(03)00030-7

Donia, M. B. L., O'Neill, T. A., and Brutus, S. (2018). The longitudinal effects of peer feedback in the development and transfer of student teamwork skills. *Learn. Ind. Diff.* 61, 87–98. doi: 10.1016/j.lindif.2017.11.012

Ebstrup, J. F., Eplov, L. F., Pisinger, C., and Jørgensen, T. (2011). Association between the five factor personality traits and perceived stress: is the effect mediated by general self-efficacy? *Anxiety Stress Coping* 24, 407–419. doi: 10.1080/10615806.2010.540012

Edmondson, A. (1999). Psychological safety and learning behavior in work teams. *Admin. Sci. Quart.* 44, 350–383. doi: 10.2307/2666999

Edwards, J. R. (2001). Ten difference score myths. *Organ. Res. Methods* 4, 265–287. doi: 10.1177/109442810143005

Forsyth, D. R. (2018). *Group Dynamics*. Boston, MA: Cengage Learning. doi: 10.1177/109442810143005

Goldberg, L. R. (1990). An alternative "description of personality": the big-five factor structure. *J. Personal. Soc. Psychol.* 59, 1216–1229. doi: 10.1037/0022-3514.59.6.1216

Goldberg, L. R., Johnson, J. A., Eber, H. W., Hogan, R., Ashton, M. C., Cloninger, C. R., et al. (2006). The international personality item pool and the future of public-domain personality measures. *J. Res. Personal.* 40, 84–96. doi: 10.1016/j.jrp.2005.08.007

Goncalo, J. A., Polman, E., and Maslach, C. (2010). Can confidence come too soon? Collective efficacy, conflict and group performance over time. *Organ. Behav. Hum. Decis. Process.* 113, 13–24. doi: 10.1016/j.obhdp.2010.05.001

Grimm, K. J., Steele, J. S., Ram, N., and Nesselroade, J. R. (2013). Exploratory latent growth models in the structural equation modeling framework. *Struct. Equat. Model.* 20, 568–591. doi: 10.1080/10705511.2013.824775

Grossman, R., Friedman, S. B., and Kalra, S. (2017). "Teamwork processes and emergent states," in *The Wiley Blackwell Handbook of the Psychology of Team Working and Collaborative Processes*, eds E. Salas, R. Rico, and J. Passmore (Sussex: John Wiley & Sons), 245–269.

Gully, S. M., Incalcaterra, K. A., Joshi, A., and Beaubien, J. M. (2002). A meta-analysis of team-efficacy, potency, and performance: interdependence and level of analysis as moderators of observed relationships. *J. Appl. Psychol.* 87, 819–832. doi: 10.1037/0021-9010.87.5.819

Guzzo, R. A., Yost, P. R., Campbell, R. J., and Shea, G. P. (1993). Potency in groups: articulating a construct. *Br. J. Soc. Psychol.* 32, 87–106. doi: 10.1111/j.2044-8309.1993.tb00987.x

Hakanen, J. J., Perhoniemi, R., and Toppinen-Tanner, S. (2008). Positive gain spirals at work: from job resources to work engagement, personal initiative and work-unit innovativeness. *J. Vocat. Behav.* 73, 78–91. doi: 10.1016/j.jvb.2008.01.003

Halbesleben, J. R., and Bowler, W. M. (2007). Emotional exhaustion and job performance: the mediating role of motivation. *J. Appl. Psychol.* 92, 93–106. doi: 10.1037/0021-9010.92.1.93

Halbesleben, J. R., Neveu, J. P., Paustian-Underdahl, S. C., and Westman, M. (2014). Getting to the "COR" understanding the role of resources in conservation of resources theory. *J. Manage.* 40, 1334–1364. doi: 10.1177/0149206314527130

Hastings, S. E., and O'Neill, T. A. (2009). Predicting workplace deviance using broad and narrow personality traits. *Personal. Ind. Diff.* 47, 289–293. doi: 10.1016/j.paid.2009.03.015

Hobfoll, S. E. (2001). The influence of culture, community, and the nested-self in the stress process: advancing conservation of resources theory. *Appl. Psychol.* 50, 337–421. doi: 10.1111/1464-0597.00062

Hobfoll, S. E. (2011). Conservation of resource caravans and engaged settings. *J. Occup. Organ. Psychol.* 84, 116–122. doi: 10.1111/j.2044-8325.2010.02016

Hobfoll, S. E., Halbesleben, J., Neveu, J. P., and Westman, M. (2018). Conservation of resources in the organizational context: the reality of resources and their consequences. *Annu. Rev. Organ. Psychol. Organ. Behav.* 5, 103–128. doi: 10.1146/annurev-orgpsych-032117-104640

Hu, L.-t., and Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. *Struct. Equ. Modeling* 6, 1–55. doi: 10.1080/10705519909540118

Ilgen, D., Hollenbeck, J., Johnson, M., and Jundt, D. (2005). Teams in organizations: from input-process-output models to IMOI models. *Annu. Rev. Psychol.* 56, 517–543. doi: 10.1146/annurev.psych.56.091103.070250

Kozlowski, S. W. (2018). Enhancing the effectiveness of work groups and teams: a reflection. *Perspect. Psychol. Sci.* 13, 205–212. doi: 10.1177/1745691617697078

Kozlowski, S. W., Chao, G. T., Grand, J. A., Braun, M. T., and Kuljanin, G. (2013). Advancing multilevel research design: capturing the dynamics of emergence. *Organ. Res. Methods* 16, 581–615. doi: 10.1177/1094428113493119

Kozlowski, S. W., and Ilgen, D. R. (2006). Enhancing the effectiveness of work groups and teams. *Psychol. Sci. Public Interest* 7, 77–124. doi: 10.1111/j.1529-1006.2006.00030.x

Kozlowski, S. W., Mak, S., and Chao, G. T. (2016). Team-centric leadership: an integrative review. *Annu. Rev. Organ. Psychol. Organ. Behav.* 3, 21–54. doi: 10.1146/annurev-orgpsych-041015-062429

Kozlowski, S. W. J., and Klein, K. J. (2000). "A multilevel approach to theory and research in organizations: contextual, temporal, and emergent processes," in *Multilevel Theory, Research, and Methods in Organizations: Foundations, Extensions, and New Directions*, eds K. J. Klein and S. W. J. Kozlowski (San Francisco, CA: Jossey-Bass), 3–90.

Lance, C. E., Vandenberg, R. J., and Self, R. M. (2000). Latent growth models of individual change: the case of newcomer adjustment. *Organ. Behav. Hum. Decis. Process.* 83, 107–140. doi: 10.1006/obhd.2000.2904

Lang, J. W. B., Bliese, P. D., and de Voogt, A. (2018). Modeling consensus emergence in groups using longitudinal multilevel methods. *Pers. Psychol.* 71, 255–281. doi: 10.1111/peps.12260

Larrick, R. P., Burson, K. A., and Soll, J. B. (2007). Social comparison and confidence: when thinking you're better than average predicts overconfidence (and when it does not). *Organ. Behav. Hum. Decis. Process.* 102, 76–94. doi: 10.1016/j.obhdp.2006.10.002

LeBreton, J. M., and Senter, J. L. (2008). Answers to 20 questions about interrater reliability and interrater agreement. *Organ. Res. Methods* 11, 815–852. doi: 10.1177/1094428106296642

LePine, J. A., Buckman, B. R., Crawford, E. R., and Methot, J. R. (2011). A review of research on personality in teams: accounting for pathways spanning levels of theory and analysis. *Hum. Resour. Manage. Rev.* 21, 311–330. doi: 10.1016/j.hrmr.2010.10.004

LePine, J. A., Piccolo, R. F., Jackson, C. L., Mathieu, J. E., and Saul, J. R. (2008). A meta-analysis of teamwork processes: tests of a multidimensional model and relationships with team effectiveness criteria. *Pers. Psychol.* 61, 273–307. doi: 10.1111/j.1744-6570.2008.00114.x

Lester, S. W., Meglino, B. M., and Korsgaard, M. A. (2002). The antecedents and consequences of group potency: a longitudinal investigation of newly formed work groups. *Acad. Manage. J.* 45, 352–368. doi: 10.5465/3069351

Little, T. D. (2013). *Longitudinal Structural Equation Modeling*. New York, NY: Guilford Press. doi: 10.5465/3069351

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manage. Rev.* 26, 356–376. doi: 10.5465/amr.2001.4845785

Mathieu, J. E., Tannenbaum, S. I., Donsbach, J. S., and Alliger, G. M. (2014). A review and integration of team composition models: moving toward a dynamic and temporal framework. *J. Manage.* 40, 130–160. doi: 10.1177/0149206313503014

McClurg, C. E., Chen, J. L., Petruzzelli, A., and Thayer, A. L. (2017). "Challenges and new directions in examining team cohesion over time," in *Research on Managing Groups and Teams*, Vol. 18, eds E. Salas, W. Vessey, and L. Landon (Bingley: Emerald Publishing Limited), 261–286. doi: 10.1108/s1534-085620160000018011

McGrath, J. E. (1964). *Social Psychology: A Brief Introduction*. New York, NY: Holt, Rinehart and Winston. doi: 10.1108/s1534-085620160000018011

McLarnon, M. J. W., and Carswell, J. J. (2013). The personality differentiation by intelligence hypothesis: a measurement invariance investigation. *Personal. Ind. Diff.* 54, 557–561. doi: 10.1016/j.paid.2012.10.029

McLarnon, M. J. W., and O'Neill, T. A. (2018). Extensions of auxiliary variable approaches for the investigation of mediation, moderation, and conditional effects in mixture models. *Organ. Res. Methods* 21, 955–982. doi: 10.1177/1094428118770731

McNeish, D., Stapleton, L. M., and Silverman, R. D. (2017). On the unnecessary ubiquity of hierarchical linear modeling. *Psychol. Methods* 22, 114–140. doi: 10.1037/met0000078

Morgeson, F. P., Reider, M. H., and Campion, M. A. (2005). Selecting individuals in team settings: the importance of social skills, personality characteristics, and team work knowledge. *Pers. Psychol.* 58, 583–611. doi: 10.1111/j.1744-6570.2005.655.x

Muthén, B. O. (2001). "Second-generation structural equation modeling with a combination of categorical and continuous latent variables: New opportunities for latent class/latent growth modeling," in *New Methods for the Analysis of Change*, eds L. M. Collins and A. Sayer (Washington, D.C: APA), 291–322.

Muthén, L. K., and Muthén, B. O. (2012). *Mplus User's Guide*, 7th Edn. Los Angeles, CA: Mutheìn & Mutheìn.

Muthén, L. K., and Muthén, B. O. (2015). *Mplus 7.4. [Computer Program]*. Los Angeles, CA: Muthén & Muthén.

Ng, T. W., and Feldman, D. C. (2014). A conservation of resources perspective on career hurdles and salary attainment. *J. Vocat. Behav.* 85, 156–168. doi: 10.1016/j.jvb.2014.05.008

O'Neill, T. A., and Allen, N. A. (2012). Team meeting attitudes: conceptualization and investigation of a new construct. *Small Groups Res.* 43, 186–210. doi: 10.1177/1046496411426485

O'Neill, T. A., and Allen, N. J. (2011). Personality and the prediction of team performance. *Eur. J. Personal.* 25, 31–42. doi: 10.1002/per.769

O'Neill, T. A., and McLarnon, M. J. W. (2018). Optimizing team conflict dynamics for high performance teamwork. *Hum. Resour. Manage. Rev.* 28, 378–394. doi: 10.1016/j.hrmr.2017.06.002

O'Neill, T. A., McLarnon, M. J. W., Hoffart, G. C., Woodley, H. J., and Allen, N. J. (2018). The structure and function of team conflict state profiles. *J. Manage.* 44, 811–836. doi: 10.1177/0149206315581662

O'Neill, T. A., McLarnon, M. J. W., Xiu, L., and Law, S. J. (2016). Core self-evaluations, perceptions of group potency, and job performance: the

moderating role of individualism and collectivism cultural profiles. *J. Occup. Organ. Psychol.* 89, 447–473. doi: 10.1111/joop.12135

Pitariu, A. H., and Ployhart, R. E. (2010). Explaining change: theorizing and testing dynamic mediated longitudinal relationships. *J. Manage.* 36, 405–429. doi: 10.1177/0149206308331096

Ployhart, R. E., and Vandenberg, R. J. (2010). Longitudinal research: the theory, design, and analysis of change. *J. Manage.* 36, 94–120. doi: 10.1177/0149206309352110

Roe, R. A., Gockel, C., and Meyer, B. (2012). Time and change in teams: where we are and where we are moving. *Eur. J. Work Organ. Psychol.* 21, 629–656. doi: 10.1080/1359432x.2012.729821

Salas, E., Rico, R., and Passmore, J., (eds) (2017a). *The Wiley Blackwell Handbook of the Psychology of Team Working and Collaborative Processes*. West Sussex: John Wiley & Sons. doi: 10.1016/j.hrmr.2006.03.004

Salas, E., Vessey, W. B., and Landon, L. B. (eds) (2017b). *Team Dynamics Over Time: Research on Managing Groups and Teams*, Vol. 18. Bingley: Emerald Publishing Limited. doi: 10.1016/j.hrmr.2006.03.004

Satorra, A., and Bentler, P. M. (2001). A scaled difference chi-square test statistic for moment structure analysis. *Psychometrika* 66, 507–514. doi: 10.1007/bf02296192

Schaubroeck, J. M., Peng, A. C., and Hannah, S. T. (2016). The role of peer respect in linking abusive supervision to follower outcomes: dual moderation of group potency. *J. Appl. Psychol.* 101, 267–278. doi: 10.1037/apl0000050

Sosik, J. J., Avolio, B. J., and Kahai, S. S. (1997). Effects of leadership style and anonymity on group potency and effectiveness in a group decision support system environment. *J. Appl. Psychol.* 82, 89–103. doi: 10.1037/0021-9010.82.1.89

Stajkovic, A. D., Lee, D., and Nyberg, A. J. (2009). Collective efficacy, group potency, and group performance: meta-analyses of their relationships, and test of a mediation model. *J. Appl. Psychol.* 94, 814–828. doi: 10.1037/a0015659

Stajkovic, A. D., and Luthans, F. (1998). Self-efficacy and work-related performance: a meta-analysis. *Psychol. Bull.* 124, 240–261. doi: 10.1037/0033-2909.124.2.240

Svenson, O. (1981). Are we all less risky and more skillful than our fellow drivers? *Acta Psychol.* 47, 143–148. doi: 10.1016/0001-6918(81)90005-6

Thoms, P., Moore, K. S., and Scott, K. S. (1996). The relationship between self-efficacy for participating in self-managed work groups and the big five personality dimensions. *J. Organ. Behav.* 17, 349–362. doi: 10.1002/(SICI)1099-1379(199607)17:4<349::AID-JOB756<3.0.CO;2-3

Vantilborgh, T., Hofmans, J., and Judge, T. A. (2018). The time has come to study dynamics at work. *J. Organ. Behav.* 39, 1045–1049. doi: 10.1002/job.2327

Waller, M. J., Okhuysen, G. A., and Saghafian, M. (2016). Conceptualizing emergent states: a strategy to advance the study of group dynamics. *Acad. Manage. Ann.* 10, 561–598. doi: 10.1080/19416520.2016.1120958

Wang, M., Beal, D. J., Chan, D., Newman, D. A., Vancouver, J. B., and Vandenberg, R. J. (2016). Longitudinal research: a panel discussion on conceptual issues, research design, and statistical techniques. *Work Aging Retirement* 3, 1–24. doi: 10.1093/workar/waw033

Whitman, M. V., Halbesleben, J. R., and Holmes, O. IV (2014). Abusive supervision and feedback avoidance: the mediating role of emotional exhaustion. *J. Organ. Behav.* 35, 38–53. doi: 10.1002/job.1852

Widaman, K. F., and Thompson, J. S. (2003). On specifying the null model for incremental fit indices in structural equation modeling. *Psychol. Methods* 8, 16–37. doi: 10.1037/1082-989x.8.1.16

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Woodley, McLarnon and O'Neill. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

CONCEPTUAL ANALYSIS
published: 09 May 2019
doi: 10.3389/fpsyg.2019.01006

Teams in a New Era: Some Considerations and Implications

Lauren E. Benishek[1] and Elizabeth H. Lazzara[2]*

[1] Johns Hopkins School of Medicine, Armstrong Institute for Patient Safety and Quality, Baltimore, MD, United States, [2] Department of Human Factors and Behavioral Neurobiology, Embry–Riddle Aeronautical University, Daytona Beach, FL, United States

Teams have been a ubiquitous structure for conducting work and business for most of human history. However, today's organizations are markedly different than those of previous generations. The explosion of innovative ideas and novel technologies mandate changes in job descriptions, roles, responsibilities, and how employees interact and collaborate. These advances have heralded a new era for teams and teamwork in which previous teams research and practice may not be fully appropriate for meeting current requirements and demands. In this article, we describe how teams have been historically defined, unpacking five important characteristics of teams, including membership, interdependence, shared goals, dynamics, and an organizationally bounded context, and relating how these characteristics have been addressed in the past and how they are changing in the present. We then articulate the implications these changes have on how we study teams moving forward by offering specific research questions.

Keywords: teams and groups, teamwork, team performance, team dynamics, team membership, team interdependence, team goals, team context

OPEN ACCESS

Edited by:
Michael Rosen, Johns Hopkins Medicine, United States

Reviewed by:
Gro Ellen Mathisen, University of Stavanger, Norway
Paul B. Paulus, University of Texas at Arlington, United States

****Correspondence:***
Lauren E. Benishek
lebenishek@jhu.edu

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *30 November 2018*
Accepted: *15 April 2019*
Published: *09 May 2019*

Citation:
Benishek LE and Lazzara EH (2019) Teams in a New Era: Some Considerations and Implications. Front. Psychol. 10:1006. doi: 10.3389/fpsyg.2019.01006

INTRODUCTION

Today's organizations are markedly different than previously established. With the explosion of innovative ideas and novel technologies, organizations are redesigning the way work is accomplished (Wageman et al., 2012). This new redesign is mandating a change in job descriptions, roles, and responsibilities as well as how employees interact and perform collaborative work. According to Graesser et al. (2018), collaborative work can have potential disadvantages: ineffective communication, social loafing, diffusion of responsibility, and conflict. When harnessed correctly, though, collaborative work can entail division of labor, multiple perspectives, emergent ideas, and multi-source evaluation which enhances quality (Graesser et al., 2018). Collaborative work, as the name would suggest, involves collaborations. Collaborations manifest differently with the rise of geographic dispersion, working remotely, and collaborative technologies. Essentially, collaborations entail teams and teamwork that have evolved and resemble a new era.

The original conceptualization of teams considered them to be intact, tightly bounded, and coupled with members from a single organization who are co-located, interacting face-to-face to generate an identifiable product, service, or solution (Hackman, 2012; Tannenbaum et al., 2012; Wageman et al., 2012). Conversely, teams today consist of members from multiple organizations shifting in and out of the team while relying heavily on technology to complete a variety of tasks (Hackman, 2012; Tannenbaum et al., 2012). To illustrate, previous research has found that up to 84% of teams experience change (Espinosa et al., 2012), and another study found that the number of members from different countries was the same compared to the number of members located in

the same room (Cummings and Haas, 2012). These studies simply illustrate that the archetype of teams is changing, and fluidity is increasingly prevalent.

Organizations are relying on fluid teams for several reasons. One, organizations must remain agile, responding quickly to opportunities and market changes, and strive for strategic and operational innovation (Tannenbaum et al., 2012; Chiu et al., 2017). Two, organizations are often using independent contractors to execute work, which traditionally entails a finite duration and potentially limited involvement (Chiu et al., 2017). Three, organizations rely on such teams to stimulate and energize members (Mortensen and Haas, 2016). Fourth, organizations are designing teams according to the specific skills and expertise needed to execute particular tasks, and the requisite knowledge and skills may vary as the tasks fluctuate (Tannenbaum et al., 2012).

Because organizations have new demands that leverage fluid teams, the implicit assumptions surrounding teams are not necessarily applicable. Previously, the well-established definitions assumed that the long-standing characteristics of teams (i.e., multiple members interacting dynamically and interdependently working in a bounded context toward a shared goal; Hackman, 1987; Salas et al., 1992; Cohen and Bailey, 1997; Kozlowski et al., 1999) remain stable and consistent throughout the team's life span (Tannenbaum et al., 2012). See **Table 1** for a list team characteristics highlighted in various definitions of teamwork. These characteristics, though, as originally conceptualized may not be accurate as the landscape of organizations, work, and teams has evolved considerably to be much more diverse and heterogeneous (Harrison and Humphrey, 2010; Mathieu et al., 2017).

Understanding there is a need to discern teams differently, researchers have argued that there is a notable distinction with teams either being "real" or "pseudo" (Hackman, 2002; Wageman et al., 2005; Richardson, 2010; West and Lyubovnikova, 2012). Hackman (2002) suggested that real teams consist of four primary elements: clear boundaries, established interdependence, moderately stable members, and authority. Wageman et al. (2005) contended that real teams are comprised of three features: clear boundaries, collective responsibility for shared goals, and moderate membership stability. A more recent update posited that real teams are hallmarked by six dimensions: tightly coupled interdependence, agreed upon objectives, systematic reflex or review of performance, clear boundaries, high autonomy, and specified roles (Richardson, 2010; West and Lyubovnikova, 2012). Pseudo teams, on the other hand, are defined as a group of people who call themselves a team and work independently or interdependently toward a potentially different perception of their goal while having permeable boundaries (Richardson, 2010; West and Lyubovnikova, 2012). While we understand the desire for a distinction and applaud those trying to more aptly apprehend and examine teams, we contend that this division may not be totally suitable. The idealized conceptualization of teams is a rare reality; rather, most teams are messy. That is, most teams in today's climate are emergent social systems that are fluid in various aspects (Chiu et al., 2017). With this fluidity in mind, it begs the question – how much variation and fluctuation in a team's core characteristics is permissible? And, what are the implications of these characteristics with regard to team composition, process, and performance?

Recognizing the reality of teams, researchers are beginning to advocate for more novel yet realistic approaches to theorizing and investigating teams (Harrison and Humphrey, 2010; Hackman, 2012; Tannenbaum et al., 2012). Some have proposed that the concept of teams should be modified to reflect "teaming" – a continual process where teams are constituted and reconstituted (Edmondson, 2012). Others have suggested the idea of team fluidity to address this evolution of teams. However, many define team fluidity as simply changes in team membership (e.g., Dineen and Noe, 2003; Bushe and Chu, 2011). More recently, though, researchers contend that team fluidity is more than membership change because that does not accurately depict today's teams and experiences (Chiu et al., 2017). Understanding that teams are in a new era, the purpose of this paper is to dissect each of the fundamental components of teams – membership, dynamics, interdependence, goals, and boundaries, – delineate the implications of how these components are conceptualized, and recommend avenues for future research that will better capture the current nature of team membership, contexts, and dynamics.

CONSIDERATIONS REGARDING THE CORE CHARACTERISTICS OF TEAMS

The fluidity and versatility of how actual teams operate in real-world settings present serious challenges for those scientists and practitioners attempting to understand teams. We suggest that placing careful limits and boundaries on how we qualify 'real' teams is not the path forward if we are to provide research insights applicable to these real-world teams. Instead, we suggest we may find more practical direction in a comprehensive/integrated deconstruction of the defining features of teams that seriously considers how fluctuations within each feature practically affect our approach to studying and improving teams.

Membership

Perhaps the most defining characteristic of teams is membership. After all, what makes a team recognizable as a specific team is its members. Extending even further, team composition, team size, and team tenure have team membership as the foundation. According to many definitions, teams must be comprised of two or more members (Kozlowski et al., 1999; Salas et al., 2005; Kozlowski and Ilgen, 2006; Rousseau et al., 2006; Salas et al., 2007). Although these definitions do not imply that the members have to remain the same, it is often assumed that they are consistent (Wageman et al., 2012), and research has traditionally treated teams as stable entities (Hirst, 2009).

Teams that have stable membership are considered to be intact or closed (Ziller, 1965); meanwhile, teams that have fluctuating membership are thought to be open (Ziller, 1965) or fluid (Bushe and Chu, 2011), and membership changes with regards to addition, subtraction, or substitution.

TABLE 1 | Team characteristics.

Source	Two or more members	Inter-dependent	Shared goal	Social interactions	Distinct roles	Embedded in larger entity
Alderfer, 1977	x	x			x	
Anderson and West, 1998				x		
Cannon-Bowers and Bowers, 2011		x	x		x	x
Cohen and Bailey, 1997	x	x	x		x	x
Devine et al., 1999	x		x	x		
Francis and Young, 1970	x		x			
Gladstein, 1984	x	x	x			
Guzzo and Dickson, 1996	x	x		x		x
Hackman, 1990		x			x	
Hollenbeck et al., 1995		x	x			
Katzenbach and Smith, 1998				x		x
Kazemak and Albert, 1988		x	x			
Kozlowski et al., 1999	x	x	x			x
Kozlowski and Ilgen, 2006	x	x	x	x	x	x
Kozlowski and Bell, 2003		x	x	x		x
Lanza, 1985		x	x			
McGrath et al., 2000			x			
Rasmussen and Jeppesen, 2006	x	x				
Richardson, 2010	x	x	x	x	x	x
Rousseau et al., 2006	x	x	x			
Salas et al., 1992	x	x	x			
Salas et al., 2007	x	x	x	x		
Salas et al., 2005	x	x	x			
Schippers et al., 2007		x		x		x
Shea and Guzzo, 1987	x					x
Sundstrom et al., 1990		x	x		x	x
Wageman et al., 2005		x	x			
West, 2004		x	x		x	x
West et al., 1998			x		x	x
Zander, 1977	x	x				

Bedwell et al. (2012) ascribes this fluidity to three scenarios: (1) integrating a new member to an existing team, (2) losing a member of an existing team without replacing the lost member, or (3) losing a member and integrating a new member to an existing team. Such changes can occur at the simple level of a single member to the complex level of an entire cohort (Mathieu et al., 2014). Consequently, team membership can range from "frozen rigidity" to "radical discontinuity" (Arrow and McGrath, 1995) with changes in frequency (i.e., turnover) and duration (i.e., tenure) serving as two major indices (Chiu et al., 2017). Within an organization, such membership change occurs for seven reasons: (1) desire to have different skills through various stages of work, (2) need for flexible allocation of personnel, (3) drive to provide developmental career opportunities, (4) response to high turnover, (5) need for organizational upsizing or downsizing, (6) desire to promote effective communication, and (7) motive to avoid collusive behaviors among employees (Bushe and Chu, 2011). In addition to within organization, membership change occurs across organizations. The philosophy of maintaining the same employment and retiring from the same organization is becoming an old adage (Landrum, 2017), and recent evidence suggests that 'job hopping' is on the rise (Robert Half, 2018).

Adding another layer of complexity to membership change is the consideration of 'multi-team' or multiple team membership (MTM), which refers to members serving on multiple teams simultaneously (van de Brake et al., 2018). MTM adds complexity in that there are two relevant considerations: context switching and temporal misalignment (O'Leary et al., 2011). Context switching occurs when members shift their focus from one team context to another, and temporal misalignment occurs when there is a gap in time from focusing on tasks. Understanding these considerations is important since some estimates indicate 81% of individuals have MTM (O'Leary et al., 2011), and others suggest 94.9% of members serving on multiple teams (Martin and Bal, 2006). The pervasiveness of MTMs is due to particularly skilled individuals being a desired commodity, teams being project-centered that necessitate individuals with specialized expertise, and work that has shifted toward being flat and dispersed (O'Leary et al., 2011).

Recognizing the prevalence of MTM or even membership change within a single team, researchers have begun to

investigate the potential implications for taskwork, teamwork, and team performance. Two opposing views regarding the role of membership change have emerged. One school of thought frames such changes as being disadvantageous. Membership change results in a loss in individual knowledge and shared knowledge, a diverted focus away from the task, lowered member commitment, and lack of cohesion (Bushe and Chu, 2011; Bedwell et al., 2012) as well as diminished coordination (Summers et al., 2012) and reduced cooperation (Arrow and Crosson, 2003). Additionally, such teams have poorly developed shared mental models and transactive memory systems making them unable to orient quickly to new tasks and transitions (Bush et al., 2018). Finally, there is evidence that demonstrates member instability detrimentally impacts performance (Argote et al., 1995; Lewis et al., 2007); while, team familiarity strengthens team processes and states (Mathieu et al., 2014). The other school of thought frames membership change as beneficial, citing as evidence an increase in breadth of knowledge (Bedwell et al., 2012), transfer of knowledge and resources (Tannenbaum et al., 2012), and the number and diversity of ideas generated (Choi and Thompson, 2005) as well as increased productivity (Choi and Thompson, 2005) and heightened team learning (Savelsbergh et al., 2015). Moreover, such fluidity may help maintain a team's flexibility, which is particularly beneficial in emergent situations and circumstances (Tannenbaum et al., 2012). To illustrate, teams that are more fluid may be equipped to address task conflict, which can be a beneficial catalyst for communication as well as a tool for mitigating groupthink (Bush et al., 2018). Therefore, the objective of team membership decisions should be to strategically support the organizational mission and promote organizational flexibility in competitive environments (Bell et al., 2018b). Regardless of the school of thought, membership change undoubtedly has an impact on processes, states, and outcomes.

Given that research has repeatedly indicated that a team's members substantially influence teamwork (Mathieu et al., 2017; Bell et al., 2018a) and performance (Bell, 2007) and the ever-changing nature of membership, new questions start to surface. If membership is so fluid, how should measurement be implemented to accurately reflect the state of the team as well as the dynamism of the team? Is resorting to traditional cross section or correlational designs still appropriate? Can we make fair comparisons longitudinally if the composition of the team is different? These questions simply scratch the surface as the dynamism of membership does not only affect the team dynamics, but it also influences the team's interdependence, goals, and boundaries. Additionally, such fluid membership also raises questions about selection, interventions, and work design that merit investigation.

Interdependence

Interdependence refers to the level or sequencing of interaction required of team members in order to complete a given task or achieve a particular goal or outcome and is often the reason why teams are formed in the first place (Campion et al., 1993). The nature of what a team is trying to accomplish can be characterized by a two-dimensional framework – scope and complexity (Mathieu et al., 2017). A team's objectives work symbiotically with interdependence. Interdependence moderates the relationship between team processes (i.e., cognitions and behaviors) and team performance (Gully et al., 1995, 2002; Beal et al., 2003). As such, it is a critical team feature that is almost ubiquitously included in every team definition. The underlying tenet of interdependence is that the more interdependent team members are with one another, the closer they approach "real" team status while lower interdependence is more indicative of a "working group" as opposed to a "real" team (Katzenbach and Smith, 1993, 1998; Wageman et al., 2005).

The source of interdependence can be multifaceted. It may be determined by the nature of the task, the manner in which goals are defined, the process through which those goals are achieved, and the method for assessing team performance (Wageman, 1995; Campion et al., 1996; Van der vegt et al., 2001). *Task interdependence* refers to the degree of task-driven interaction among team members (Shea and Guzzo, 1987). Stated differently, task interdependence is the level to which colleagues must rely on one another in order to effectively perform their individual roles and job responsibilities (Saavedra et al., 1993). As task interdependence increases, demands for coordination, communication, and cooperation also tend to increase. Consistent with the idea that interdependence exists in degrees, task interdependence has been conceptualized as existing in different forms that range from a lower degree of integration to a much higher and more complex degree.

Pooled interdependence can be summarized as a performance-sum relationship where each member contributes to the group without needing to directly interact with other group members. Naturally, this is the lowest level of interdependence because it simply means that team performance is the simple sum of each individual's performance. When task interdependence is pooled each team member contributes his/her own work to the final product without being reliant on any other member. A loose example of pooled interdependence might be an edited textbook wherein each chapter an author contributes content based on his or her own expertise without needing to consult the authors of other chapters. The final publication is the result of multiple authors' contributions and would not have been possible without each, but the chapters within are individual products. *Sequential* task interdependence occurs when one group member must complete his task before another member is able to complete hers and different parts of the task must be completed in a prescribed order. The classic example is of a car assembly line where each employee performs a specific action that contributes to the final product. In this example, interdependence is a bit stronger than in the pooled example because members are dependent on others to complete their work. *Reciprocal* interdependence is the next conceptualization and occurs when team performance requires individuals to hand tasks back-and-forth between one another. These "temporally lagged, two-way interactions" (Saavedra et al., 1993, p. 63) generally exist when team members have different specialty roles that can be completed in a flexible order. For instance, two colleagues co-authoring a paper may write different sections and then go back and edit one another's work until the manuscript is ready for review. Finally, *team* interdependence exists when members jointly diagnose, problem solve, and

collaborate to complete a task. There is considerable freedom within this level of interdependence to design your own job responsibilities, but the final product requires mutual interaction. An example may be a design team working together to co-create a redesign of a gaming platform.

The problem with conceptualizing interdependence in this way is that it is probably more complex in reality than how it is presently conceived. In fact, many modern teams are involved with multiple tasks simultaneously, and each of these tasks might be associated with different levels of collaboration (Bell et al., 2018a). Similarly, the longer the lifespan of the team, the more likely it is that a work group moves between different levels of interdependence. A development team, for example, may demonstrate high-levels of interdependence when they are steeped in the divergent and convergent thinking stages of development, but as they navigate other stages of creation, they may find that their interdependencies become less complex. Furthermore, this team may find that they regularly shift between interdependencies as they come together for intense brainstorming and co-creation then somewhat disband to work on individual tasks then come together again to assemble and test their prototype.

The questions we as researchers must ask is, if interdependence is an organic moving target, how does that affect our definition and conceptualization around 'team'? Can 'real' teams be considered teams if the level of their interdependencies changes over their life span? Does the shift in interdependency within a working group affect the 'teamness' of that group? Can a single team be more or less of a team throughout its lifespan as its interdependent nature fluctuates? Importantly, what does that mean for teams operating in the real world?

If we conclude that teams can and do in fact fluctuate with regards to interdependencies and this affects their 'team status,' there are clear implications for research. Measurement becomes more challenging because we will need to consider what level or even combination of interdependence teams are experiencing at the time of measurement, and if their interdependence profile is different across measurement timepoints, we may need determine whether fair comparisons can be drawn or whether we need to develop more sophisticated methods to understand the impact on their performance. We must also consider more practical concerns such as how do we make sure that team members are selected and/or trained to be able to navigate these fluctuations. It is quite possible that the team member who operates best when interdependence more closely reflects pooled or sequential process will find periods of more intense interdependence difficult to maneuver and vice versa. Thus, we will need to find better ways to support employees as they engage in various forms of collaboration.

Goals/Shared Responsibility for Outcomes

Another defining feature of teams is the existence of at least one shared goal. This feature is central because without a shared objective, there would be no reason for multiple individuals to collaborate. They would instead be engaged in separate pursuits. However, once two or more individuals are united in the attainment of the *same* objective, they become interconnected. While the pathway to goal attainment can vary (see task interdependence), the unity between them manifests as goal interdependence and guides their performance (Saavedra et al., 1993). Thus, goals direct the attention, effort, and persistence of group members (LePine, 2005) while also influencing interactions within teams (Hu and Liden, 2011). Specifically, goals direct teams on how to define individual responsibilities, coordinate actions, and develop efficient work procedures (Klein and Mulvey, 1995). This influence manifests through planning, cooperation, mutual support, and member interactions (Mitchell and Silver, 1990; Weingart, 1992; Weldon and Weingart, 1993; Crown and Rosse, 1995).

The effort extended by group members in the pursuit of shared goals creates variance in the rewards, punishments, and feedback teams receive. Competitive and individual distribution of outcomes can inhibit team effectiveness through blocking, undermining, and hindering behaviors (Miller and Hamblin, 1963). Alternatively, shared goals can create shared responsibility for outcomes among team members (Shea and Guzzo, 1987) which are likely to enhance effectiveness by motivating members to cooperate and assist in the performance of other members (Gully et al., 2002).

The interplay of shared goals and responsibilities of outcomes clearly has implications for how teams perform. They affect team motivations, work distribution, and team member interactions because they set the direction in which the team is moving and serve as glue cementing the team together. Thus, teams are partially defined by the goal(s) they are harmonized in striving toward. The implication is that if team goals change, then the team may also be qualitatively different. Work may need to be restructured. Team members may need to be subtracted or added. The dynamics of work and team member interactions may be substantively different. In sum, the morphing of team goals and responsibilities for outcomes should be considered as a parameter for determining whether a work unit can be meaningfully compared over time or across performance contexts. Changes in team processes and emergent states may not be the result of team learning, for example, so much as they may be natural reactions to changes in goals. From a practical standpoint, the implications may be that lessons team members learned by working with one another toward different objectives may not entirely translate into the current project. Teams may discover growing pains resulting from goal shifts. It may require additional work for teams to readjust to changing demands and goals, so special efforts may be necessary as a team strives toward a new goal, even when there is a history of collaboration among its members.

Of course, from a theoretical and research perspective it means that we may have to be cautious about how we define and measure teams. If goals are substantially changing and work flows are also changing as a result, it may no longer be appropriate to consider a specific collection of individuals to be the same team. In that instance, we have to be careful about the inferences

we are drawing from assessment of these groups over time or across circumstances.

Team Dynamics

Clearly, team members must interact with one another in order to pursue shared goals and manage task interdependencies. However, team dynamics and interactions vary greatly and are moderated by a number of attitudes and behaviors. The leading taxonomy for characterizing team interactions and dynamics comes from Marks et al. (2001, p. 357) who describe processes and emergent states. *Processes* are "members' interdependent acts that convert inputs to outcomes through cognitive, verbal, and behavioral activities directed toward organizing taskwork to achieve collective goals." More simply, team process is the interaction of members with each other and their task environment. Processes are the means through which team members use essential and varied resources such as experience, expertise, equipment, and financial support to garner team outcomes. Thus, it is team process (i.e., action and interaction) that drives accomplishment of team goals (LePine et al., 2008).

Of course, teamwork involves more than simple behaviorally based action. Teamwork also consists of attitudes, values, cognitions, and motivations (Morgan et al., 1993; Salas et al., 2011). Marks et al. (2001, p. 357) call these affective and cognitively oriented qualities of teamwork emergent states. *Emergent states* are "constructs that characterize properties of the team that are typically dynamic in nature and vary as a function of team context, inputs, processes, and outcomes." These team properties are states in that their quality is not guaranteed to be stable. As such, emergent states can influence how team process unfolds while themselves changing in response to team member interactions. For example, teams low in psychological safety (an emergent state) may struggle to ask each other for task assistance (a process), which might result in performance delays or errors, which could stir conflict or discord (another emergent state) within the team where none previously existed. In other words, emergent states are products of the team experience that also can impact the way in which team members interact, be it positive or negatively.

Certain competencies are needed to manage these evolving processes and dynamic emergent states. According to Cannon-Bowers et al. (1995), teamwork-related competencies vary on two domains – task and team – that span a continuum of specificity that ranges from specific to general. Task specific competencies are those that are applicable only in a specific task or type of task. For example, aviation skills are highly task-specific. Task generic competencies are those that are applicable across a variety of task settings. For instance, project management skills are applicable across a variety of projects and contexts. Correspondingly, team competencies can also be categorized as specific or general. Team specific competencies require the team members to know one another well and have experience working together whereas team generic competencies are applicable across different teams with different team members.

When considered on a matrix (see **Table 2**) these domains combine into four distinct types of competencies: Context-driven, task-contingent, team-contingent, and transportable.

TABLE 2 | Matrix of teamwork competencies.

		Team	
		Specific	**Generic**
Task	**Specific**	Context-driven	Task-contingent
	Generic	Team-contingent	Transportable

Context-driven competencies are specific to both the task and the team, making them highly specialized. As such, these competencies are generally best developed within in-tact teams trained or practiced in realistic settings. They are not especially good candidates for selection since it is difficult to understand in advance how a team member may integrate his or her KSAs into an existing team. *Task-contingent* competencies are specific to the task but not to the team. These are best trained in a realistic task environment and may be useful for selecting new team members. Team-contingent competencies are specific to the team but not to the task. It is generally unhelpful to select team members based on these competencies and instead they are better developed with intact teams across a variety of tasks. Finally, transportable skills are the most flexible. They are applicable to all teams across all tasks.

Irrespective of the specifics of the task or team, all teams experience transitions as they evolve from one task to the next. Marks et al. (2001) clearly outlined the relevant processes for transition periods (i.e., mission analysis, goal specification, and strategy formulation) as well as the processes for action periods (i.e., monitoring goal progress, systems monitoring, team monitoring, and coordination); however, modern teams likely do not experience these clear delineations as postulated by Marks et al. (2001). In other words, modern teams experience transitions along a continuum of length and punctuated between tasks that range on a continuum from similar to dissimilar (Bush et al., 2018). Consequently, the requisite processes may differ given the temporality of the transition periods and the similarity (or dissimilarity) of the tasks surrounding those transition periods.

As teams maneuver these phases, they must make decisions in an evolving world, requiring them to be flexible in the presence of change. Team adaptation is the process through which teams respond cognitively, affectively, and behaviorally to change (Baard et al., 2014), which can stem from internal (e.g., membership turnover) or external (resource availability) sources (Frick et al., 2018). Successful adaptation has beneficial outcomes for teams; however, it may also manifest maladaptively for numerous reasons (Frick et al., 2018). Frick et al. (2018) describe the Four Rs heuristic to explain how team adaptation occurs and explain the points of failure in this process that could result in maladaptation. The stages include recognize (i.e., noticing and acknowledging a change), reframe (i.e., shifting cognitions about the situation as a result of the change), respond (modifying behavior), and reflect (i.e., contemplating the change and the team's subsequent response).

Affecting these tasks and transitions while constraining and influencing team dynamics is team structure. Team structure encompasses the team relationships that drive the assignment

of tasks, roles and responsibilities, and leadership (Bresman and Zellmer-Bruhn, 2013; Chiu et al., 2017). Like many other defining elements of teams, structure has historically been assumed to be somewhat stable in nature. That is, task assignments are pre-defined, roles and responsibilities are clear and consistent over time, and leadership manifests as command and control (Chiu et al., 2017). However, in modern teams these traits are also increasingly fluid. Task assignments occur on an as-needed basis and are given to team members with the ability and bandwidth to perform them. Roles and responsibilities, therefore, become more blurred (Dube, 2014) as team members coordinate to move with greater adaptability and agility. Leadership is increasingly self-directed (Aime et al., 2014) and shared across team members (Carson et al., 2007). Team member status emerges quickly based on observable characteristics and expected performance but is subject to change if those in positions of authority fail to perform adequately (Driskell T. et al., 2018). The result is that modern teams rely less on stringent pre-defined plans, rules, procedures, and communication norms (Malone and Crowston, 1994) and more on informal and emergent coordination (Okhuysen and Bechky, 2009).

While these frameworks help us to organize the way we approach, think about, and manage team dynamics, they somewhat fail to account for the complexity that are real world teams. For example, it is likely that many teams require some combination of specific, general, team, and task competencies to support team emergent states and processes. These competencies are further influenced by the transitions teams experience between tasks. In fact, even the dynamics themselves as well as the transitions may be contingent upon the tasks.

Team Boundaries

The final defining characteristic of a team is the idea that a team does not exist in a vacuum but rather is influenced by context. According to Bell et al. (2018a), context shapes the team in three ways. One, the context influences the salience of a particular attribute. Two, the context can alter the relevance and importance of an attribute. Three, the context ignites which attributes are of value. Some conceptualize context broadly by making a distinction between external, influences mostly outside of the control of the team, and internal, influences within the team (Bell et al., 2018a). Meanwhile, others conceptualize context more granularly by referring to context as the characteristics of the task, the timeframe of the performance episode(s), the governance structure over the team, and a team being embedded within a larger entity or context (Edmonson and Harvey, 2018). In essence, the context functions by providing boundaries.

Boundaries in a general sense facilitate togetherness and serve as a distinction between what something is versus what it is not (Alderfer, 1976). Within the team context, a team has boundedness with boundedness being a delineation between members and non-members, and individuals use three criteria to identify boundedness (Mortensen and Haas, 2016). One, members rely on an official team roster (formal criterion). Two, individuals receive the label of team member by themselves or someone else (identity-based criterion). Three, members are identified through a pattern of interactions (interaction-based criterion). Although these criteria may provide clarity for how boundedness is determined, and literature often assumes clear team boundaries are the norm, the actual boundaries in real-world teams are often less clear (Tannenbaum et al., 2012). Some have long proposed that boundedness may be actually be a spectrum with highly permeable boundaries (i.e., underbounded) to highly impermeable boundaries (i.e., overbounded; Alderfer, 1980); meanwhile, others have posited that boundaries are more dynamic and fluid and are constituted and reconstituted (Edmondson, 2012). In fact, there is so much fluctuation that it is often difficult to determine who comprises the team (Hackman, 2012).

Such ambiguous boundaries are a result of team fluidity, overlap, and dispersion (Mortensen and Haas, 2016). Fluidity entails members who are dynamically moving in and out of the team. Overlap involves members who work on multiple teams simultaneously, and dispersion refers to members working from different organizations or geographic regions. Such fluctuations in team membership are often arranged and coordinated rather than being chaotic and impromptu (Tannenbaum et al., 2012). Because the boundary is being reshaped with such fluctuations, it impacts shared identity and shared understanding. With every fluctuation, the team must rebuild its identity and must update the shared understanding based upon the member's mental models of the team, task, and context.

Fluidity, overlap, and dispersion affects boundedness between the team and the outside context, but it also affects boundaries *within* the team and the tasks. Team members create boundaries within the team based upon the extent that they perceive themselves to be similar to one another. That is, team members rely upon surface-level cues (i.e., attributes that are easily accessible and detectable) and deep-level cues (i.e., psychological characteristics) to inform categorization. Categorization enables team members to rely upon heuristics which can serve as an impetus for subsequent attitudes and behaviors (Feitosa et al., 2018). Consequently, such categorization and perceptions influence the roles, interactions, and structures (Bell et al., 2018a; Feitosa et al., 2018; Graesser et al., 2018). To elaborate, teams often develop a core and a periphery structure (Tannenbaum et al., 2012; Mortensen and Haas, 2016). Albeit colloquially, the concept of a core and a periphery is analogous to an inner and outer circle. The core structure is comprised of members who perform a "major" role; whereas, the periphery structure includes members who perform a more "minor" role. Similarly, tasks can also manifest as a central working sphere and a peripheral working sphere (Gonzalez and Mark, 2004). A central working sphere is considered important and urgent; whereas, a peripheral working sphere is deemed to be less important and critical. Additionally, members dedicate more time on central working spheres yet allocate minimal time toward peripheral working spheres.

Given the dynamism of boundedness between entities, within teams, and tasks, it is evident that boundary clarity is integral. When teams experience boundary clarity, members experience individual certainty, and the team experiences a collective agreement (Mortensen and Haas, 2016). Conversely, teams that have poor boundary clarity are comprised of members

with individual uncertainty and an overall sense of collective disagreement. Members are unsure of who is considered a member of the team, and members have opposing views on who is an actual member of the team.

Regardless of the clarity or ambiguity, the boundedness of a team has implications for researchers and practitioners (Mortensen and Haas, 2016). That is, researchers may need to alter their theorizing and measuring depending upon the stability and clarity of the boundedness. For example, many team processes or states are grounded in the idea that teams are tightly coupled and bounded (e.g., transactive memory systems), but how do these manifest if teams have loose and permeable boundaries? Similarly, roles and responsibilities are often theorized based on the assumption that they remain consistent, but if a team's boundaries are fuzzy, the idea of a boundary spanner needs revisiting (Mortensen and Haas, 2016). Practitioners, similarly, may need to select, design, and support teams differently depending upon the consistency and certainty of the boundedness.

IMPLICATIONS

For decades, the needs and experiences that teams faced in the real-world as well as the policies and procedures that practitioners used to manage teams corresponded to the studies that researchers were conducting (Tannenbaum et al., 2012; Wageman et al., 2012). However, the organizational landscape that has manifested is not always aligning with prevailing research; therefore, research and even practice needs to evolve according to current needs to advance team effectiveness. Although "old questions" become relevant again when the very nature of teams has changed (Wageman et al., 2012), others argue that the questions should actually shift given the gravity of changes (Mathieu et al., 2017). Below we discuss implications of the evolution of teams in the modern era for research.

Team Types

When attempting to understand what constitutes a team, many have theorized about team types. For example, Sundstrom et al. (1990) postulated that there are four main team types: advice/involvement, production/service, action/negotiation, and project/developmental teams. Cohen and Bailey (1997) followed suit by suggesting there are project teams, traditional work teams, parallel teams, and management teams. Devine et al. (1999) created another taxonomy to include four team types: ad hoc project teams, ongoing project, ad hoc production, and ongoing production and actually modified the taxonomy to include 14 different team types (Devine, 2002). Even still, De Dreu and Weingart (2003) created their own team type taxonomy, which included project teams, production teams, decision making teams, and mixed teams. Finally, Wildman et al. (2011) presented a team type taxonomy based upon tasks: managing others, advising others, human service, negotiation, psychomotor action, defined problem solving, and ill-defined problem solving. Although these are simply several examples demonstrating various interpretations and suggestions for team type taxonomies, it does portray that there is no consensus regarding how teams should be classified and that many taxonomies approach classification based primarily on task type. Teams have greater distinctions beyond task type, so such categorization actually limits our apprehension of team effectiveness (Tannenbaum et al., 2012). Recognizing the limitations of instituting a categorical classification system for team types, Hollenbeck et al. (2012) created a dimensional scaling framework to describe teams positing that teams varied on authority differentiation, skill differentiation, and temporal stability. The dimensional scaling approach is closer to potentially representing teams; however, the theory might need to be altered further to account for the dynamism of all facets of modern teams. For example, because boundaries can be ambiguous and membership can be fluid, the team type may also change with time and as the team progresses and transitions between tasks. If the team type does in fact change and is in fact dynamic, what are the implications for teamwork and taskwork as well as team and task performance? Do variations on teams (e.g., virtual teams; Gilson et al., 2015 and multi-team systems; Shuffler and Carter, 2018) impact teamwork, taskwork, and outcomes? Essentially, what constitutes different teams may need to be updated with the changes to reflect contemporary work and organizations. Understanding what constitutes such teams as well as what conditions are most important helps lead to greater insights regarding team effectiveness (Hackman, 2012). Questions for future research include:

- What features beyond the task constitute team types? How does the evolution of these features impact the team type?
- What approaches are most suitable for characterizing teams (e.g., categorical or dimensional scaling)?
- What other categorizations or dimensional scaling factors need to be considered and included?
- How do variants on traditional team types impact teamwork?

Models and Frameworks

Perhaps the foundation of most team theorists is the depiction of team effectiveness models. Many team models are rooted in the input–process–output (IPO) foundation put forth by McGrath (1964). Inputs are the antecedents that influence the dynamics of team members. The processes are the interactions that team members undertake to achieve the desired goal, and the outputs are the outcomes or results accomplished by the team. As Hackman (2012, p. 431) says, "the core idea of the model is that input states affect group outcomes via the interaction that takes place among members."

Despite being a valuable infrastructure, the IPO framework has several limitations leading others to modify the original conceptualization. Many adaptations have included an environmental or contextual component since teams do not operate in a vacuum and are certainly influenced by contextual factors (e.g., Cohen and Bailey, 1997). Introducing a contextual component lead to the realization of the multilevel nature of teams – individuals are nested within teams, and teams are nested within organizations which exist within even

broader environments (Klein and Kozlowski, 2000). A second limitation of the IPO approach is the narrow focus on process. Processes are interdependent cognitive, verbal, and behavioral activities that convert inputs to outputs (Marks et al., 2001), but not all teamwork components are simply processes. Teamwork is also comprised of emergent states, which are properties that represent the attitudinal and cognitive properties of the team (Marks et al., 2001). Further, not all "processes" are mediators as originally depicted in the IPO organization; unpacking teamwork entails that some processes and emergent states can be moderators as well as mediators. Understanding these conceptual limitations, Ilgen et al. (2005) delineated "process" by presenting the input–mediator/moderator–output–input (IMOI) framework. A third limitation in the IPO approach is the lack of temporality, noting the limitations of suggesting that teams operate linearly and not episodically (Marks et al., 2001). To address the temporality of teams, there are two prominent approaches: developmental and episodic (Mathieu et al., 2008). The developmental approach suggests that teams have differential influences and qualitatively change over time. The episodic approach posits that teams exhibit different processes and states at different times. See Mathieu et al. (2008) for a review of team effectiveness.

All of the models that attempt to address previous limitations certainly advance our understanding of the complex phenomena of team effectiveness; however, we argue that more work regarding the theoretical nature of teams is still needed. The influences and the underpinnings of teams do not reside in clear and distinct packages, but rather the effectiveness of teams lies in the complex web inherent within teams and teamwork (Hackman, 2012). Modern teams are likely not well-represented within simple cause-effect models because what ensues as teams strive to accomplish their goal(s) is not a linear progression; instead, a complex combination of factors varying differentially is a more accurate representation. Modern teams are likely to juggle tasks over time, experience membership churn, coordinate with other teams, and reconfigure throughout its lifecycle (Driskell J.E. et al., 2018). Future approaches should consider more sophisticated frameworks that move beyond causal models and involve an analysis of all factors and conditions (Hackman, 2012). Additionally, other processes, such as team creativity and innovation, and emergent states, such as team well-being, may become more central drivers of modern team effectiveness and should situate more prominently in team performance frameworks and research (Driskell J.E. et al., 2018). With these considerations, we put forth the following research questions:

- What approach(es) are more suitable if the input-process-state-output structure is outdated and not applicable?
- How should modern team effectiveness models and frameworks be represented to accurately depict contemporary teams?
- How can team models and frameworks correctly depict the fluidity of all of the characteristics of modern teams?
- What team attitudes, behaviors, and cognitions should be considered when creating team effectiveness frameworks?
- What are the relationships between all of the contextual factors as well as the team processes, states, and outcomes if they are not linear?
- What are the unique contributions of team attitudes, behaviors, and cognitions, and how do these vary over time?
- How can temporal components be best incorporated and depicted?

Measurement

As we have indicated, previous thinking depicted teams with relatively stable factors (e.g., goals and roles). Because team factors were primarily theorized as being stable, they are often only measured once or used as correlates (Tannenbaum et al., 2012). Such data is often collected at the individual level, but because it is evident that individuals are nested within teams, individual data is often aggregated to the team level. Some argue, though, that simple linear aggregations are not appropriate since the inputs, processes, and states are not perceived similarly across members and are not interchangeable (Murase et al., 2012). Aggregates represent compositional characteristics, and compositional thinking assumes the content and structure are created linearly and represented similarly (Bell, 2012). The characteristics of today's teams are much more fluid and dynamic. Therefore, teams and the factors that comprise teams need to be studied and measured with regards to patterns over time (Bell, 2012; Mortensen and Haas, 2016). More specifically, measures of patterns could include: density, reciprocity, transitivity, and centrality. Studying networks and patterns is more representative since extensive fluidity raises the question of whether the relevant team members are being measured across time and whether the multilevel nature of teams is being captured. Simply stated, researchers are at risk of comparing different sets of team factors (e.g., membership) when only using cross sectional measurement (Murase et al., 2012). A network approach acquires information about individuals and their attributes as well as the team-level properties, and it captures the nature of the interactions. This approach is useful for understanding where an individual is embedded within a larger team or multiteam system (Bell et al., 2018b), helping to identify essential players and create a more comprehensive understanding of teamwork through a relational lens. Ultimately, theorizing and researching current teams requires a shift from the old fashioned to a more modernized approach. Mathieu et al. (2017) posit that a more modernized approach likely means that there is no standard set of measures for team research. The specifics that influence or are inherent within each team vary too greatly between and across teams making them markedly different and necessitating more nuanced metrics. Consequently, we propose the following questions:

- What research designs should be leveraged to most appropriately generalize from lab settings and study teams in applied settings?
- What statistical techniques should be employed to correctly represent the complex web of teamwork and team performance?

- What approaches are more suitable if central tendencies no longer provide a clear picture and understanding?
- What tools and metrics are most suitable to best understand and unpack the simultaneous and interrelated nature of teamwork? What tools and metrics are appropriate for time-dependent constructs?
- How can illustrative case studies be leveraged to highlight novel constructs and relationships?
- What continual streaming metrics (e.g., wearable sensors) can be utilized to address longitudinal issues?

Staffing Teams

The dynamism and fluidity of today's teams present special challenges for staffing teams. In some cases, such as in surgical units, teams may come together for fairly brief periods of time, even just a few hours to complete a single surgery. These teams might complete multiple projects or cases in rapid succession, or they may disband after just one project together. It is possible for these short-duration teams to reconfigure, sometimes with a majority subset of the original team and other times with a composition of team members that barely resembles the original team. This is a stark difference from the "traditional" team, with its longer-duration lifecycle and mostly stable membership. Traditional teams have the benefit of time, allowing them to more deeply develop critical emergent states like trust, psychological safety, and transactive memory systems. Because members of traditional teams have to work with one another for longer durations, it is possible that individual idiosyncrasies and work habits are more important in these contexts. However, for the rapid cycle teams that are appearing with greater regularity in the modern workplace, these individual differences may be less important to staffing a team. Instead, it is likely that *who* is on the team is less important than what knowledge, skills, and attitudes they contribute. Selection, therefore, may require less attention on compatibility of team members' personality and work preferences and instead emphasize the compatibility of team member strengths and competencies.

We must also consider how dynamism in roles, goals, and tasks can impact selection of team members. Teams should be staffed based on members' value to organizational competitive advantage (Bell et al., 2018b). Changing needs, which may or may not be anticipated, adds complexity to the issue of staffing teams. While each team member may still bring a specific background or expertise to the team, expertise particulars may not be able to be successfully anticipated. It, therefore, may be more appropriate to look for individuals with certain attributes that might facilitate adaptability to changing circumstances and demands. Such attributes may include learning orientation, self-directed motivation, tolerance for ambiguity, and willingness to empathize, brainstorm, and prototype. It is also likely that selection should focus on identifying candidates with transportable teamwork competencies as opposed to those that are task-contingent.

As always, identifying team members for cultural fit is paramount when staffing teams, even as teams become more and more dynamic and short-lived. It is potentially even more important for staff working on rapid-cycle teams to have a strong identification with the company culture so that these individuals are better able to collaborate and coordinate with other members of the organization even as their teams assemble, disband, and reassemble in different configurations and navigate changing expectations, goals, and demands. Organizational value congruence is expected to reduce both task and relationship conflict between team members (Chuang et al., 2004), therefore, selecting staff for congruence with organizational values will help team members subject to participating on multiple teams or teams that quickly configure and disband work collaboratively with their colleagues. With this in mind, we present the following research questions:

- What competencies or values should be considered when staffing teams?
- How does staffing influence the manifestation of team competencies or values?
- How does the fluidity of team characteristics (e.g., interdependence) impact staffing decisions? Conversely, how does staffing impact the dynamism of team characteristics?
- What are the qualities of a flexible team member, and how can team members help one another to become more flexible?
- How do team member characteristics impact how work is completed?
- What task characteristics should be considered when staffing modern teams? How does the evolution of the task and its characteristics influence staffing decisions?

Team Interventions

Of course, it does not make logistical, practical, or even conceptual sense to rely on selection as the main source of controlling team membership and performance during dynamic situations. However, team-based interventions (i.e., systematic activity aimed at strengthening team competencies and dynamics and improving team performance; Lacerenza et al., 2018) are also employed. As described above, interventions are especially useful for modifying context-specific and team-specific competencies (Cannon-Bowers et al., 1995). However, given the faster pace of change in modern organizations and the agility that many teams must demonstrate in order to perform well, traditional approaches to interventions may also need to be re-thought. Known hallmarks of well-designed training include communicating information, demonstrating the principles, skills, or behaviors to be learned, providing opportunities for students themselves to practice, and providing subsequent feedback on their performance (Salas et al., 2012, 2015). Typically, instruction has been constrained to formal classroom style approaches wherein participants come together in a face-to-face setting and learn from an instructor. In these sessions, participants usually must plan in advance to attend, register, commute to the classroom, and have protected time in their calendars to participate in training, all of which can present as barriers to the communication of necessary information. Traditional approaches may be suitable for teaching

transportable competencies but may no longer be sufficient for imparting other types of knowledge, skills, and attitudes when needed. They also may not reflect how learning actually takes place. Much of learning is experiential, occurring in informal or on-the-job real-world settings (Shank, 2012).

On-the-job training is not a new idea. Adult learners want to have access to information, practice, and feedback when they need it most and since experience plays a major part in how we learn and perform, the thought of incorporating these lessons at work, where they are most relevant is attractive. Compound this proclivity for convenience and applicability of materials to current work processes with a dynamic environment and the implication is that interventions intended to improve teamwork and team performance may be better presented on-the-job, to actual team incumbents. Furthermore, with changing conditions, whether they are reconfigured team membership, a new team goal, changing interdependencies, or new task assignments and responsibilities, there is greater need to have access to relevant information and interventions real-time. Teams may not have the time or resources to schedule formal training off-site, taking time away from their jobs and the work that needs to be accomplished.

The natural next question is what delivery mechanisms can be used that would be suitable for these demands? Technology is likely to play a large role. Access to online repositories of information that teams and individual team members can access and download at will would be ideal. Of course, incorporating demonstration, practice, and feedback opportunities into these materials will be equally important and may require more creative approaches when a knowledgeable instructor, mentor, or coach is unavailable to provide teams with direction and sensemaking of content. Teams would also need access to reliable equipment like internet and computers capable of presenting content. For many teams, these materials are easily accessed but for teams such as military, medical, and construction teams that work in a variety of settings equipment of this type may not be already provided. Take construction teams as an example; these teams may not have access to reliable WiFi while on a job site. However, most Western employees do have access to smartphones and data plans. Practitioners and researchers should consider how these technologies can be tapped as a platform for accessing team resources real-time.

Finally, interventions and delivery of content for modern teams needs to be bite-sized and digestible, with only relevant information being presented. Teams operating in dynamic environments may not have the time to muddle through excessive content when there is work to be completed and very little, if any, dedicated time for additional learning. Couple that with recent estimates that the adult attention span may be as short as eight seconds (Microsoft, 2015), and there is further evidence for the need to keep intervention and informational content brief. Finding the balance between how little content is essential and how much content is excessive will be a challenge moving forward, especially when individual learner needs will naturally vary. Regarding team interventions, we propose the following research questions:

- How do we embed interventions within the team performance context so they are available precisely when needed?
- What tools and resources beyond training (whether classroom-based or on-the-job) can help teams respond flexibly to changing demands?
- How should interventions be employed given the movement toward globalization and the rapid advent of new technology?
- To whom should interventions target when attempting to maximize teamwork and team performance?

Digitization and Technology

Perhaps the biggest factor influencing how we define, work in, and study teams is digitization. Digital technologies are radically changing the world and the ways we live and work. Face-to-face meetings have given way to phone and video conferencing; paper-based mail has been replaced by email; typewriters exchanged for laptops and smart phones; wired connections substituted for wireless always-connected devices. Team members are able to communicate with each other across time and distances in ways that were previously impossible. Tannenbaum et al. (2012) outline many of the advantages and pitfalls that technology has for teamwork. Among the perceived advantages are greater ability to collaborate over distance (enabling the collaboration of experts across the globe), automatization of routine tasks, swifter communication, and flexibility in scheduling. These characteristics have the potential to enhance teamwork and team effectiveness, but they come with their own set of challenges that may off-set potential gains. For example, it is easier than ever to work non-traditional hours. While the flexibility afforded by technology may be believed to facilitate individual employee productivity, it can also invade personal time for non-work activities and create dissatisfaction with work-life balance (Barber et al., 2019). While employees are working longer hours, this does not necessarily translate into greater productivity as they forego necessary rest and down time needed for renewal (Fritz et al., 2010). Furthermore, technology-mediated collaboration can create lags in information exchange, more misunderstandings, fewer information seeking attempts, and less coherent messages (Andres, 2012).

Digitization and technology may underlie most, if not all, of the challenges and advancements we see in modern teams. However, much like Pandora, we cannot put our digital tools back in their boxes. The world in which we collaborate is not like the world of yesterday; but neither does tomorrow's world look like that which we see today. The technologies we are using now will likely be outdated within a decade, and teams will continue to evolve. Future teams research centered on technology and digitization might explore:

- How can technology be leveraged to facilitate increasingly important team processes, such as creativity?
- What impact does technology have on team and team member well-being?

- Does technology need to mimic the advantages of face-to-face interactions or can teamwork be organized to better leverage the advantages of technology?
- How do technologies impact the emergence of team states such as cohesion, trust, identity, and adaptation?
- How do we limit the invasiveness of technology within our collaborations?

CONCLUSION

Teams have been ubiquitous, so there have been longstanding theories and research. However, teams are very different given the macro trends in organizations and tasks. Consequently, these well-established theories and methodologies may necessitate some modernizing as the landscape of teams looks very differently in today's society. Contemporary teams and collaborations require new thinking and approaches to gain real insights and answer enlightening questions (Murase et al., 2012; Wageman et al., 2012). Additionally, as Tannenbaum et al. (2012) indicated, the need for future research is exacerbated by conflicting evidence (e.g., membership fluidity). To understand what novel thinking and research is necessary, we must first unpack the defining components of teams. Thus, the purpose of this paper was delineate how the traditional defining characteristics of teams are actually being represented in the real working environment and offer avenues for investigators to conduct future research to better unpack the theorizing and implications surrounding teams. We hope that future researchers begin to dissect the theory regarding and surrounding teams with finer detail to advance an accurate depiction of contemporary teams.

AUTHOR CONTRIBUTIONS

Both authors contributed substantially to the development of ideas, drafting, and preparation of the final manuscript.

REFERENCES

Aime, F., Humphrewy, S., DeRue, D. S., and Paul, J. B. (2014). The riddle of heterarchy: power transition in cross-functional teams. *Acad. Manag. J.* 57, 327–352. doi: 10.5465/amj.2011.0756

Alderfer, C. P. (1976). "Change processes in organizations," in *Handbook of Industrial and Organizational Psychology*, ed. M. Dunnette (Chicago, IL: Rand McNally), 1591–1638.

Alderfer, C. P. (1977). "Group and intergroup relations," in *Improving Life at Work*, eds J. R. Hackman, and J. L. Suttle (Santa Monica, CA: Goodyear), 227–296.

Alderfer, C. P. (1980). "Consulting to underbounded systems," in *Advances in Experiential Social Processes*, eds C. P. Alderfer, and C. L. Cooper (Chichester: John Wiley and Sons), 267–295.

Anderson, N. R., and West, M. A. (1998). Measuring climate for work group innovation: development and validation of the team climate inventory. *J. Organ. Behav.* 19, 235–258. doi: 10.1002/(SICI)1099-1379(199805)19:3<235::AID-JOB837>3.0.CO;2-C

Andres, H. P. (2012). Technology-mediated collaboration, shared mental model and task performance. *J. Organ. User Comput.* 24, 2558–2580.

Argote, L., Insko, C. A., Yovetich, N., and Romero, A. A. (1995). Group learning curves: the effects of turnover and task complexity on group performance. *J. Appl. Soc. Psychol.* 25, 512–529. doi: 10.1111/j.1559-1816.1995.tb01765.x

Arrow, H., and Crosson, S. (2003). Musical chairs: membership dynamics in self-organized group formation. *Small Group Res.* 34, 523–556. doi: 10.1177/1046496403254585

Arrow, H., and McGrath, J. E. (1995). Membership dynamics in groups at work: a theoretical framework. *Res. Organ. Behav.* 17, 373–411.

Baard, S. K., Rench, T. A., and Kozlowski, S. W. (2014). Performance adaptation: a theoretical integration and review. *J. Manag.* 40, 48–99. doi: 10.1177/0149206313488210

Barber, L. K., Conlin, A. L., and Santuzzi, A. M. (2019). Workplace telepressure and work life balance outcomes: the role of work recovery experiences. *Stress Health* doi: 10.1002/smi.2864 [Epub ahead of print].

Beal, D. J., Cohen, R. R., Burke, M. J., and McLendon, C. L. (2003). Cohesion and performance in groups: a meta-analytic clarification of construct relations. *J. Appl. Psychol.* 88, 989–1004. doi: 10.1037/0021-9010.88.6.989

Bedwell, W. L., Ramsay, S., and Salas, E. (2012). Helping fluid teams work: a research agenda for effective team adaptation in healthcare. *Transl. Behav. Med.* 2, 504–509. doi: 10.1007/s13142-012-0177-9

Bell, B. S. (2012). Three conceptual themes for future research on teams. *Ind. Organ. Psychol.* 5, 45–48. doi: 10.1111/j.1754-9434.2011.01403.x

Bell, S. T. (2007). Deep-level composition variables as predictors of team performance: a meta-analysis. *J. Appl. Psychol.* 92, 595–615. doi: 10.1037/0021-9010.92.3.595

Bell, S. T., Brown, S. G., Colaneri, A., and Outland, N. (2018a). Team composition and the ABCs of teamwork. *Am. Psychol.* 73, 349–362. doi: 10.1037/amp0000305

Bell, S. T., Brown, S. G., and Weiss, J. A. (2018b). A conceptual framework for leveraging team composition decisions to build human capital. *Hum. Resour. Manag. Rev.* 28, 450–463. doi: 10.1016/j.hrmr.2017.06.003

Bresman, H., and Zellmer-Bruhn, M. (2013). The structural context of team learning: effects of organizational and team structure on internal and external learning. *Organ. Sci.* 24, 1120–1139. doi: 10.1287/orsc.1120.0783

Bush, J. T., LePine, J. A., and Newton, D. W. (2018). Teams in transition: an integrative review and synthesis of research on team task transitions and propositions for future research. *Hum. Resour. Manag. Rev.* 28, 423–433. doi: 10.1016/j.hrmr.2017.06.005

Bushe, G. R., and Chu, A. (2011). Fluid teams: solutions to the problems of unstable team membership. *Organ. Dyn.* 40, 181–188.

Campion, M. A., Medsker, G. J., and Higgs, A. C. (1993). Relations between work group characteristics and effectiveness: implications for designing effective work groups. *Pers. Psychol.* 46, 823–847. doi: 10.1111/j.1744-6570.1993.tb01571.x

Campion, M. A., Papper, E. M., and Medsker, G. J. (1996). Relations between work team characteristics and effectiveness: a replication and extension. *Pers. Psychol.* 49, 429–452. doi: 10.1111/j.1744-6570.1996.tb01806.x

Cannon-Bowers, J. A., and Bowers, C. (2011). "Team development and functioning," in *APA Handbooks in Psychology. APA Handbook of Industrial and Organizational Psychology*, Vol. 1, *Building and developing the organization*, ed. S. Zedeck (Washington, DC: American Psychological Association), 597–650.

Cannon-Bowers, J. A., Tannenbaum, S. I., Salas, E., and Volpe, C. E. (1995). "Defining competencies and establishing team training requirements," in *Team Effectiveness and Decision Making in Organizations*, eds R. Guzzo and E. Salas (San Francisco, CA: Jossey-Bass), 333–380.

Carson, J. B., Tesluk, P. E., and Marrone, J. A. (2007). Shared leadership in teams: an investigation of antecedent conditions and performance. *Acad. Manag. J.* 50, 1217–1234. doi: 10.5465/amj.2007.20159921

Chiu, Y.-T., Khan, M. S., Mirzaei, M., and Caudwell, C. (2017). "Reconstructing the concept of team fluidity for the digitized era," in *Paper Presented at ISPIM Innovation Summit*, Melbourne.

Choi, H., and Thompson, L. (2005). Old wine in a new bottle: impact of membership change on group creativity. *Organ. Behav. Hum. Dec. Process.* 98, 121–132. doi: 10.1016/j.obhdp.2005.06.003

Chuang, Y., Church, R., and Zikic, J. (2004). Organizational culture, group diversity and intra-group conflict. *Team Perform. Manag.* 10, 26–34. doi: 10.1108/13527590410527568

Cohen, S. G., and Bailey, D. E. (1997). What makes teams work: group effectiveness research from the shop floor to the executive suite. *J. Manag.* 23, 239–290. doi: 10.1016/s0149-2063(97)90034-9

Crown, D. F., and Rosse, J. G. (1995). Yours, mine, and ours: facilitating group productivity through the integration of individual group goals. *Organ. Behav. Hum. Dec. Process.* 64, 138–150. doi: 10.1006/obhd.1995.1096

Cummings, J., and Haas, M. (2012). So many teams, so little time: time allocation matters in geographically dispersed teams. *J. Organ. Behav.* 33, 316–341. doi: 10.1002/job.777

De Dreu, C. K. W., and Weingart, L. R. (2003). Task versus relationship conflict, team performance, and team member satisfaction: a meta-analysis. *J. Appl. Psychol.* 88, 741–774.

Devine, D. J. (2002). A review and integration of classification systems relevant to teams in organizations. *Group Dyn. Theory Res. Pract.* 6, 291–310. doi: 10.1037//1089-2699.6.4.291

Devine, D. J., Clayton, L. D., Philips, J. L., Dunford, B. B., and Melner, S. B. (1999). Teams in organizations: prevalence, characteristics, and effectiveness. *Small Group Res.* 30, 678–711. doi: 10.1177/104649649903000602

Dineen, B. R., and Noe, R. A. (2003). "The impact of team fluidity and its implications for human research management research and practice," in *Research in Personnel and Human Resources Management*, eds J. Martocchio and G. Ferris (Bingley: Emerald Group Publishing), 1–38.

Driskell, J. E., Salas, E., and Driskell, T. (2018). Foundations of teamwork and collaboration. *Am. Psychol.* 73, 334–348. doi: 10.1037/amp0000241

Driskell, T., Salas, E., and Driskell, J. E. (2018). Teams in extreme environments: alterations in team development and teamwork. *Hum. Resour. Manag. Rev.* 28, 434–449. doi: 10.1016/j.hrmr.2017.01.002

Dube, L. (2014). Exploring how IT professionals experience role transitions at the end of successful projects. *J. Manag. Inf. Syst.* 31, 17–46. doi: 10.2753/mis0742-1222310102

Edmondson, A. C. (2012). *Teaming: How Organizations Learn, Innovate, and Compete in the Knowledge Economy*. San Francisco, CA: Jossey-Bass.

Edmonson, A. C., and Harvey, J.-F. (2018). Cross-boundary teaming for innovation: integrating research on teams and knowledge in organizations. *Hum. Resour. Manag. Rev.* 28, 347–360. doi: 10.1016/j.hrmr.2017.03.002

Espinosa, J. A., Cummings, J. N., and Pickering, C. (2012). Time separation, coordination, and performance in technical teams. *IEEE Trans. Eng. Manag.* 59, 91–103. doi: 10.1109/tem.2011.2126579

Feitosa, J., Grossman, R., and Salazar, M. (2018). Debunking key assumptions about teams: the role of culture. *Am. Psychol.* 73, 376–389. doi: 10.1037/amp0000256

Francis, D., and Young, D. (1970). *Improving Work Groups: A Practical Manual for Teambuilding*. La Jolla, CA: University Associates.

Frick, S. E., Fletcher, K. A., Rasay, P. S., and Bedwell, W. L. (2018). Understanding team maladaptation through the lens of the four R's of adaptation. *Hum. Resour. Manag. Rev.* 28, 411–422. doi: 10.1016/j.hrmr.2017.08.005

Fritz, C., Yankelevich, M., Zarubin, A., and Barger, P. (2010). Happy, healthy, and productive: the role of detachment from work during nonwork time. *J. Appl. Psychol.* 95, 977–983. doi: 10.1037/a0019462

Gilson, L. L., Maynard, M. T., Young, N. C. J., Vartianinen, M., and Hakonen, M. (2015). virtual teams research: 10 years, 10 themes, and 10 opportunities. *J. Manag.* 41, 1313–1337. doi: 10.1177/0149206314559946

Gladstein, D. L. (1984). Groups in context: a model of task group effectiveness. *Adm. Sci. Q.* 29, 499–517. doi: 10.2307/2392936

Gonzalez, V., and Mark, G. (2004). "Constant, constant, multi-tasking craziness: managing multiple working spheres," in *Paper Presented at the SIGCHI Conference on Human Factors in Computing Systems*, New York, NY.

Graesser, A. C., Fiore, S. M., Greiff, S., Andrews-Todd, J., Foltz, P. W., and Hesse, F. W. (2018). Advancing the science of collaborative problem solving. *Psychol. Sci. Public Interest* 19, 59–92.

Gully, S. M., Devine, D. J., and Whitney, D. J. (1995). A meta-analysis of cohesion and performance: effects of level of analysis and task interdependence. *Small Group Res.* 26, 497–520. doi: 10.1177/1046496495264003

Gully, S. M., Incalcaterra, K. A., Joshi, A., and Beaubien, J. M. (2002). A meta-analysis of team-efficacy, potency, and performance: interdependence and level of analysis and moderators of observed relationships. *J. Appl. Psychol.* 87, 819–832. doi: 10.1037/0021-9010.87.5.819

Guzzo, R. A., and Dickson, M. W. (1996). Teams in organizations: recent research on performance and effectiveness. *Annu. Rev. Psychol.* 47, 307–338. doi: 10.1146/annurev.psych.47.1.307

Hackman, J. R. (1987). "The design of work teams," in *Handbook of Organizational Behavior*, ed. J. Lorsch (Englewood Cliffs, NJ: Prentice-Hall), 315–342.

Hackman, J. R. (1990). *Groups that Work (and those that don't)*. San Francisco, CA: Jossey-Bass.

Hackman, J. R. (2002). *Leading Teams. Setting the Stage for Great Performances*. Brighton, MA: Harvard Business School Press.

Hackman, J. R. (2012). From causes to conditions in group research. *J. Organ. Behav.* 33, 428–444. doi: 10.1002/job.1774

Harrison, D. A., and Humphrey, S. E. (2010). Designing for diversity or diversity for design? Tasks, interdependence, and within-unit differences at work. *J. Organ. Behav.* 31, 328–337. doi: 10.1002/job.608

Hirst, G. (2009). Effects of membership change on open discussion and team performance: the moderating role of team tenure. *Eur. J. Work Organ. Psychol.* 18, 231–249. doi: 10.1080/13594320802394202

Hollenbeck, J. R., Beersma, B., and Schouten, M. E. (2012). Beyond team types and taxonomies: a dimensional scaling conceptualization for team description. *Acad. Manag. Rev.* 37, 82–106. doi: 10.5465/armr.2010.0181

Hollenbeck, J. R., Ilgen, D. R., Sego, D. J., Hedlund, J., Major, D. A., and Phillips, J. (1995). Multilevel theory of team decision making: decision performance in teams incorporating distributed expertise. *J. Appl. Psychol.* 80, 292–316. doi: 10.1037/0021-9010.80.2.292

Hu, J., and Liden, R. C. (2011). Antecedents of team potency and team effectiveness: an examination of goal and process clarity and servant leadership. *J. Appl. Psychol.* 96, 851–862. doi: 10.1037/a0022465

Ilgen, D. R., Hollenbeck, J. R., Johnson, M., and Jundt, D. (2005). Teams in organizations: from input-process-output models to IMOI models. *Annu. Rev. Psychol.* 56, 517–543. doi: 10.1146/annurev.psych.56.091103.070250

Katzenbach, J. R., and Smith, D. K. (1993). The discipline of teams. *Harv. Bus. Rev.* 71, 111–120.

Katzenbach, J. R., and Smith, D. K. (1998). *The Wisdom of Teams*. Berkshire: McGraw-Hill.

Kazemak, E., and Albert, B. (1988). Learning the secret to teamwork. *Healthc. Financ. Manag.* 42, 108–110.

Klein, H. J., and Mulvey, P. W. (1995). Two investigations of the relationships among group goals, goal commitment, cohesion, and performance. *Organ. Behav. Hum. Dec. Process.* 61, 44–53. doi: 10.1006/obhd.1995.1004

Klein, K., and Kozlowski, S. W. J. (2000). *Multilevel theory, Research and Methods in Organization*. San Francisco, CA: Jossey-Bass.

Kozlowski, S. W. J., and Bell, B. S. (2003). "Work groups and teams in organizations," in *Comprehensive Handbook of Psychology: Industrial and Organizational Psychology*, Vol. 12, eds W. Borman, D. Ilgen, and R. Klimoski (New York, NY: Wiley), 333–375.

Kozlowski, S. W. J., Gully, S. M., Nason, E. R., and Smith, E. M. (1999). "Developing adaptive teams: a theory of compilation and performance across levels and time," in *The Changing Nature of Work Performance: Implication for Staffing, Personnel Actions and Development*, eds D. R. Ilgen and E. D. Pulakos (San Francisco, CA: Jossey Bass), 240–292.

Kozlowski, S. W. J., and Ilgen, D. R. (2006). Enhancing the effectiveness of work groups and teams. *Psychol. Sci. Public Interest* 7, 77–124. doi: 10.1111/j.1529-1006.2006.00030.x

Lacerenza, C. N., Marlow, S. M., Tannenbaum, S. I., and Salas, E. (2018). Team development interventions: evidence-based approaches for improving teamwork. *Am. Psychol.* 73, 517–531. doi: 10.1037/amp0000295

Landrum, S. (2017). *Millennials Aren't Afraid to Change Jobs, and Here's why. Forbes*. Available at: https://www.forbes.com/sites/sarahlandrum/2017/11/10/millennials-arent-afraid-to-change-jobs-and-heres-why/#2688a85719a5 (accessed November 10, 2017).

Lanza, P. (1985). Team appraisals. *Pers. J.* 64, 47–51.

LePine, J. A. (2005). Adaptation of teams in response to unforeseen change: effects of goal difficulty and team composition in terms of cognitive ability and goal orientation. *J. Appl. Psychol.* 90, 1153–1167. doi: 10.1037/0021-9010.90.6.1153

LePine, J. A., Piccolo, R. F., Jackson, C. L., Mathieu, J. E., and Saul, J. R. (2008). A meta-analysis of teamwork processes: tests of a multidimensional model and relationships with team effectiveness criteria. *Pers. Psychol.* 61, 273–307. doi: 10.1111/j.1744-6570.2008.00114.x

Lewis, K., Belliveau, M., Herndon, B., and Keller, J. (2007). Group cognition, membership change, and performance: investigating the benefits and detriments of collective knowledge. *Organ. Behav. Hum. Dec. Process.* 103, 159–178. doi: 10.1016/j.obhdp.2007.01.005

Malone, T. W., and Crowston, K. (1994). The interdisciplinary study of coordination. *ACM Comput. Surv.* 26, 87–119. doi: 10.1145/174666.174668

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manag. Rev.* 26, 356–376. doi: 10.5465/amr.2001.4845785

Martin, A., and Bal, V. (2006). *The State of Teams*. Greensboro, NC: Center for Creative Leadership.

Mathieu, J., Maynard, M. T., Rapp, T., and Gilson, L. (2008). Team effectiveness 1997-2007: a review of recent advancements and a glimpse into the future. *J. Manag.* 34, 410–476. doi: 10.1177/0149206308316061

Mathieu, J. E., Hollenbeck, J. R., van Knippenberg, D., and Ilgen, D. R. (2017). A century of work teams in the Journal of Applied Psychology. *J. Appl. Psychol.* 102, 452–467. doi: 10.1037/apl0000128

Mathieu, J. E., Tannenbaum, S. I., Donsbach, J. S., and Alliger, G. A. (2014). A review and integration of team composition models: moving toward a dynamic and temporal framework. *J. Manag.* 40, 130–160. doi: 10.1177/0149206313503014

McGrath, J. E. (1964). *Social Psychology: A Brief Introduction*. New York, NY: Holt, Rinehart, & Winston.

McGrath, J. E., Arrow, H., and Berdahl, J. L. (2000). The study of groups: past, present, and future. *Pers. Soc. Psychol. Rev.* 4, 95–105. doi: 10.1207/S15327957PSPR0401_8

Microsoft (2015). *Attention Spans*. Canada: Consumer Insights, Microsoft Canada.

Miller, L. K., and Hamblin, R. L. (1963). Interdependence, differential rewarding, and productivity. *Am. Sociol. Rev.* 28, 768–778. doi: 10.2307/2089914

Mitchell, T. R., and Silver, W. S. (1990). Individual and group goals when workers are interdependent: effects on task strategies and performance. *J. Appl. Psychol.* 75, 185–193. doi: 10.1037//0021-9010.75.2.185

Morgan, B. B. Jr., Salas, E., and Glickman, A. S. (1993). An analysis of team evolution and maturation. *J. Gen. Psychol.* 120, 277–291. doi: 10.1080/00221309.1993.9711148

Mortensen, M., and Haas, M. R. (2016). *Rethinking Team Boundaries*. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2841150 (accessed September 21, 2016).

Murase, T., Doty, D., Wax, A., DeChurch, L., and Contractor, N. S. (2012). Teams are changing: time to "think networks". *Ind. Organ. Psychol.* 5, 41–44. doi: 10.1111/j.1754-9434.2011.01402.x

Okhuysen, G. A., and Bechky, B. A. (2009). 10 coordination in organization: an integrative perspective. *Acad. Manag. Ann.* 3, 463–502. doi: 10.5465/19416520903047533

O'Leary, M. B., Woolley, A. W., and Mortensen, M. (2011). "Multiteam membership in relation to multiteam systems," in *Multiteam Systems: An Organization form for Dynamic and Complex Environments*, eds S. J. Zaccaro, M. A. Marks, and L. A. DeChurch (New York, NY: Routledge), 141–172.

Rasmussen, T. H., and Jeppesen, H. J. (2006). Teamwork and associated psychological factors: a review. *Work Stress* 20, 105–128. doi: 10.1080/02678370600920262

Richardson, J. (2010). *An Investigation of the Prevalence and Measurement of Teams in Organisations: The Development and Validation of the Real Team Scale*. Doctoral dissertation, Aston University, Birmingham.

Robert Half (2018). *Does Job Hopping Help or Hurt Your Career?* Available at: http://rh-us.mediaroom.com/2018-04-05-Does-Job-Hopping-Help-Or-Hurt-Your-Career?utm_campaign=Press_Release&utm_medium=Link&utm_source=Press_Release (accessed April 5, 2018).

Rousseau, V., Aubé, C., and Savoie, A. (2006). Teamwork behaviors: a review and an integration of Frameworks. *Small Group Res.* 37, 540–570. doi: 10.1136/bmjopen-2015-007685

Saavedra, R., Earley, P., and Van Dyne, L. (1993). Complex interdependence in task-performing groups. *J. Appl. Psychol.* 78, 61–72. doi: 10.1037/0021-9010.78.1.61

Salas, E., Benishek, L. E., Coultas, C., Dietz, A., Grossman, R., Lazzara, E. H., et al. (2015). *Team Training Essentials: A Research-Based Guide*. New York, NY: Routledge.

Salas, E., Dickinson, T. L., Converse, S. A., and Tannenbaum, S. I. (1992). "Toward an understanding of team performance and training," in *Teams: Their Training and Performance*, eds R. W. Swezey and E. Salas (Norwood, NJ: Ablex), 3–29.

Salas, E., Shuffler, M. L., Thayer, A. L., Bedwell, W. L., and Lazzara, E. H. (2011). Understanding and improving teamwork in organizations: a scientifically based practical guide. *Hum. Resour. Manag.* 54, 599–622. doi: 10.1002/hrm.21628

Salas, E., Sims, D. E., and Burke, C. S. (2005). Is there a "big five" in teamwork? *Small Group Res.* 36, 555–599. doi: 10.1177/1046496405277134

Salas, E., Stagl, K. C., Burke, C. S., and Goodwin, G. F. (2007). "Fostering team effectiveness in organizations: toward an integrative theoretical framework of team performance," in *Modeling Complex Systems: Motivation, Cognition and Social Processes*, eds R. A. Dienstbier, J. W. Shuart, W. Spaulding, and J. Poland (Lincoln, NE: University of Nebraska Press), 185–243.

Salas, E., Tannenbaum, S. I., Kraiger, K., and Smith-Jentsch, K. A. (2012). The science of training and development in organizations: what matters in practice. *Psychol. Sci. Public Interest* 13, 74–101. doi: 10.1177/1529100612436661

Savelsbergh, C. M. J. H., Poell, R. F., and van der Heijden, B. I. J. M. (2015). Does team stability mediate the relationship between leadership and team learning? An empirical study among Dutch project teams. *Int. J. Proj. Manag.* 33, 406–418. doi: 10.1016/j.ijproman.2014.08.008

Schippers, M. C., Hartog, D. N. D., and Koopman, P. L. (2007). Reflexivity in teams: a measure and correlates. *Appl. Psychol.* 56, 189–211. doi: 10.1111/j.1464-0597.2006.00250.x

Shank, P. (2012). *Smart Companies Support informal Learning*. Available at: https://www.elearningguild.com/insights/index.cfm?id=159&action=viewonly&utm_campaign=research-inf12&utm_medium=link&utm_source=lsmag&_ga=2.249953734.1734585252.1543552949-1329011644.1543552949 (accessed August 16, 2012).

Shea, G. P., and Guzzo, R. A. (1987). "Groups as human resources," in *Research in Personnel and Human Resources Management*, Vol. 5, eds K. M. Rowland and G. R. Ferris (Greenwich, CT: JAI Press), 323–356.

Shuffler, M. L., and Carter, D. R. (2018). Teamwork situated in multiteam systems: key lessons learned and future opportunities. *Am. Psychol.* 73, 390–406. doi: 10.1037/amp0000322

Summers, J. K., Humphrey, S. E., and Ferris, G. R. (2012). Team member change, flux in coordination, and performance: effects of strategic core roles, information transfer, and cognitive ability. *Acad. Manag. J.* 55, 314–338. doi: 10.5465/amj.2010.0175

Sundstrom, E., De Meuse, K. P., and Futrell, D. (1990). Work teams: applications and effectiveness. *Am. Psychol.* 45, 120–133. doi: 10.1037//0003-066x.45.2.120

Tannenbaum, S. I., Mathieu, J. E., Salas, E., and Cohen, D. (2012). Teams are changing: are research and practice evolving fast enough. *Ind. Organ. Psychol.* 5, 2–24. doi: 10.1111/j.1754-9434.2011.01396.x

van de Brake, H. J., Walter, F., Rink, F. A., Essens, P. J. M. D., and van der Vegt, G. S. (2018). The dynamic relationship between multiple team membership and individual job performance in knowledge-intensive work. *J. Organ. Behav.* 39, 1219–1231. doi: 10.1002/job.2260

Van der vegt, G. S., Emans, B. J. M., and van de vliert, E. (2001). Patterns of interdependence in work teams: a two-level investigation of the relations with job and team satisfaction. *Pers. Psychol.* 54, 51–69. doi: 10.1111/j.1744-6570.2001.tb00085.x

Wageman, R. (1995). Interdependence and group effectiveness. *Adm. Sci. Q.* 40, 145–180. doi: 10.2307/2393703

Wageman, R., Gardner, H., and Mortensen, M. (2012). The changing ecology of teams: new directions for teams research. *J. Organ. Behav.* 33, 301–315. doi: 10.1002/job.1775

Wageman, R., Hackman, J. R., and Lehman, E. (2005). Team diagnostic survey: development of an instrument. *J. Appl. Behav. Sci.* 41, 373–398. doi: 10.1177/0021886305281984

Weingart, L. R. (1992). Impact of group goals, task component complexity, effort, and planning on group performance. *J. Appl. Psychol.* 77, 682–693. doi: 10.1037/0021-9010.77.5.682

Weldon, E., and Weingart, L. R. (1993). Group goals and group performance. *Br. J. Soc. Psychol.* 32, 307–334. doi: 10.1111/j.2044-8309.1993.tb01003.x

West, M. A. (2004). *Effective Teamwork: Practical Lessons from Organizational Research*. Oxford: Blackwell.

West, M. A., Borrill, C. S., and Unsworth, K. L. (1998). "Team effectiveness in organisations," in *International Review of Industrial and Organisational Psychology*, eds C. L. Cooper and I. T. Robertson (Chichester: Wiley), 1–48.

West, M. A., and Lyubovnikova, J. (2012). Real teams or pseudo teams: the changing landscape needs a better map. *Ind. Organ. Psychol.* 5, 25–55.

Wildman, J. L., Thayer, A. L., Rosen, M. A., Salas, E., Mathieu, J. E., and Rayne, S. R. (2011). Task types and team-level attributes: synthesis of team classification literature. *Hum. Resour. Dev. Rev.* 11, 37–129.

Zander, A. (1977). *Groups at Work*. San Francisco, CA: Jossey-Bass.

Ziller, R. C. (1965). Toward a theory of open and closed groups. *Psychol. Bull.* 64, 164–182. doi: 10.1037/h0022390

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The handling Editor declared a shared affiliation, though no other collaboration, with one of the authors LB.

Copyright © 2019 Benishek and Lazzara. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

SYSTEMATIC REVIEW
published: 15 May 2019
doi: 10.3389/fpsyg.2019.00811

What We Know About Team Dynamics for Long-Distance Space Missions: A Systematic Review of Analog Research

Suzanne T. Bell[1]*, *Shanique G. Brown*[2] *and Tyree Mitchell*[3]

[1] Department of Psychology, DePaul University, Chicago, IL, United States, [2] Department of Psychology, Wayne State University, Detroit, MI, United States, [3] School of Leadership & Human Resource Development, Louisiana State University, Baton Rouge, LA, United States

OPEN ACCESS

Edited by:
Eduardo Salas,
Rice University, United States

Reviewed by:
Mathias Basner,
University of Pennsylvania,
United States
Gloria Rakita Leon,
University of Minnesota Twin Cities,
United States

***Correspondence:**
Suzanne T. Bell
sbell11@depaul.edu

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: 01 December 2018
Accepted: 26 March 2019
Published: 15 May 2019

Citation:
Bell ST, Brown SG and Mitchell T (2019) What We Know About Team Dynamics for Long-Distance Space Missions: A Systematic Review of Analog Research. Front. Psychol. 10:811. doi: 10.3389/fpsyg.2019.00811

Background: To anticipate the dynamics of future long-distance space exploration mission (LDSEM) teams, research is conducted in analog environments (e.g., Antarctic expeditions, space chamber simulations), or environments that share key contextual features of LDSEM such as isolation and confinement. We conducted a systematic review of research conducted on teams in LDSEM-analog environments to identify which factors have been examined with quantitative research, and to summarize what the studies reveal about team dynamics in LDSEM-analog environments.

Methods: We used a comprehensive search strategy to identify research on teams that lived and worked together. Data on team dynamics were extracted where possible, and sources were coded for key contextual features. The data did not lend themselves to traditional meta-analysis. We used two approaches to summarize the data: a weighted averages approach when the study reported enough data to calculate an effect size, and descriptive figures when data across studies were directly comparable.

Results: Seventy-two sources met our inclusion criteria, yielding 253 effect sizes and 1,150 data points. Results from our weighted averages approach suggested that the team cohesion and performance relationship may be operating differently in isolated and confined environments than other teams that lived and worked together (e.g., military teams), and that, given the available data, we can say very little about the magnitude and direction of the relationship. Our descriptive figures revealed important trends: (a) team members in longer missions generally spent less social time together than shorter missions; (b) consistent team efficiency over time was typical, whereas decreased team efficiency over time was atypical; (c) by 40% of mission completion or 90 days, all teams reported at least one conflict, (d) commanders' written communication with mission control decreased in length over time, and (e) team mood dynamics did not consistently support the third-quarter phenomenon.

Conclusions: There are inherent limitations to our study, given the nature of the analog research (e.g., correlational studies, small sample size). Even so, our systematic review provides key insights into team dynamics in LDSEM-analog environments. We discuss the implications of our research for managing future space crews. Importantly, we also provide guidance for future research.

Keywords: team dynamics/processes, space exploration, astronaut, conflict, small sample, analog, over time changes, teams and groups

INTRODUCTION

Extreme teams help to solve complex problems outside of traditional performance environments and have significant consequences associated with failure (Bell et al., 2018). As a type of extreme team, astronaut crews will be expected to live and work under psychologically and physically demanding conditions for future long-distance space exploration missions (LDSEMs), such as missions to Mars (Salas et al., 2015b). For example, LDSEM astronaut crews will be required to function effectively as a team in isolated and confined environments for up to 30 months (Human Exploration of Mars Design Reference Architecture [DRM] 5.0; Drake, 2009). LDSEMs will require crews to operate more autonomously as their communication with mission control (MC) will be delayed up to 22 min (DRM; Drake, 2009). Crewmembers will switch between periods of high and low workload, as well as between individual and team tasks. It will be necessary for the LDSEM crew to work together seamlessly for demanding team performance situations such as landing on Mars, keep conflicts manageable, and provide one another with social support as crewmembers deal with the stressors of prolonged space flight.

Rationale

The National Aeronautics and Space Administration (NASA) and other space agencies seek to optimize team performance to minimize the risk of mission failure, and work with researchers from various scientific disciplines to prepare for future LDSEM missions. While meta-analytic investigations of important team relationships exist (e.g., team cognition, cohesion, composition, and performance), these investigations include traditional work team samples and findings may not necessarily generalize to the LDSEM context (Beal et al., 2003; Bell, 2007; DeChurch and Mesmer-Magnus, 2010; Bell et al., 2011). As such, researchers collect data in spaceflight and Earth-based analog environments, which are thought to mimic the challenges crews will encounter in LDSEM, to best design, prepare, and support future LDSEM crews and mission teams. Research on natural analogs examines teams that exist outside of research purposes; examples include polar stations in the Antarctic, where teams conduct scientific research while living in an isolated and harsh environment (e.g., Leon et al., 2011). Research in controlled analogs includes teams that exist specifically for research purposes; examples include teams in HI-SEAS, Human Exploration Research Analog (HERA) at Johnson Space Center, and the NEK facility at the Russian Academy of Science's Institute of Biomedical Problems (e.g., Ushakov et al., 2014; Binsted, 2015; Roma, 2015).

Analog settings share similar characteristics of LDSEMs expected to challenge crews and possibly impinge on team dynamics. As examples, analog crews live in a confined space (i.e., small living and working spaces with minimal privacy, physical discomfort), are isolated from others (i.e., limited interaction with others outside the crew, difficulty in communicating with family), are surrounded by a harsh physical environment (i.e., an environment in which survival is not possible without special equipment), have variable workload (i.e., a high and low volume of work at different periods), and have long-duration missions (i.e., the team works together for an extended period of time). Each analog may have its strengths and weaknesses given that not all of the environmental factors may be present in a particular analog. For example, crews in Antarctic stations experience physical confinement and isolation, but are typically isolated as smaller crews for shorter periods than is expected for LDSEMs. They also have environmental cues not available in spaceflight (e.g., daylight). Crews in space simulations (e.g., HUBES, SFINCSS) may experience isolation and confinement but are typically not surrounded by a harsh physical environment.

Research on teams in analog environments has a rich history. In fact, a number of factors (e.g., compatibility and cohesion, mood, communication, conflict, performance) have been investigated in natural analogs (e.g., Antarctic; Wood et al., 1999; Steel, 2001), space simulations (e.g., HUBES, Mars 105, SFINCSS; Gushin et al., 2001; Sandal, 2004; Nicolas et al., 2013), and isolated and confined laboratory settings (e.g., Emurian et al., 1984) dating back to at least the 1960s (e.g., Gunderson and Nelson, 1963; Altman and Haythorn, 1965; Gunderson and Ryman, 1967). This research suggests several dynamics unique to the LDSEM-analog settings.

As examples, while a meta-analysis of the traditional team literature suggests that the team cohesion and team performance relationship is generally small (Beal et al., 2003), team cohesion may be of particular significance when crewmembers live and work together and rely on one another for social support (Landon et al., 2015). Astronaut journals collected in the International Space Station (ISS) reveal a decreasing number of positive comments about team interaction over the course of a mission (Stuster, 2010). Further, problems associated with poor unit-level team cohesion such as subgrouping and isolation can occur, which have implications for conflict, information sharing, and team performance (Kanas, 1998; Kanas et al., 2009).

The psychological health of the crew is likely to be important for LDSEMs as crews will be living and working in an extreme environment for an extended duration. Communication between space crews and MC is thought to provide information about the crew's psychological health and the crew's psychological climate. Analysis of a space crew's communication with MC is the standard operating procedure of the psychological support group in Russian MC and is used to examine crews' emotional status and the communicators' coping strategies (Gushin et al., 2012, 2016). Among other things, research by Gushin et al., 1997, 2012 indicated that crews decreased the scope and content of their communication to outside personnel over time—a phenomenon called psychological closing.

Some crews have reported changes in mood over time. The third quarter phenomenon is the tendency for positive mood levels to decrease while negative mood levels and conflict increase after the midpoint of the mission (Bechtel and Berning, 1991; Steel, 2001; Dion, 2004; Kanas, 2004; Wang et al., 2014). Though mood is typically measured in LDSEM-analog research as an individual-level variable, researchers sometimes use the team mean of individual-level mood scores to represent team mood. Team mood is important because it contributes to team emotion, which is defined as a team's affective state that arises from bottom-up components such as affective composition, and top-down components such as affective context (Kelly and Barsade, 2001). Team emotion starts with individual-level moods and emotions and is then shared with the team either implicitly through emotional contagion or explicitly through means such as affect management. Environmental context such as lighting and physical layout can affect moods (see Kelly and Barsade, 2001). Thus, a better understanding of how team mood changes over time is necessary, especially given the extreme conditions expected for LDSEMs, such as living in a small transit vehicle with no natural light. The aforementioned evidence on team cohesion, communication, and mood are examples of findings that may be unique to the LDSEM context; this underscores the importance of examining team phenomena in LDSEM-analog environments.

While a body of research examines teams in analog environments, to date, it has not been quantitatively summarized. A quantitative summary of the analog team research is important for several reasons. First, it summarizes what we know about teams in LDSEM analog environments, given the available data. Specifically, it can provide insights into how team dynamics may unfold over time for LDSEM teams, and be used to benchmark typical and atypical team dynamics in the LDSEM environment. It also can identify potential threats to LDSEM team dynamics and performance. Second, it can help guide future research in analog environments by identifying what areas are in need of more research, new areas for research, and strategies that aid with knowledge accumulation over time. Guidance for future research is particularly important given the expense and time required to collect analog research.

Objectives and Research Questions

The primary purpose of our research was to provide an overall picture of the available data on team dynamics and performance in LDSEM-analog environments. To do this, we systematically reviewed quantitative research conducted on teams in LDSEM-analog environments. We answer two primary questions with our systematic review: (1) which factors have been examined with quantitative research, and (2) what do these studies reveal about team dynamics in LDSEM-analog environments?

METHODS

Study Design and Inclusion Criteria

Typically, meta-analysis is preferred for integrating estimates of the same relationship of interest across studies; it allows us to generate cumulative knowledge about a set of studies. The benefits of meta-analysis over narrative reviews have been widely noted (see Glass, 1976; Schmidt and Hunter, 2015). Early in our review process, however, we suspected that most studies conducted on teams in analog environments would not lend themselves to traditional meta-analysis. Frequentist meta-analytic techniques can be inappropriate when a limited number of studies have examined a particular relationship or when sample sizes or data do not permit the calculation of an effect size, for example, when data are only reported for a single team. Further, a review of the analog research at the individual-level determined that traditional meta-analytic techniques were inappropriate (e.g., Shea et al., 2011). Given this, our general approach (e.g., search strategies, coding) was consistent with best practices in meta-analysis in organizational psychology (e.g., Schmidt and Hunter, 2015); however, we retained a broader set of studies and ultimately used alternative analytic approaches to summarizing the data. Our reporting is consistent with the PRISMA guidelines (Moher et al., 2009) to the extent that they apply to non-medical systematic reviews.

We sought to be as inclusive as possible while also striving to ensure that the data were relevant to understanding team dynamics in an LDSEM environment. We applied three general inclusion criteria. First, we retained sources that reported quantitative data from teams in LDSEM-analog environments, however, we excluded descriptive case studies and narrative reviews. Second, we identified and included only team-level data (as opposed to individual-level data). We excluded articles that reported individual-level data that were not tied to a particular team (e.g., Bartone et al., 2002), or that were tied to a large polar station (>40 people) but not to a team or a small station (e.g., Doll and Gunderson, 1971; Palinkas et al., 1989). Third, we included research in which members of the focal team (e.g., the "crew" analog) live and work together for a period. We provide more detail on this decision next.

Defining an LDSEM-analog environment has challenges because a particular extreme environment (e.g., Antarctic winter-overs) may only share some of the same characteristics expected of LDSEM. All analogs are imperfect approximations of LDSEM, and researchers must weigh the importance of different features of the context in understanding the phenomena of interest. Because of this, we broadly defined LDSEM-analog research as research in which members of the focal team (e.g., the "crew" analog) live and work together for a period. We included military teams when they were expressly described as intact teams (e.g., combat teams; Ko, 2005; Lim and Klein, 2006) even if the

research did not explicitly mention that the unit lived together. We did not include military or firefighter training exercises when it was unclear whether the team lived together either while at training or while not at training (e.g., Oser et al., 1989; Hirschfeld and Bernerth, 2008). We excluded sources that included data on children (e.g., Tyerman and Spencer, 1983). We coded features of the analog environment and sample characteristics as moderators, rather than excluding studies based on specific features of the analog (e.g., mission length, autonomy). We chose this approach so that we could make comparisons across different conditions (e.g., in isolated and confined setting, non-isolated confined settings; how phenomena change over time), as opposed to designating arbitrary cutoffs related to fidelity. It is important to note, however, that our decision criteria led to the inclusion of some missions in which teams lived and worked in an isolated and confined setting for shorter-durations (e.g., 6 and 10 days). We retained these in order to be able observe any potential changes over time, but note that they have lower fidelity in regards to duration.

Search Strategy

We used a comprehensive search strategy to obtain quantitative research on teams in LDSEM-analog environments. Our efforts included: (1) searches of 13 databases that ranged from general databases such as Google Scholar and EBSCOhost, specialized databases such as the Military and Government Collection and space agency databases and technical report repositories (e.g., NASA, ESA, JAXA); (2) searches of specific journals such as Acta Astronautica, Aerospace Medicine and Human Performance, Human Factors; (3) contacting 29 researchers that we identified through the NASA taskbook, our project contact at NASA, or because they frequently publish in the area (e.g., Vinokhodova, Leon); (4) posts to listservs (e.g., Science of Team Science, INGRoup, relevant Academy of Management area listservs); and (5) a review of reference lists of key articles, including those from which we were able to obtain an effect size (e.g., Gunderson and Ryman, 1967; Emurian and Brady, 1984), reviews of similar domains (e.g., Schmidt, 2015), and recent technical reports on team research funded by NASA (e.g., Bell et al., 2015b; Burke and Feitosa, 2015; DeChurch and Mesmer-Magnus, 2015; Gibson et al., 2015; Smith-Jentsch, 2015). The search process included research published until November 2016. Researchers were contacted in May 2015.

Data Sources, Studies Sections, and Data Extraction

In total, we identified approximately 309 sources (e.g., books, technical reports, dissertations, journal articles, and conference papers) for possible inclusion. To better understand the nature of the available data, we sorted the 309 sources into three categories: (1) sources that included quantitative data with a team-level sample size of 5 or greater, for which a team-level effect size between a predictor and criteria related to team functioning could be generated; (2) sources that included quantitative data on fewer than 5 teams or only data for one variable over time; and (3) sources that did not provide relevant data for our quantitative review. Sources in the third category were excluded from further review. The decision to exclude an article was agreed upon by at least two members of the research team. Seventy-two sources were retained for inclusion and coded for fidelity characteristics and other moderators, and the quantitative data on team dynamics. Of these, 11 different sources (e.g., journal articles, technical reports) provided enough information to calculate effect sizes representing the relationship between a predictor and a criterion related to team functioning, and 61 different sources reported quantitative data on team dynamics over time in LDSEM-analog environments but did not include enough data to calculate an effect size.

To extract data, two coding forms were created: one for coding effect sizes and one for coding data (e.g., means and standard deviations) related to team dynamics over time. When a source reported data on 5 or more teams and a predictor and team outcome relationships, we coded or calculated an effect size, either r or Spearman's r. For sources with a team sample size <5 we coded quantitative data such as means (or another team-level representation) and within-team standard deviation, when available, for team dynamics across time. We included data that were presented numerically as well as those presented in figures, except when the approximate value reported in the figure could not be reasonably estimated (e.g., due to ambiguities in labeling of the axis).

Coding forms were similar in that both captured characteristics of the source, the sample, fidelity characteristics, and information about the predictor and/or criteria. In addition, a codebook with definitions of the variables and descriptions for the different categories for each variable was developed. We coded fidelity characteristics when they were described or could be reasonably assumed by two independent coders, given the descriptions provided in the sources. We used the Internet to locate information about specific simulations or Antarctic stations to complete missing fidelity information, where possible.

We coded study design as: (a) descriptive, (b) correlational, (c) quasi-experimental, and (d) experimental. We coded the degree of similarity between the sources' samples and the anticipated characteristics of LDSEM crews in terms of demographic differences (e.g., gender, national background). We coded the fidelity of the team to the characteristics expected for LDSEM crews. Studies were coded as occurring in dangerous environments when the setting had features that required individuals to use special equipment (e.g., winter-overs in Antarctic) or posed an imminent threat (e.g., polar bear threat). Studies were coded as isolated when team members were limited in physical interaction with outside parties for a substantial period of time during the study, and confined when they primarily operated in a highly restricted space. For example, winter-overs in small Antarctic stations or space simulations were coded as an isolated and confined environment. Autonomy was coded as high, moderate, low, or not reported. Many studies did not describe the level of autonomy in detail and were coded as "not reported." Mission length was coded as the total of number of days in the team's life span. Ongoing teams such as firehouses (e.g., Kniffin et al., 2015) were coded to the max of the distribution (e.g., 730 days). We also coded crew size, workload amount and variability, how the crew communicated with those

outside of the focal crew (e.g., mission control) and whether there was a time delay in the communication.

Coder Training and Agreement

The second and third authors served as coders for this study. The primary author trained the coders on the coding scheme described in the previous section. Coders first received a coding sheet and a codebook that provided descriptive information about each category of variables. All three authors then used the codebook and coding sheet to independently code three articles. The three authors met to discuss the coding, observe areas of agreement and disagreement, and make modifications to the coding sheet and codebook. Next, all three authors recoded the initial set of articles to help establish a frame of reference that incorporated the modifications made to the coding documents. Disagreements about the coding were resolved during a follow-up meeting using a consensus approach. After the second round of coding, a common set of 5 articles was coded to determine the efficacy of the coding process and to establish decision rules. When there was little disagreement (i.e., <3 disagreements across the variables coded in the studies), two coders coded the remaining articles. A randomly sampled common set of coded articles indicated that initial agreement, prior to the consensus meeting between coders, was relatively high (mean agreement of 87% on the variables that were coded). Discrepancies between the two coders were discussed and agreement was reached using a consensus approach. When consensus could not be reached with certainty between the two coders, the coders met with the primary author to discuss how the characteristic in question should be coded. After the coding was completed, we inspected the data sets to better understand the nature of the data, to determine the appropriateness of meta-analysis for summarizing the data, and to determine the best way to summarize the available evidence.

Analytical Strategy

Although we were able to locate a relatively large amount of data for our review, the small sample sizes in most studies (e.g., <5 teams) and the variety of relationships examined in the effect size studies, suggested the majority of the data did not lend themselves to traditional meta-analytic techniques. Thus, we used the following approaches. First, when the team factor and team outcome relationship could be represented using an effect size, we calculated a weighted average of the effect size from the local (analog) population and the relevant meta-analytic

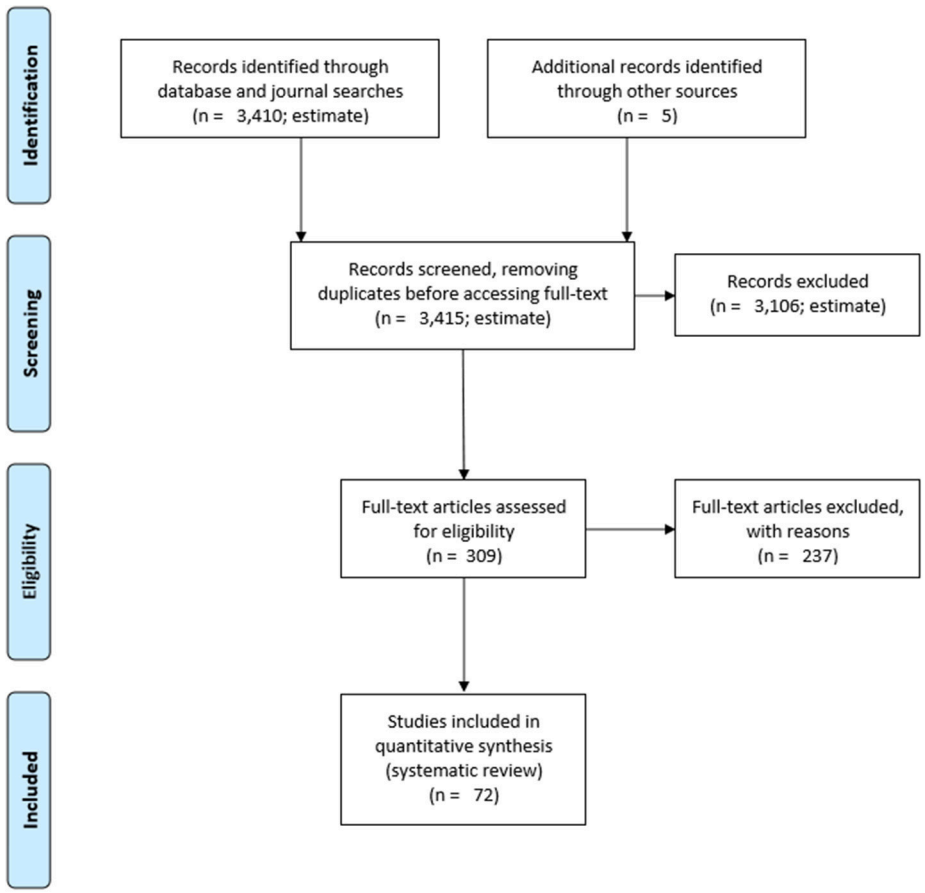

FIGURE 1 | PRISMA 2009 Flow diagram. Moher et al. (2009).

estimate from the traditional teams literature as a minimum-variance estimate. We used this approach as a means of balancing the precision that meta-analysis can provide in estimating a relationship across multiple settings with the high uncertainty (especially due to small sample sizes, etc.) but localness that a specific effect size generated in an LDSEM-analog environment can provide. We also calculated the average inaccuracy of the estimates and used these to create 95% credible intervals to quantify the uncertainty of the estimates.

We used equations 1, 2, 3, and A12 from Newman et al. (2007) in forming our weighted averages. We used estimates from meta-analyses in the extant literature (e.g., Beal et al., 2003; LePine et al., 2008; Bell et al., 2011) to inform the prior probability distribution. We only generated an estimated distribution of the true population local validity when there was a relevant meta-analytic effect reported in the extant literature that could inform our prior distribution. This limited the number of relationships we estimated and narrowed the effects to team performance as the outcome. Further, even with performance as the outcome, there were a number of relationships for which we could not locate relevant meta-analyses; the relationships between leader-member exchange—the idea that leaders have relationships with their followers that vary in quality (Graen and Uhl-Bien, 1995)—and team performance, and between personality characteristics (e.g., conscientiousness) of the leader and team performance are examples. We also did not locate relevant meta-analyses for many of the personality and needs variables examined by Gunderson and Ryman (1967), such as wanted affection and nurturance personality. Finally, there were two estimates from military teams [e.g., shared mental models from Lim and Klein (2006) and collectivism from Ko (2005)] that were already included in meta-analyses that would have been used in the calculation of the weighted averages [(DeChurch and Mesmer-Magnus, 2010); and Bell (2007) respectively]; we did not estimate local validity of these two estimates. We corrected the observed correlations in a given analog study for unreliability of the predictor and criterion in order to match the corrections used in meta-analyses that were used to inform our prior distribution. Although we would have preferred not to correct the local validity estimates for unreliability because of the small sample sizes on which they were based, the majority of the variances used to inform the prior distributions were corrected for unreliability. Newman et al. (2007) indicate the importance of ensuring that the prior and local effects have the same corrections. When reliability was not reported, we used the closest estimation of reliability from the most similar research in our data set. When the correction resulted in an estimate >1, we did not compute a weighted average. This is because the weighted averages approach relied on the z transformation, which for values over 1 is undefined. Values exceeded 1 for correlations from Gunderson and Nelson (1963) and Gunderson and Ryman (1967), which were based on the same source data (e.g., self-report cooperation and performance) and exceeded 0.90 prior to correction.

Second, when the number of teams included in the study was too few to generate an effect size, and when data across studies were comparable, we descriptively summarized the data on team dynamics over time via a series of figures. We plotted team dynamics over time when data were comparable (e.g., similar scales, similar response formats), and reported for at least three different teams across at least two different data sources (e.g., articles, conference presentations). We plotted team dynamics over time in terms of mission days and over relative time. Relative time was calculated as the mission day divided by the total mission length. Relative mission time was examined given that some effects for factors such as team cohesion and conflict, are thought to different because of the point of the team in the lifespan (e.g., third quarter phenomenon) rather than the mission day itself.

RESULTS

Flow Diagram of the Studies Retrieved for the Review

Figure 1 depicts the flow diagram of the studies retrieved for review.

Study Selection and Characteristics

Eleven sources (e.g., journal articles, technical reports) provided enough data (team $n \geq 5$) to generate 253 team-level effect sizes that represent a team factor (e.g., team cohesion) and team outcome (e.g., team performance) relationship. We refer to this as our effect size data set. Sixty-one sources included data on team functioning from fewer than 5 teams; from these sources we were able to glean 1,150 data instances (i.e., data collected on one or more variable at a particular time point) to benchmark team dynamics in LDSEM-analog environments over time. We refer to this as our benchmarking data set. We provide a summary of the fidelity characteristics of our samples in **Supplementary Table 1**.

Synthesized Findings

Our first research question asked: what factors related to team dynamics has quantitative research examined in analog environments? In the effect size data set, the majority of effects (i.e., 102 effects across 9 studies) represented the relationship between a predictor and team performance. Forty-seven effects across 6 studies represented the relationship between a predictor and cohesion or compatibility, and the remaining effects represented a variety of outcomes that differed across studies. The specific predictor and criterion relationship examined varied across studies. Predictors included inputs, emergent states, and team process variables (see Marks et al., 2001), personality (e.g., Gunderson and Ryman, 1967), values, leader-member exchange, and team-member exchange (e.g., Ko, 2005), compatibility and cohesion (e.g., Gunderson and Nelson, 1963), mental models (e.g., Lim and Klein, 2006), conflict (e.g., Seymour, 1970), leadership (e.g., Lim and Ployhart, 2004), ability, experience, mood, exploratory search, and planning (e.g., Knight, 2015). Outcome variables included performance effects (e.g., accomplishment, accuracy, time to completion, efficiency, and quality), emergent states, team processes, and other team dynamics such as cohesion, team mood, egalitarian atmosphere, viability, team-member exchange, leader-member exchange, exploratory search, and cooperation. The data were

largely dependent (i.e., the 253 effects came from only 11 different sources), and a variety of predictor and outcome relationships were examined. Only the relationship between measures of cohesion (e.g., compatibility, spending time together) and team performance was examined in more than 3 independent samples ($k = 6$).

In the benchmarking data set, team factors included emergent states, team processes, outcomes, and additional team dynamics markers. For example, emergent states included team cohesion (e.g., Allison et al., 1991; Vinokhodova et al., 2012), and team processes included conflict and interpersonal relations (e.g., Leon et al., 2004; Šolcová et al., 2014). Outcomes included performance (e.g., Emurian and Brady, 1984) and more subjective outcomes such as satisfaction (e.g., Bhargava et al., 2000; Leon et al., 2004). Finally, other dynamics markers, such as team mood (e.g., Kahn and Leon, 2000; Steel, 2001; Bishop et al., 2010), were commonly reported in analog studies. A full list of all team factors examined for the effect size and benchmarking data sets is available in **Supplementary Table 2**.

Our second research question asked what quantitative research reveals about team functioning in LDSEM-analog environments. We discuss the results of the weighted averages approach, and descriptive figures benchmarking team dynamics next.

Weighted Averages Approach

We used our weighted averages approach to provide the best possible estimate of the magnitude and direction of the relationships between team factors and team outcomes in the analog environments, given the available data. **Figure 2** summarizes the weighted averages results, the credible intervals around the estimates, and displays the forest plot. Specific information about the local validity information obtained from LDSEM-analog studies, the meta-analytic effects that we used in the calculation of the weighted averages, and the estimated posterior distributions are provided in **Supplementary Table 3**. Local validity estimates include team performance with cohesion, age homogeneity, education homogeneity, team learning, planning, team task-relevant experience, cooperation, and transformational leadership.

First, we discuss the team cohesion and team performance relationships. Studies 1, 3, and 5 (as noted in **Figure 2**) were conducted on teams in isolated and confined environments (ICE); each of these studies measured team cohesion and team performance with different operationalizations. Estimates 7 and 13 reflect the team cohesion and team performance relationships for teams that are sometimes used as LDSEM-analogs but which are not isolated or confined for extended periods (non-ICE).

That data suggest that with 95% certainty, we cannot speak to the direction or size of the team cohesion and team performance relationship in ICE. For example, estimate 1 reflects the estimated results for the team cohesion and team performance relationship for data collected in Antarctic stations where team cohesion was operationalized as self-rated compatibility of station members, and team performance was operationalized as self-rated station achievement. The mean estimated validity is −0.10, and with 95% certainty, we estimate that the true population validity falls between −0.46 and 0.28. This is rather imprecise, as the prediction interval includes large, moderate, and small negative effects, no effect, and small and moderate positive effects. Conversely, with 95% certainty, we can describe the team cohesion and team performance relationship in the firehouses studied as positive and small to moderate (i.e., estimate 7), and in the special operations military teams studied, as positive and moderate to large (estimate 13).

Data for a few additional relationships other than team cohesion and team performance were also available. The age homogeneity and team performance (**Figure 2**, Estimate 2) and the educational level homogeneity and team performance relationships (**Figure 2**, Estimate 4) in an ICE (e.g., Antarctic station winter-over) were estimated with a large degree of imprecision; the prediction interval included positive, negative and no effect. Conversely, with 95% certainty, the true population effect between cooperation and team performance is estimated to be positive and large (**Figure 2**, Estimates 11, 12) for firehouses and special operations teams. Finally, with 95% certainty, the true population effect between transformational leadership and team performance for special operations teams, and the true population effect between team task-relevant expertise and team performance for military training teams are positive and exceed a small effect (**Figure 2**, Estimates 9, 10).

Taken together, there is a high degree of imprecision associated with estimates of the true predictor and team performance relationships from studies with teams in ICEs. Specifically, unlike most of the estimated relationships from teams in non-ICE, given the current data, if we retain a 95% level of certainty, we have limited to no understanding of the size or direction of the relationship of team cohesion and team performance observed in multiple ICE, age homogeneity and team performance in an ICE, and educational homogeneity and team performance in an ICE.

Benchmarking Team Functioning Over Time

Next, we benchmarked team dynamics over time in studies with sample sizes too small to generate a between-team effect size, but for which data were comparable (e.g., similar measures, similar response formats) on at least three different teams from at least two different data sources (e.g., articles, conference presentations). With this requirement, we were able to generate figures on cohesion, efficiency, team conflict, communication with MC, and team mood.

Team Cohesion

While we identified several studies with cohesion data reported over time from 5 or fewer teams, these data were collected using a variety of cohesion operationalizations making it difficult to directly aggregate and make for meaningful comparisons across settings. We were able to benchmark a subset of this data by identifying 3 sources with data from 11 teams spending time together (e.g., social activities, eating meals). We classified these activities as evidence as social cohesion. **Figure 3A** illustrates team cohesion across mission days. **Figure 3B** plots team

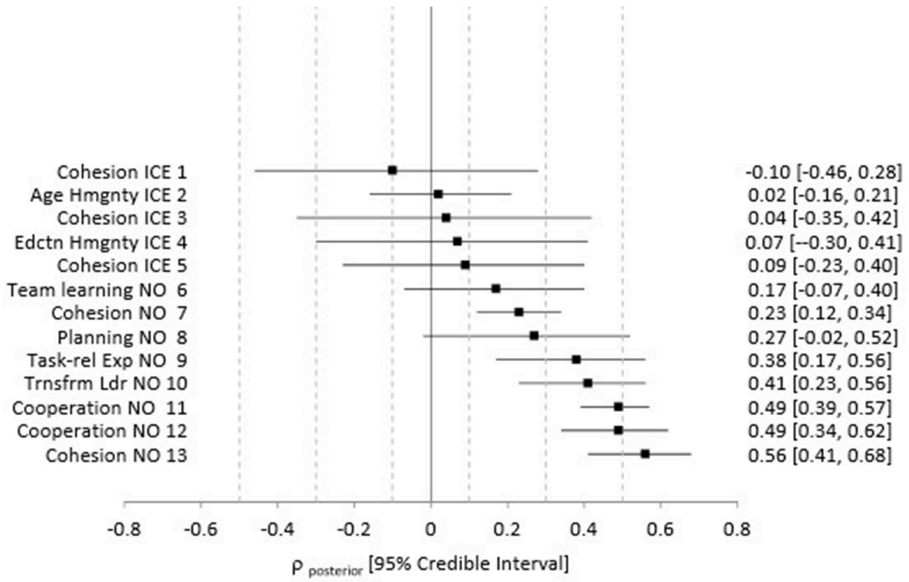

FIGURE 2 | Estimated distributions for the predictor and team performance relationship in analog environments. ICE = analog team was in an ICE environment (e.g., Winter-overs in Antartica) NO = team was living and working together but not in an ICE. Hmgnt = Homogenity. Task-rel Exp = task-relevant experience. Trnsfrm Ldr = Transformational Leadership. The square represents the weighted average local validity population estimate ($\rho_{posterior}$) and the bar represents the 95% credible interval. Specific estimates are provided in the right column as per $\rho_{posterior}$ [95% credible interval]. The credible interval can be interpreted as follows: there is a 95% chance that the true population predictor and team performance relationship (ρ) is between the first number and the second number. Number in the left column indicates the analog data source. 1. Gunderson and Nelson (1963), Outcome = self-report team achievement, Antarctic stations; 2 and 4 from Gunderson and Ryman (1967), Outcome = team accomplishment, mixed sources, Antarctic stations; 3. Emurian and Brady (1984), outcome = performance on lab task; 10-day isolated lad experiment; 5. Nelson (1964), outcome = supervisor ratings of individual performance aggregated within station, Antarctic station; 6, 8, and 9 Knight (2015), outcome = team's time and number of obstacles completed in a final challenge task, military training; 7 and 11 Kniffin et al. (2015), outcome = supervisor rating of performance, firehouses; 10, 12, 13. Ko (2005), outcomes = team performance, mixed sources, special operations teams.

cohesion over relative time (i.e., the mission day divided by the total mission length).

The data reported suggests some fluctuations in cohesion over time. However, two patterns are present. First, it appears team members spend more time together during shorter missions. The Concordia, Tara Drift, and Mars 500 missions lasted for 268, 507, and 520 days, respectively. In comparison to shorter missions [i.e., Emurian et al., 1978, 1985], which lasted for 6, 10 and 12 days, team members in longer simulations generally spent less social time together. There was one exception to this: time together increased sharply at certain points for a team at Concordia station. These instances could have been the result of significant events at the station during those periods (Tafforin et al., 2015). It is important to note that we included shorter-duration missions to avoid an arbitrary cut off and to observe changes over time. The stark contrast between shorter-duration and longer-duration missions on time spent together suggest limited usefulness of shorter-duration studies in understanding team cohesion for LDSEM.

Team Performance

Homeostat was used to collect data on team performance across a number of space simulations (e.g., HUBES, SFINCSS). Homeostat is a computer task in which, under time pressure, a team solves tasks that require the coordinated action of the whole team (Eskov, 2011). A number of metrics can be assessed using Homeostat, including an efficiency metric (Csh) and leadership tactics. **Figure 4A** is a plot of team efficiency across mission days. **Figure 4B** is a plot of team efficiency over relative time.

The data suggest that three teams (i.e., a team in EXEMSI and two of the teams in SFINCSS simulations) were relatively consistent in terms of efficiency over time. The HUBES team decreased steadily in efficiency over time. One of the SFINCSS teams (Group 3) had a sharp decline in efficiency early in the simulation and then steadily increased during the remainder of the simulation.

Descriptive information on team dynamics in the HUBES and SFINCSS simulations implicate ineffective role structure and conflict as possible triggers of the performance decrements of HUBES and SFINCSS–Group 3. Specifically, in addition to measures of efficiency, the Homeostat also collects information on leadership tactics by individual team members as a means of understanding the leadership structure used while completing the task. For SFINCSS group 3, Vinokhodova et al. (2002) indicated that the data did not suggest that a role distribution structure had sufficiently developed. Further, the SFINCSS simulation also included a New Year's Eve incident between a member of another group and a woman in Group 3 of the simulation, which led to tension between crews (Sandal, 2004). The sharp decrease in effectiveness in

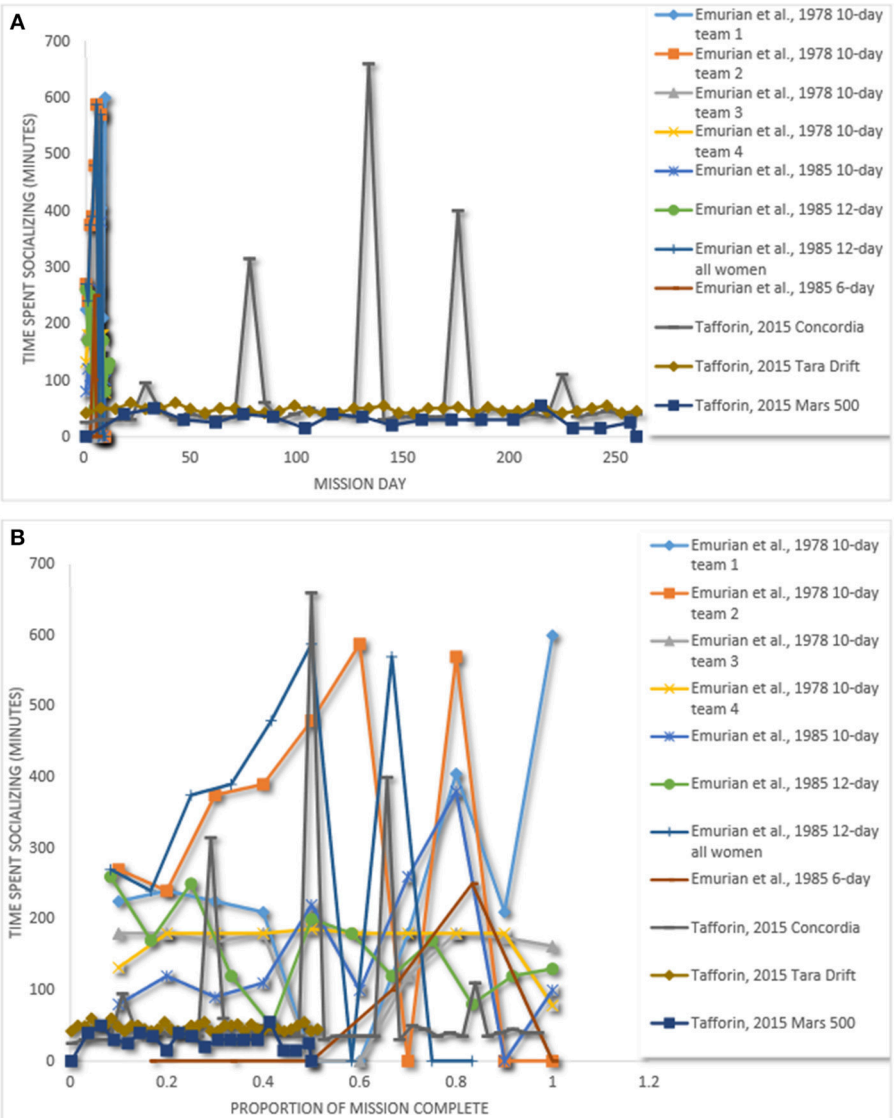

FIGURE 3 | (A) Team cohesion over time. **(B)** Team cohesion over relative time. Emurian et al. (1978), Emurian et al. (1985), Tafforin (2015).

the SFINCSS Group 3 depicted in **Figure 4A** also happened around this time. For HUBES, Sandal (2001) reports that there was evidence of an unstable crew structure; specifically, the commander's leadership was challenged during the first 8 to 10 weeks of the mission. Further, crew relations in the simulation were marked by interpersonal tension and alienation of one crew member during later parts of the experiment. Taken together, this may suggest ineffective role structure, conflict, and alienation as possible threats to team efficiency.

Team Conflict

A few sources ($k = 4$) reported conflict scores over time for 8 different teams using 2 types of conflict metrics (e.g., total number of conflicts reported, Likert scale). **Figures 5A,B** summarize data that were comparable across multiple teams from different analog environments for the total number of conflicts reported within crews. Data do not show a consistent trend across teams. Some teams are more variable than others in the number of conflict incidents per month, while others are more stable. Some teams report conflict early on, while others do not. By 40% of the mission completion (with this data the equivalent of at least 90 days) all teams had reported a least one instance of conflict. No team had more than six instances of conflict per month with a given target (i.e., the crew or MC).

Communication With Mission Control (MC)

Gushin et al. have examined crew communication with MC in several studies (e.g., Gushin et al., 1997, 2001; Gushin

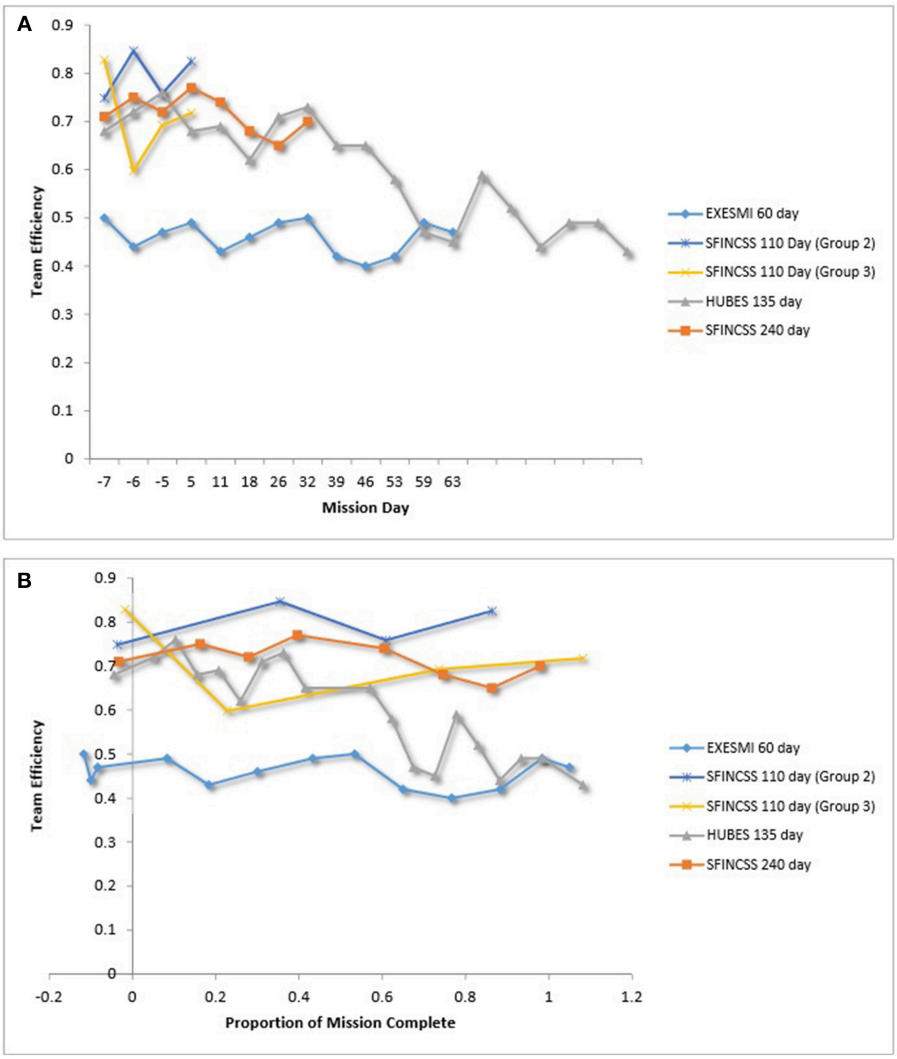

FIGURE 4 | (A) Team efficiency over time. **(B)** Team efficiency over relative time. Le Scanff et al. (1997), Vinokhodova et al. (2001), Eskov (2011).

and Yusupova, 2003) and have reported comparable data, which allowed us to plot the total duration of crew–MC audio-communication sessions (in seconds) over time (see **Figures 6A,B**), as well the average report length per week of the commander's end-of-day report to MC (see **Figures 7A,B**). For the SFINCSS, HUBES, and ECOPSY simulations, audio communication paralleled the standards of Mir in that 30 min were made available for audio communication every 90 min in the daily schedule but use of the time was not required. At the end of each day, the commander submitted a written report to MC on mission status and fulfillment of the daily schedule (Gushin et al., 1997, 2001). Data in Gushin and Yusupova (2003) was collected by researchers listening to crew-MC communication once a week (for ISS mission 1) and twice a week (for ISS mission 2).

As depicted in **Figures 6A,B**, patterns of average audio-communication length between the commander and MC were inconsistent across teams. It is interesting to note, that the HUBES crew that had decreasing efficiency over time (**Figure 4A**) also had shorter audio communication with MC over time (**Figures 6A,B**). As depicted in **Figures 7A,B**, average mission report length to MC per week decreased over the course of the mission in SFINCSS, EXEMSI, and ECOPSY. Gushin et al. (2012) describe this as the closing of a communication channel, or psychological closing. Psychological closing can include a decrease of the communication volume throughout isolation, decrease in the issues discussed, and preference for communication partners.

It should be noted that there is a wealth of specific details (e.g., negative statements, jokes) that can be gleaned and assessed via content analysis of within- and between-group communications. Our figures here only reflect report length and total time for audio communication, which were reported in the same format across multiple teams. We refer the interested reader to Gushin

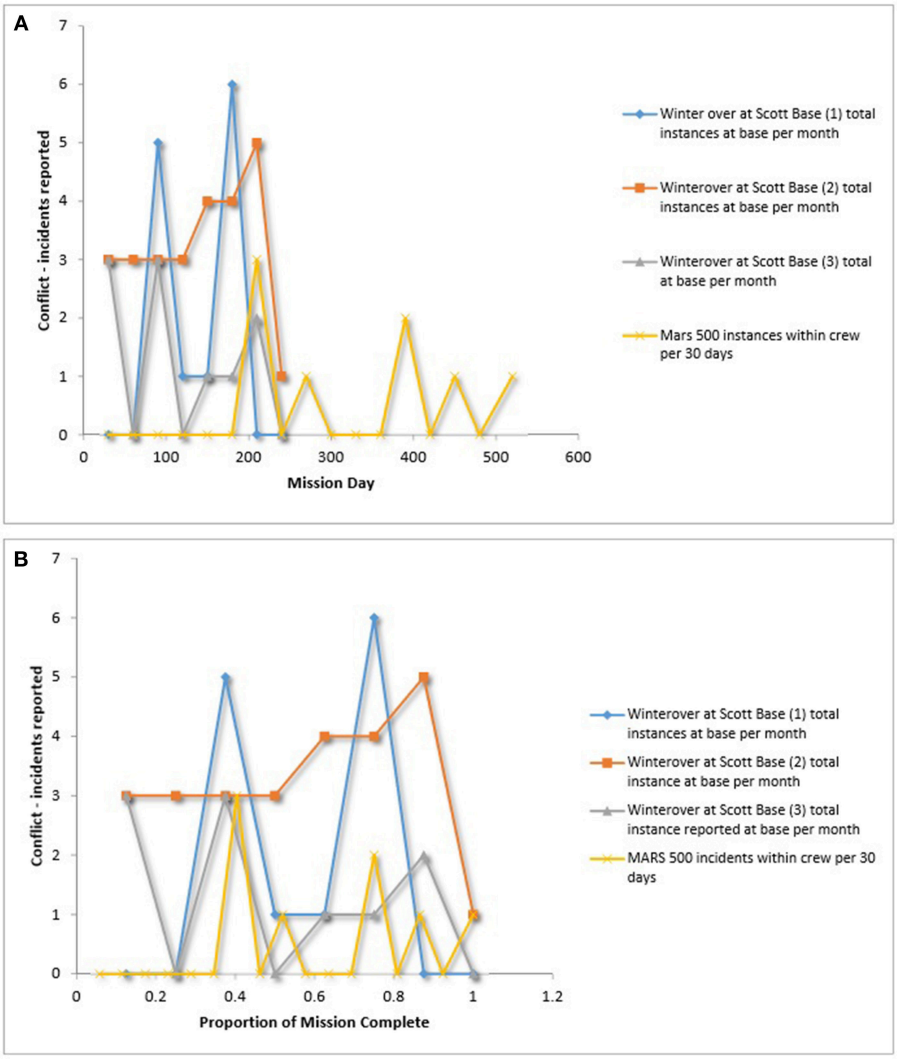

FIGURE 5 | (A) Team conflict over time. **(B)** Team conflict over relative time. Steel (2001), Basner et al. (2014).

et al. (2012) and Tafforin (2015) for more detail on the range of communication parameters that have been examined.

Team Mood

Multiple studies reported the affect of team members using Profile of Mood States (POMS; Shacham, 1983; Curran et al., 1995). POMS captures individuals' mood via self-report ratings on six dimensions using a 5-point Likert scale. The dimensions are tension-anxiety, depression-dejection, anger-hostility, fatigue-inertia, confusion-bewilderment, and vigor-activity. To arrive at an overall total mood disturbance score, the first five subscales listed are summed and then the vigor-activity subscale is subtracted. Team mood is captured with the average total mood disturbance across the team. **Figures 8A,B** show team mood over time and team mood over relative time, respectively. **Figure 8A** shows that the MARS 500 crew reported elevated total mood disturbance compared with teams in other LDSEM-analog environments, although it should be noted that the scaling reported for Scott Base was 0 to 4 instead of 1 to 5 as in the other simulations. Thus, the winter-over at Scott Base may have ratings more similar to Mars 500. Both studies that included teams in ICE for a year or more (e.g., Mars 500, an Antarctic winter-over) showed a spike in team total mood disturbance around the 1-year mark, and this was confirmed in the text of the studies reporting the data (e.g., Steel, 2001; Wang et al., 2014). **Figure 8B**, which shows total mood disturbance over time relative to the proportion of the mission complete, does not support a clear third-quarter phenomenon at the team level.

Team mood also has been operationalized in LDSEM-analog environments as the team mean of self-report ratings on the positive and negative mood components of the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988, see Leon et al., 2004, 2011, for examples). **Figures 9A,B,10A,B**, show the relationship between affect operationalized as the team

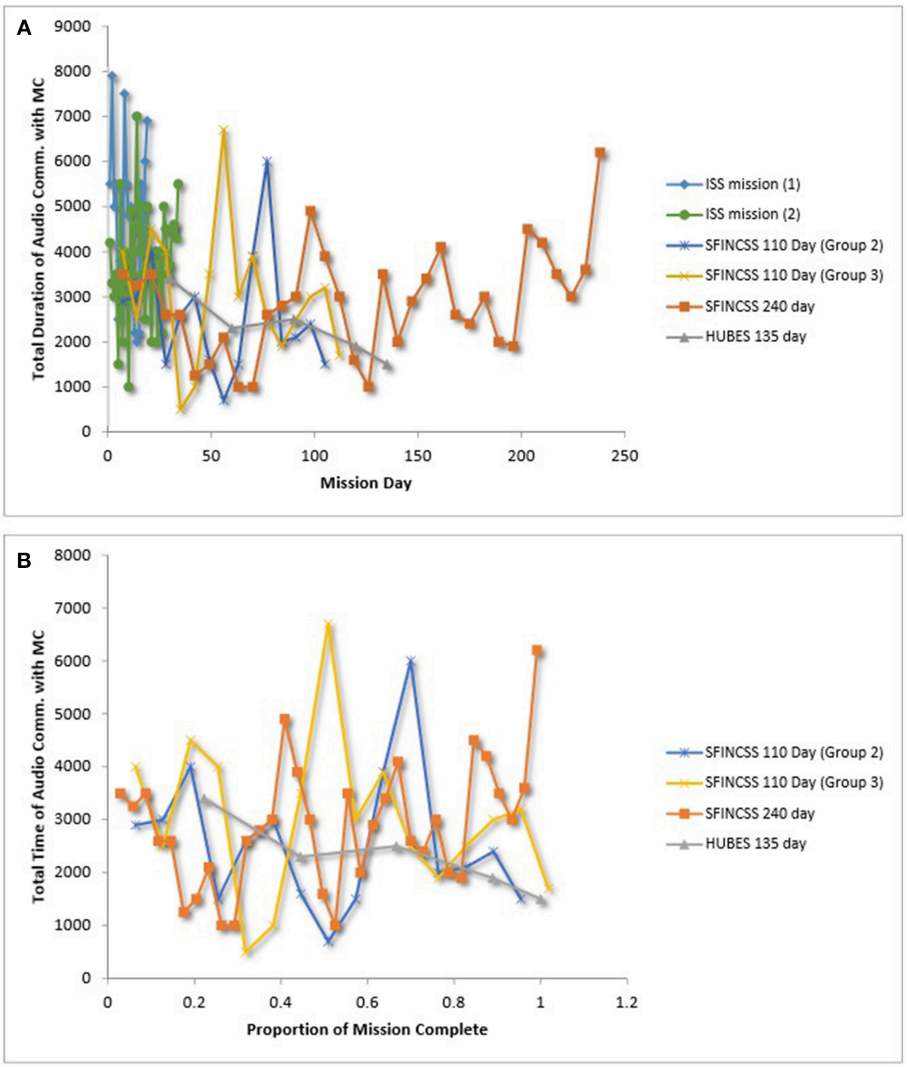

FIGURE 6 | (A) Team communication with mission control over time. **(B)** Team communication with mission control over relative time. Gushin et al. (1997), Gushin et al. (2001), Gushin and Yusupova (2003).

mean PANAS scores over time. **Figures 9A**, **10A** show team positive affect over time and relative time. **Figures 9B**, **10B** show team negative affect over time and relative time. For team negative affect over relative time, three of seven LDSEM-analog teams show an increased negative affect during the third quarter.

Risk of Bias

There are two key risks of bias in our systematic review. First, publication bias may be a problem, especially given the small sample sizes associated with analog research. More extreme findings are more likely to be published. Small sample sizes compound the issue because the extreme findings are less likely to replicate. Given this, we made a focused effort to obtain unpublished research. Second, there were two potential biases associated with our weighted analyses approach. Some of the effect sizes used in our weighted averages approaches were based on very small sample sizes, which may influence the normality of the local validity distribution. We based our weighted averages approach on Newman et al. (2007) local validity Bayesian estimation approach. However, the local validity Bayesian approach is only regarded as Bayesian when the distribution of the local estimate is normally distributed. Because it is not possible for us to test this assumption without access to raw data, we referred to our approach as taking a weighted average.

Further, due to the limited amount of data in different analog conditions, we were unable to estimate potential bias due to certain moderators such as whether the analog study was conducted in an ICE or non-ICE environment. However, Newman et al. (2007) indicates that the accuracy of their local validity Bayesian estimation approach holds true even in the

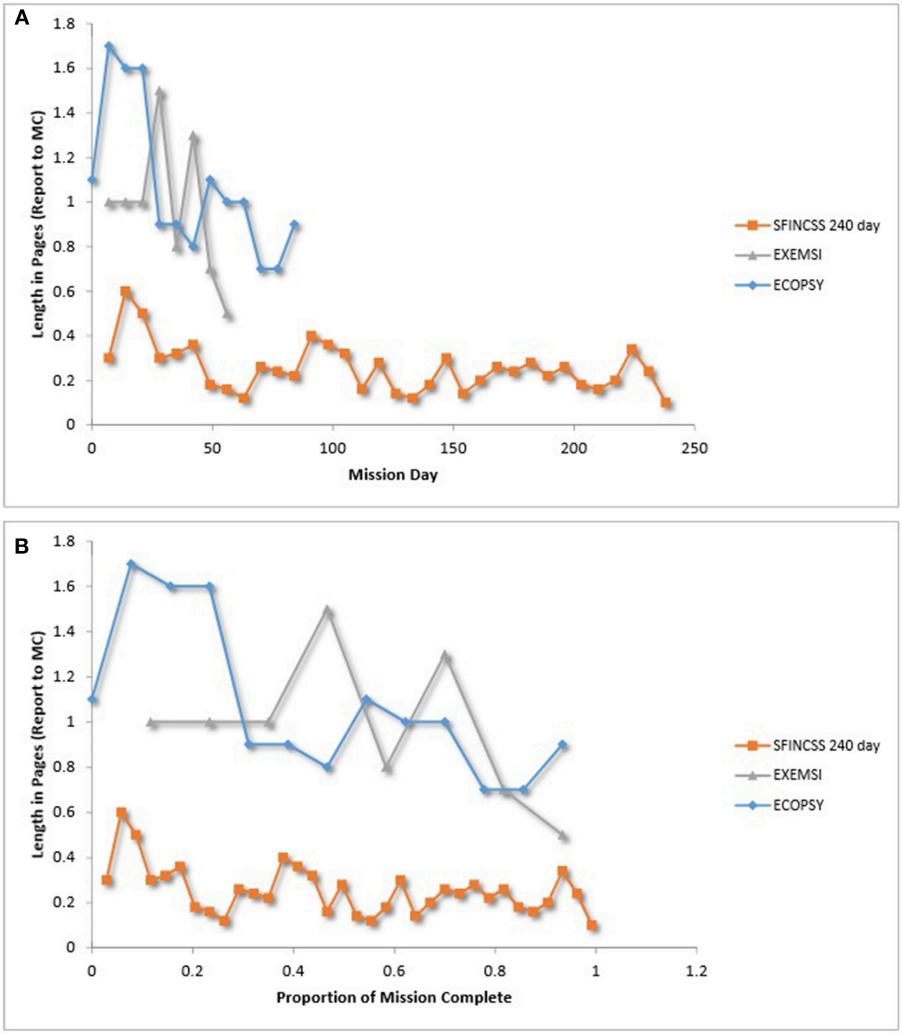

FIGURE 7 | (A) Commander report length over time. **(B)** Commander report length over relative time. Gushin et al. (1996b); Gushin et al. (1997), Gushin et al. (2001).

presence of true moderators (e.g., teams that perform in ICE environments, for example, where the ICE/non-ICE context moderates the observed predictor and outcome relationship). Even so, we acknowledge that because we cannot assess or model the bias that may be present due to combining a local effect size from an ICE environment with a meta-analytic effect from non-ICE environments, we are trading an unknown amount of bias to generate a minimum variance estimate. If raw data were available, it would be better to do a full Bayesian analysis that takes into account sampling variability at the local level, as well as any bias in using a meta-analytic estimate based on the broader team literature as the prior distribution. Given the limitations of available data, however, we believe our weighted averages approach provides the best estimate of the team predictor and outcome relationships in the specific LDSEM-analog environment. Further, given the limitations of the data from sources, which had fewer than 5 teams, we believe our descriptive figures best represent the data.

DISCUSSION

LDSEMs such as human missions to Mars are of increasing interest to NASA, space agencies, and private sector organizations. Conducting research in analog environments provides a means for understanding team dynamics for a potential LDSEM mission as well as other teams operating in similar ICE environments (e.g., oil drilling teams). Analog research on team dynamics has a long history dating back to at least the 1960's, thus it is important for researchers and agencies to learn from the past analog research to inform future analog research and prepare for future space exploration. The primary goal of this research was to summarize the existing quantitative evidence on team dynamics in LDSEM-analog environments.

Summary of Main Findings

Our study has three key takeaways. First, there is an extensive research base on teams in LDSEM-analog environments. We

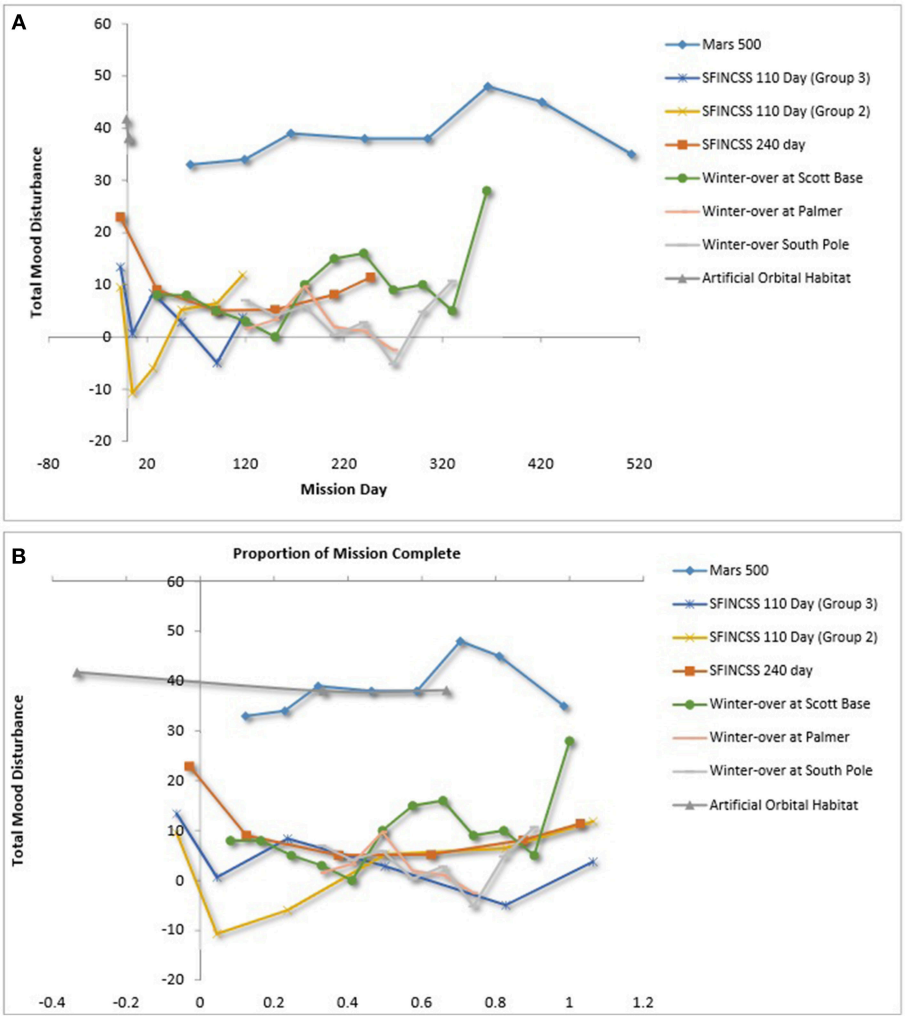

FIGURE 8 | (A) Team mood disturbance over relative time. **(B)** Team mood disturbance over relative time. Palinkas and Houseal (2000), Steel (2001), Vinokhodova et al. (2002), Sandal (2004), Wang et al. (2014).

were able to locate 72 different sources reporting quantitative research. Although there are quite a few studies that have examined teams in LDSEM-analog environments, the major of the studies had too small of a sample size to generate a between team effect size. Inconsistency in how the same construct was measured across studies further limited the ability to make comparisons across studies. Second, team dynamics are dependent on specific aspects of the context. For example, the team cohesion and team performance relationship was positive and strong for teams that lived and worked together but not in isolation and confinement (e.g., special forces teams), while little could be said about the relationship between team cohesion and team performance for teams in isolation and confined environments—an important aspect of LDSEM. Further, team dynamics varied greatly over time, underscoring the importance of temporal considerations and fidelity in analog environments. Third, we were able to document and provide interesting insights into how team dynamics unfold over time. These benchmarking figures provide insights into how team dynamics may unfold over time for LDSEM teams, benchmark typical and atypical team dynamics in the LDSEM, and identify potential threats to LDSEM team dynamics and performance. More detail on specific findings is provided next.

Results from our weighted averages approach suggest that the team cohesion and team performance relationship may be operating differently in isolated and confined environments (e.g., Antarctic stations, laboratory research with ICE characteristics) than in traditional work team environments. While we can confidently state that the relationship between team cohesion and team performance in non-ICE studies (e.g., firehouses, special operations teams) is positive and small to large, and similar to previous meta-analytic estimates (Beal et al., 2003), we cannot draw any conclusions about the direction and magnitude of the relationship between team cohesion and team performance in isolated and confined environments. Despite the limitations of such results, our findings highlight the importance

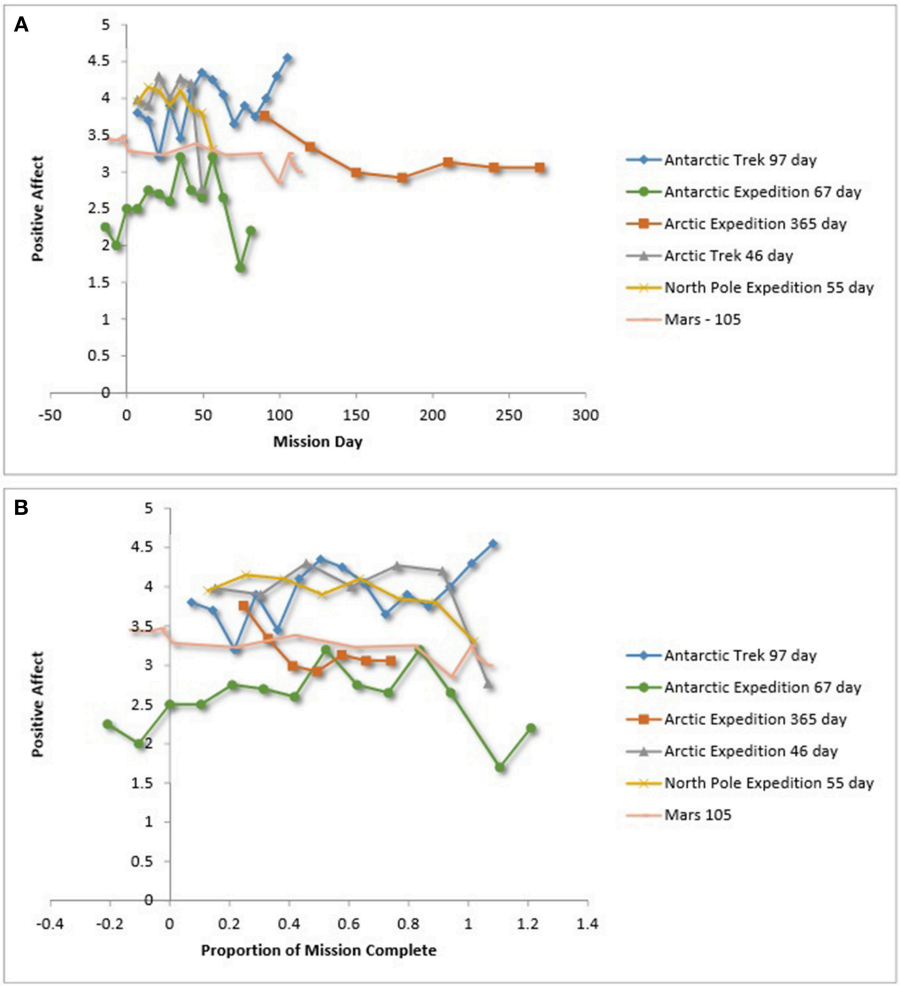

FIGURE 9 | (A) Team positive affect over time. **(B)** Team positive affect over relative time. Kahn and Leon (2000), Steel (2001), Atlis et al. (2004), Leon et al. (2004), Leon et al. (2011), Nicolas et al. (2013). Binsted (2015) provided unpublished data that may be later published. Because of the level of granularity of these figures, the data are not displayed.

of examining the effects of team cohesion on team performance in isolated and confined environments, and provide a cautionary note about generalizing findings from teams sometimes used as analogs that live and work together (non-ICE) to teams operating in isolated and confined environments. Similarly, limited information on other team factors (e.g., age homogeneity, education level homogeneity) and team performance inhibited us from estimating the true population validity of specific relationships in isolated and confined environments. Bringing further clarity to team cohesion for LDSEM, our figures that benchmarked team cohesion over time revealed that teams in shorter-duration missions spent more time with each other (an operationalization of team cohesion) than longer-duration teams. These results suggest limited usefulness of shorter-duration studies in understanding team cohesion for LDSEM.

As part of our quantitative review of team dynamics in LDSEM-analog environments, we also explored our benchmarking data set for trends in team dynamics over time (i.e., team efficiency, team conflict, team communication, team mood). Beginning with team efficiency, crews must coordinate and complete mission tasks in an efficient manner in order to achieve mission success (Salas et al., 2015a). Based on the available data, team efficiency in LDSEM-analog settings was relatively consistent across time; it was atypical for team efficiency to decrease over time. In uncommon situations in which team efficiency decreased during missions (see Vinokhodova et al., 2001; Eskov, 2011), researchers implicate ineffective role structure and conflict as possible triggers of the performance decrements (Sandal, 2001, 2004; Vinokhodova et al., 2001), suggesting that such factors are key threats to team efficiency. Further, the primary focus of team performance in LDSEM-analog environments has been efficiency. LDSEM will likely have team performance demands beyond team efficiency. For example, the team may need to be creative in order to use scare resources effectively, which suggests an expanded view of team performance in analog research is needed.

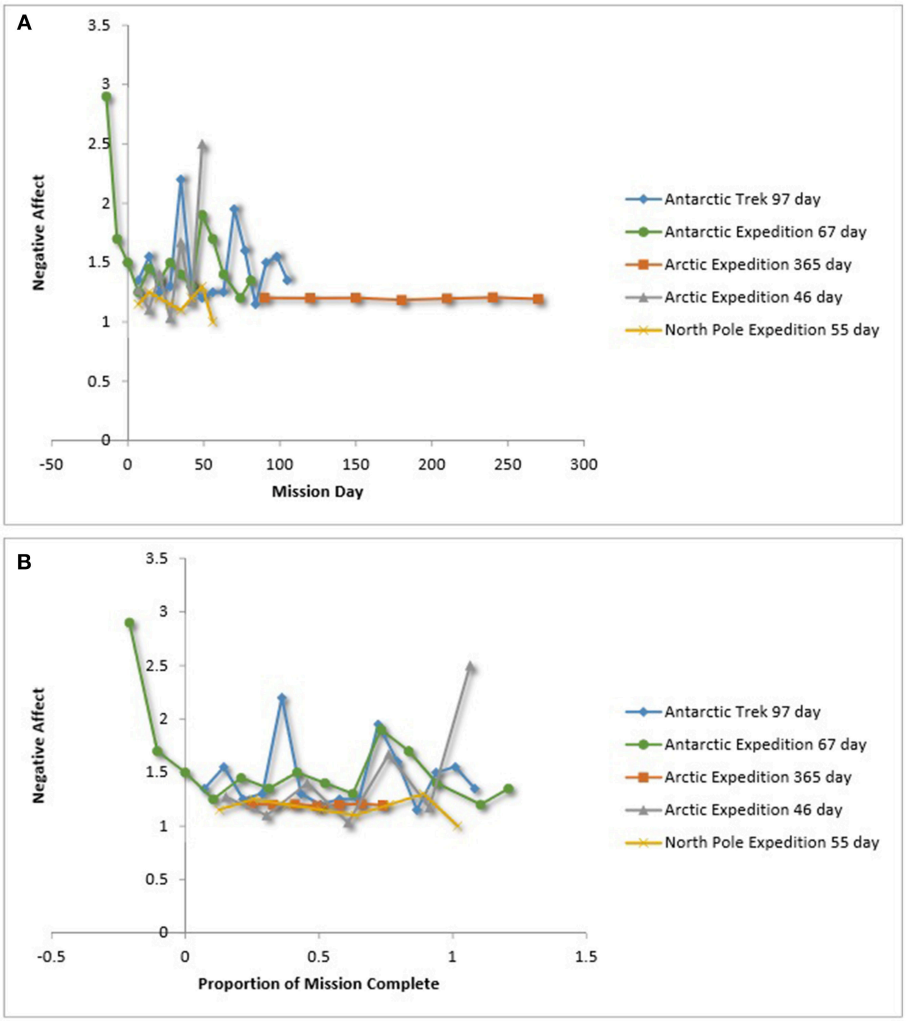

FIGURE 10 | (A) Team negative affect over time. **(B)** Team negative affect over time. Kahn and Leon (2000), Steel (2001), Atlis et al. (2004), Leon et al. (2004), Leon et al. (2011), Nicolas et al. (2013). Binsted (2015) provided unpublished data that may be later published. Because of the level of granularity of these figures, the data are not displayed.

In contrast to team efficiency, intrateam conflict data greatly varied over time in LDSEM-analog settings, such that data do not show a consistent trend across teams. However, all teams reported at least one conflict within the team or with mission control by 40% of the mission completion or 90 days. Given that all teams engage in at least some conflict in extended mission, and will likely have to resolve these conflict incident rather autonomously, it is important to better understand conflict and effective conflict management strategies in LDSEM-analog settings.

With regard to team communication in LDSEM-analog settings, communication between crews and mission control is thought to provide valuable information about the psychological health of the crew and the interpersonal climate within the crew. It is interesting to note that one of the crews that demonstrated decreased efficiency over time (i.e., HUBES crew) also had shorter audio communication with mission control over time. Moreover, commanders' written communication with mission control across several missions were in line with the psychological closing phenomenon in that the length of commanders' reports to mission control decreased over time (Gushin et al., 1997, 2012). Analysis of communication is likely to provide a fruitful means for understanding team dynamics.

As for team mood—operationalized as total mood disturbance or positively affectivity—there was inconsistent support for the third quarter phenomenon (Steel, 2001; Dion, 2004; Kanas, 2004; Wang et al., 2014); however, three of seven LDSEM-analog teams reported an increase in negative affect in the third quarter of their missions. The two teams in particular that were studied for an extended period (i.e., greater than a year) both reported an increase in total mood disturbance approximately 1 year into the mission. These findings are important to note in light of the fact that team mood plays an instrumental role in team dynamics (e.g., Kahn and Leon, 2000;

Steel, 2001). They suggests that it is prudent to better understand the effects of extended isolation on team mood for LDSEM.

Limitations

The results described should be considered in light of the limitations of this research. In our attempt to quantitatively summarize team dynamics in LDSEM-analog environments, we were limited by the empirical research available within the extant literature (e.g., small sample size, correlational). The validity coefficients from the LDSEM-analog studies used in our analyses are based on small sample sizes. When weighted average analyses are based on smaller sample sizes, there is more uncertainty regarding how well an observed effect in a given sample reflects the true population validity. To help address this issue, based on the available data, we calculated improved estimates of the true population team predictor and team criterion relationships in an LDSEM-analog environment by inversely weighting the variances of the validity coefficients from the LDSEM-analog studies and the meta-analytic estimates of the same team predictor-criterion relationships from the extant literature. Additionally, we calculated the average inaccuracy of the estimates to generate 95% credible intervals regarding the uncertainty of the estimates. This approach afforded us the precision associated with meta-analytic estimates while accounting for the localness associated with a specific effect size from an LDSEM-analog environment.

Moreover, the studies included in our quantitative review were almost exclusively descriptive or correlational in design (see the work by Emurian and colleagues for a notable exception). With this is mind, we cannot make causal statements about the relationships examined in our review, nor can we disentangle the effects of one team predictor from another. Consequently, we encourage researchers to employ experimental and quasi-experimental designs to identify key threats to team dynamics and performance in LDSEM-analog settings. We acknowledge the limitations of this data (e.g., small sample size, correlational). Importantly, however, this is the data that we currently have for understanding team dynamics in LDSEM-analog environments.

Future Directions for Research

Despite the limitations of this study, our findings provide insight into several potentially fruitful areas for research in regards to content, and research approaches related to extreme teams. In general, it seems that research should be prioritized when the nature of the relationship would be most likely to change as a function of the LDSEM context. One area in need of research is team affect. While most of the team mood data presented in this article were generated from aggregated individual-level data (for a notable exception see Šolcová et al., 2013), applying a team-level perspective and conducting investigations on team affect and team affect management could provide a more in-depth understanding of the role of affect in crew performance and crew member well-being. For example, team affect tends to become more homogenous through mechanisms such as emotional contagion (Totterdell et al., 1998), which could be magnified by specific characteristics of the LDSEM context (e.g., isolation and confinement). Also, crew composition factors (e.g., national diversity) could influence the emergence of team affect, norms for affective suppression or sharing, and the effectiveness of affect management approaches. Considering the unique features of ICE, further exploration of team affect, emotions, emotion regulation, and affect management in ICE across diverse crews and over time is warranted. Further, given that spikes in total mood disturbance were observed at the 1 year mark for studies in which teams both teams were in extended isolation, it is prudent to better understand the effects of extended isolation for LDSEM.

A second area in need of research is conflict management. LDSEMs provide a unique context in which conflict will need to be managed. Given the significant communication delays with those on Earth as teams travel into deep space, the teams will likely need to effectively manage conflict with at least some degree of autonomy. Our data suggest that at some point conflict is likely to occur between the crew, or between the crew and mission control. Indeed, LDSEMs are likely to be a situation where the crew will face competing or inconsistent priorities. For example, if more than one mission control is utilized for a particular mission, competing information may be given in regards to priorities (e.g., perform a function that requires the whole crew; require an individual adheres to a particular exercise schedule), which could create ambiguity in how crewmembers should allocate their time and resources. Crewmembers are likely to be diverse in a number of ways (e.g., professional, national background) which could also lead to misunderstandings or competing priorities (e.g., maintenance of the space vehicle, complete the science experiment) and potentially cause intra-team conflict (Bell et al., 2015a). The extent that crews effectively manage conflict will be of great importance given the expected durations of the space missions, the inability for crewmembers to leave, and the limited and delayed communication with mission control possibly compounding issues between the team and mission control. A better understanding of conflict and the conflict management cycle as teams live and work together in extended isolation and confinement is prudent.

In addition to their effects on team performance, conflict management and affect are important areas for future research because they will likely play a critical role in a team's resilience. While researchers are working diligently to mitigate all potential threats to team effectiveness, LDSEM crews will inevitably face challenges. A key aspect of correctly composing, training, and providing countermeasure support to crews will include consideration of the crew's resilience, defined as the capability to withstand and recover from stressors, pressure, or challenges (Alliger et al., 2015). Crewmembers' challenges may range from subtle changes that result in a less than ideal team state (e.g., the general decline in positive mood) to events that are more acute in nature (e.g., dispute related to the involvement of MC in conflict management). Regardless of the specific challenge, team resilience will likely be critical to the success of crews on LDSEMs. Future research should examine the effects of specific manipulations of stressors on crew resilience as well as the effects of subtle changes that occur during a team's life cycle on crew resilience.

We believe the decline in team efficiency during the HUBES simulation and the dip in team efficiency for one of the teams

during the SFINCSS simulation provide interesting directions for future research in LDSEM-analog settings. Several researchers (e.g., Sandal, 2001; Vinokhodova et al., 2001) suggested that the decline might have been due to intra-team conflict and instability in or a lack of established leadership structure. Given the autonomy of the crew at long-distances from Earth, and the likelihood that crews will include individuals from both high and low power distance countries, a better understanding of the conditions needed for teams to establish a workable leadership structure, and the process for ensuring crews high in gender and cultural diversity can effectively resolve status conflict is necessary (Bendersky and Hays, 2012).

Finally, a number of methodological recommendations can be made for future research. First, sample sizes in high fidelity environments to LDSEM, particularly ICE, are likely to be small. Where possible, data should be collected in such a way that they can be aggregated and compared across multiple studies. Ideally, enough data should be collected to generate an effect size. The normality of the data could be reported (or even better, the raw data) to allow future summaries to ensure the data are being appropriately modeled. When the sample size is too small to allow an effect size to be generated, data on key team constructs (e.g., team efficiency, communication, mood, and cohesion) should be collected with a common set of measures. Analog research on mood has consistently relied on the PANAS and POMS which made comparisons across studies possible. Researchers at the Russian Academy of Science's Institute of Biomedical Problems and some individual researchers (e.g., Leon) have consistently collected data using the same measures, which allowed us to report many of the figures in this article. In addition, NASA's Human Research Program is adopting a standardized set of measures to be collected across NASA analogs that includes measures such as team conflict, team cohesion, and team mood as well as other constructs. For key constructs (e.g., conflict, mood, cohesion), it is essential that analog research use the same measures so that the data better lend itself to the eventual culmination of studies.

Second, continued research is needed on small sample sizes. As an example, some meta-analytic approaches (e.g., Bayesian, Fisherian) calculate sample variance as $1/n$ and others as $1/(n-3)$ (Brannick, 2001), and the Schmidt and Hunter (2015) method uses n-1 in the denominator of their random effects meta-analysis of correlations. As Brannick (2001) states, "if the sample is so small that the choice of n or n-3 is critical, then the researcher has a more serious issue to confront, namely, how to collect more data" (p. 469). Unfortunately for analog researchers, more data is not likely to be a feasible option for many studies. While differences in how sampling variance is calculated and the ability to calculate sampling variance at small sample sizes may generally be less of an issue in traditional meta-analyses, it is an important issue for the eventual culmination of team LDSEM-analog research. Future research may wish to explore the accuracy of the different meta-analytic approaches for use with extremely small sample sizes (e.g., correlations based on 3 to 7 teams) through simulations as well as develop alternative versions of quantitative aggregation for small sample sizes. Continued advances in analytics that can best represent small sample size data is likely to be important for space research as well as extreme teams in general (Bell et al., 2018).

CONCLUSIONS

Future space exploration teams will be required to work effectively under complex and dangerous conditions to successfully accomplish their missions. With an understanding of team dynamics in LDSEM-analog environments, we can minimize potential threats to mission success while optimizing team performance. While an extensive research base exists that examines teams in LDSEM-analog environments, small sample sizes make traditional forms of meta-analysis inappropriate. Importantly, however, this is the data that we have for understanding team dynamics for future LDSEMs. Given this, we used a weighted averages approach to generate minimum variance estimates of team predictor and outcome relationships, and generated descriptive figures depicting team dynamics over time. Our systematic review of quantitative research on teams in LDSEM-analog settings summarizes what we know about team dynamics for future LDSEM, and provides guidance for future research.

AUTHOR CONTRIBUTIONS

STB developed the analytic approach, designed the search process and coding forms, conducted data analyses, and wrote aspects of the manuscript. SGB and TM conducted extensive literature searches, coded articles included in the review, generated tables and figures, and wrote aspects of the manuscript.

ACKNOWLEDGMENTS

This work was supported by contract NNJ15HK18P awarded to the first author from the National Aeronautics and Space Administration (NASA). There are some similarities between this article and our longer technical report submitted to the funding agency, NASA/TM-2016-219280. All opinions expressed herein are strictly those of the authors and not necessarily those of the sponsoring organization.

We thank Alan H. Feiveson for providing insight into potential risks of bias with our weighted averages approach. We thank Alla Vinokhodova and Gloria Leon for helping us obtain some limited circulation publications with valuable data, and Kim Binsted and Pete Roma for sharing unpublished data.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00811/full#supplementary-material

REFERENCES

Alliger, G. M., Cerasoli, C. P., Tannenbaum, S. I., and Vessey, W. B. (2015). Team resilience: how teams flourish under pressure. *Organ. Dyn.* 44, 176–184. doi: 10.1016/j.orgdyn.2015.05.003

**Allison, M. T., Duda, J. L., and Beuter, A. (1991). Group dynamics in the Himalayas. *Int. Rev. Soc. Sport* 26, 175–191. doi: 10.1177/101269029102600303

Altman, I., and Haythorn, W. W. (1965). Interpersonal exchange in isolation. *Sociometry* 28, 411–426. doi: 10.2307/2785992

**Arnaldi, K. M., Smith, G., and Thropp, J. E. (2015). Human behavior during spaceflight: evidence from an analog environment. *J. Aviat. Aerosp. Educ. Res.* 25, 27–71. doi: 10.15394/jaaer.2015.1676

**Atlis, M. M., Leon, G. R., Sandal, G. M., and Infante, M. G. (2004). Decision processes and interactions during a two-woman traverse of Antarctica. *Environ. Behav.* 36, 402–423. doi: 10.1177/0013916503262217

Bartone, P. T., Johnsen, B. H., Eid, J., Brun, W., and Laberg, J. C. (2002). Factors influencing small-unit cohesion in Norwegian Navy officer cadets. *Milit. Psychol.* 14, 1–22. doi: 10.1207/S15327876MP1401_01

**Basner, M., Dinges, D. F., Mollicone, D. J., Savelev, I., Ecker, A. J., Di Antonio, A., et al. (2014). Psychological and behavioral changes during confinement in a 520-day simulated interplanetary mission to Mars. *PLoS ONE* 9:e93298. doi: 10.1371/journal.pone.0093298

Beal, D. J., Cohen, R. R., Burke, M. J., and McLendon, C. L. (2003). Cohesion and performance in groups: a meta-analytic clarification of construct relations. *J. Appl. Psychol.* 88, 989–1004. doi: 10.1037/0021-9010.88.6.989

Bechtel, R. B., and Berning, A. (1991). "The third-quarter phenomenon: do people experience discomfort after stress has passed?," in *From Antarctica to Outer Space: Life in Isolation and Confinement*, eds A. A. Harrison, Y. A. Clearwater, and C. P. McKay (New York: Springer Verlag), 261–266. doi: 10.1007/978-1-4612-3012-0_24

Bell, S. T., Brown, S. G., Abben, D. R., and Outland, N. B. (2015a). Team composition issues for future space exploration: a review and directions for future research. *Aerosp. Med. Hum. Perform.* 86, 548–556. doi: 10.3357/AMHP.4195.2015

Bell, S. T. (2007). Deep-level composition variables as predictors of team performance: a meta-analysis. *J. Appl. Psychol.* 92, 595–615. doi: 10.1037/0021-9010.92.3.595

Bell, S. T., Brown, S. G., Outland, N. B., and Abben, D. R. (2015b). *Critical Team Composition Issues for Long-Distance and Long-Duration Space Exploration: A Literature Review, An Operational Assessment, and Recommendations for Practice and Research (NASA/TM-2015-218568)*. Houston, TX: Johnson Space Center, National Aeronautics and Space Administration.

Bell, S. T., Fisher, D., Brown, S., and Mann, K. (2018). An approach for conducting actionable research with extreme teams. *J. Manage.* 44, 2740–2765. doi: 10.1177/0149206316653805

Bell, S. T., Villado, A. J., Lukasik, M. A., Belau, L., and Briggs, A. L. (2011). Getting specific about demographic diversity variable and team performance relationships: A meta-analysis. *J. Manage.* 37, 709 –743. doi: 10.1177/0149206310365001

Bendersky, C., and Hays, N. A. (2012). Status conflict in groups. *Organ. Sci.* 23, 323–340. doi: 10.1287/orsc.1110.0734

**Bhargava, R., Mukerji, S., and Sachdeva, U. (2000). Psychological impact of the Antarctic winter on Indian expeditioners. *Environ. Behav.* 32, 111–127. doi: 10.1177/00139160021972450

**Binsted, K. (2015). *Third-Quarter Syndrome and Affect Synchronization on Long-Duration Space Exploration Analog Missions*. Unpublished report obtained from the author.

**Bishop, S. L., Kobrick, R., Battler, M., and Binsted, K. (2010). FMARS 2007: Stress and coping in an arctic Mars simulation. *Acta Astronaut.* 66, 1353–1367. doi: 10.1016/j.actaastro.2009.11.008

Brannick, M. T. (2001). Implications of empirical Bayes meta-analysis for test validation. *J. Appl. Psychol.* 86, 468–480. doi: 10.1037/0021-9010.86.3.468

Burke, C. S., and Feitosa, J. (2015). *Team Culture for Long-Duration Exploration Missions (NASA/TM-2015-218587)*. Houston, TX: Johnson Space Center, National Aeronautics and Space Administration.

Curran, S. L., Andrykowski, M. A., and Studts, J. L. (1995). short form of the profile of mood states (POMS-SF): psychometric information. *Psychol. Assess.* 7, 80–83. doi: 10.1037/1040-3590.7.1.80

**Décamps, G., and Rosnet, E. (2005). A longitudinal assessment of psychological adaptation during a winter-over in Antarctica. *Environ. Behav.* 37, 418–435. doi: 10.1177/0013916504272561

DeChurch, L. A., and Mesmer-Magnus, J. R. (2010). The cognitive underpinnings of effective teamwork: a meta-analysis. *J. Appl. Psychol.* 95, 32–53. doi: 10.1037/a0017328

DeChurch, L. A., and Mesmer-Magnus, J. R. (2015). *Maintaining Shared Mental Models Over Long-Duration Space Exploration Missions (NASA/TM-2015-218590)*. Houston, TX: Johnson Space Center, National Aeronautics and Space Administration.

Dion, K. L. (2004). Interpersonal and group processes in long-term spaceflight crews: Perspectives from social and organizational psychology. *Aviat. Space Environ. Med.* 75, C36–C43.

Doll, R. E., and Gunderson, E. E. (1971). The influence of group size on perceived compatibility and achievement in an extreme environment. *Pers. Psychol.* 24, 305–310. doi: 10.1111/j.1744-6570.1971.tb02478.x

Drake, B. G. (2009). *Human Exploration of Mars Design Reference Architecture (DRM) 5.0. (NASA/SP-2009-P-2566)*. Houston, TX: Johnson Space Center; National Aeronautics and Space Administration.

**Ehmann, B., Balazs, L., Fülöp, É., Hargitai, R., Kabai, P., Peley, B., et al. (2011). Narrative psychological content analysis as a tool for psychological status monitoring of crews in isolated, confined and extreme settings. *Acta Astronaut.* 68, 1560–1566. doi: 10.1016/j.actaastro.2010.01.021

*Emurian, H. H., and Brady, J. V. (1984). *Experimental analysis of Team Performance Effectiveness: Incentive and Training Factors. (Report Submitted to the Office of Naval Research Under Contract No. N00014-80-C-0467)*. Baltimore, MD: Johns Hopkins University School of Medicine.

**Emurian, H. H., Brady, J. V., Ray, R. L., Meyerhoff, J. L., and Mougey, E. H. (1984). Experimental analysis of team performance. *Naval Res. Rev.* 36, 3–19.

**Emurian, H. H., Emurian, C. S., and Brady, J. V. (1978). Effects of a pairing contingency on behavior in a three-person programmed environment. *J. Exp. Anal. Behav.* 29, 319–329. doi: 10.1901/jeab.1978.29-319

**Emurian, H. H., Emurian, C. S., and Brady, J. V. (1985). Positive and negative reinforcement effects on behavior in a three-person programmed environment. *J. Exp. Anal. Behav.* 44, 157–174. doi: 10.1901/jeab.1985.44-157

**Eskov, K. N. (2011). Evaluation of the efficiency of interpersonal interaction in a long-term isolation experiment. *Hum. Physiol.* 7, 879?882. doi: 10.1134/S0362119711070115

Gibson, C., McIntosh, T., Mulhearn, T., Connelly, S., Day, E. A., Yammarino, F., and Mumford, M. D. (2015). *Leadership/Followership for Long-Duration Exploration Missions (NASA/TM-2015-218567)*. Houston, TX: Johnson Space Center, National Aeronautics and Space Administration.

Glass, G. V. (1976). Primary, secondary, and meta-analysis of research. *Educ. Res.* 5, 3–8. doi: 10.3102/0013189X005010003

Graen, G. B., and Uhl-Bien, M. (1995). Relationship-based approach to leadership: development of leader-member exchange (LMX) theory of leadership over 25 years: applying a multi-level multi-domain perspective. *Leader. Q.* 6, 219–247. doi: 10.1016/1048-9843(95)90036-5

*Gunderson, E. K., and Nelson, P. D. (1963). *Measurement of Group Effectiveness in Natural Isolated Groups. (Report No. 63-16)*. San Diego, CA: Navy Medical Neuropsychiatric Research Unit.

*Gunderson, E. K., and Ryman, D. (1967). *Group Homogeneity, Compatibility and Accomplishment (No. NMNRU-67-16)*. San Diego, CA: Navy Medical Neuropsychiatric Research Unit.

*Gunia, B. C., Sipos, M. L., LoPresti, M., and Adler, A. B. (2015). Sleep leadership in high-risk occupations: an investigation of soldiers on peacekeeping and combat missions. *Military Psychol.* 27, 197–211. doi: 10.1037/mil0000078

**Gushin, V., Shved, D., Vinokhodova, A., Vasylieva, G., Nitchiporuk, I., Ehmann, B., and Balazs, L. (2012). Some psychophysiological and behavioral aspects of adaptation to simulated autonomous Mission to Mars. *Acta Astronaut.* 70, 52–57. doi: 10.1016/j.actaastro.2011.07.020

**Gushin, V., and Yusupova, A. (2003). "Preliminary results of isolated crew's communication psychological analysis," in *Abstracts for 54th Congress of International Astronautical Federation,* p. G-4. doi: 10.2514/6.IAC-03-G.4.04

**Gushin, V. I., Efimov, V. A., and Smirnova, T. M. (1996a). Work capability during isolation. *Adv. Space Biol. Med.* 5, 297–307. doi: 10.1016/S1569-2574(08)60066-0

**Gushin, V. I., Kolinitchenko, T. B., Efimov, V. A., and Davies, C. (1996b). Psychological evaluation and support during EXEMSI. *Adv. Space Biol. Med.* 5, 283–295. doi: 10.,1016/S1569-2574(08)60065-9

Gushin, V. I., Yusupova, A. K., Shved, D. M., Shueva, L. V., Vinokhodova, A. G., and Bubeev, Y. A. (2016). The evolution of methodological approaches to the psychological analysis of the crew communications with Mission Control Center. *REACH* 1, 74–83. doi: 10.1016/j.reach.2016.05.001

**Gushin, V. I., Zaprisa, J. M., Smirnova, T. M., and Popova. (2001). "Characteristics of Russian and non-Russian crew members' communication with external parties under prolonged isolation," in *Simulation of Extended Isolation: Advances and Problems,* ed V. M. Baranov (Moscow: FirmSLOVO), 85–100.

**Gushin, V. I., Zaprisa, N. S., Kolinitchenko, T. B., Efimov, V. A., Smirnova, T. M., Vinokhodova, A. G., and Kanas, N. (1997). Content analysis of the crew communication with external communicants under prolonged isolation. *Aviat. Space Environ. Med.* 68, 1093–1098.

**Hagen, D. H. (1961). *Crew Interaction During a Thirty-Day Simulated Spaceflight: Preliminary Study*. San Antonio, TX: School of Aerospace Medicine, Brooks AFB.

**Hatch, H. G., Algranti, J. S., Mallick, D. L., Ream, H. E., and Stinnett, G. W. (1964). *Crew Performance During Real-Time Lunar Mission Simulation (Tech Rep. No. NASA TN D-2447).* Washington, DC: NASA.

Hirschfeld, R. R., and Bernerth, J. B. (2008). Mental efficacy and physical efficacy at the team level: inputs and outcomes among newly formed action teams. *J. Appl. Psychol.* 93, 1429–1437. doi: 10.1037/a0012574

**Johnson, J. C., Boster, J. S., and Palinkas, L. A. (2003). Social roles and the evolution of networks in extreme and isolated environments. *J. Math. Soc.* 27, 89–121. doi: 10.1080/00222500305890

**Kahn, P. M., and Leon, G. R. (2000). Group climate and individual functioning in an all-womenAntarctic expedition team. *J. Hum. Perform. Extr. Environ.* 5, 35–43. doi: 10.7771/2327-2937.1005

Kanas, N. (1998). Psychosocial issues affecting crews during long-duration international space missions. *Acta astronaut.* 42, 339–361. doi: 10.1016/S0094-5765(98)00130-1

Kanas, N. (2004). Group interactions during space missions. *Aviat. Space Environ. Med.* 75, C3–C5.

Kanas, N., Sandal, G., Boyd, J. E., Gushin, V. I., Manzey, D., North, R., and Wang, J. (2009). Psychology and culture during long-duration space missions. *Acta Astronaut.* 64, 659–677. doi: 10.1016/j.actaastro.2008.12.005

**Kanas, N., Weiss, D. S., and Marmar, C. R. (1996). Crewmember interactions during a Mir space station simulation. *Aviat. Space. Environ. Med.* 67, 969–975.

**Kass, R., and Kass, J. (2001). "Team-work during long-term isolation: SFINCSS experiment group-006," in *Simulation of Extended Isolation: Advances and Problems* ed V. M. Baranov (Moscow: FirmSLOVO), 124–147.

Kelly, J. R., and Barsade, S. G. (2001). Mood and emotions in small groups and work teams. *Organ. Behav. Hum. Decision Proces.* 86, 99–130. doi: 10.1006/obhd.2001.2974

*Kniffin, K. M., Wansink, B., Devine, C. M., and Sobal, J. (2015). Eating together at the firehouse: how workplace commensality relates to the performance of firefighters. *Hum. Perform.* 28, 281–306. doi: 10.1080/08959285.2015.1021049

*Knight, A. P. (2015). Mood at the midpoint: affect and change in exploratory search over time in teams that face a deadline. *Organ. Sci.* 26, 99–118. doi: 10.1287/orsc.2013.0866

*Ko, J. (2005). *Impact of Leadership and Team Members' Individualism-Collectivism on Team Processes and Outcomes: A Leader-Member Exchange Perspective.* Unpublished doctoral dissertation. The University of Arizona, Tucson, Arizona.

**Kraft, N. O., Inoue, N., Mizuno, K., Ohshima, H., Murai, T., and Sekiguchi, C. (2002). Psychological changes and group dynamics during confinement in an isolated environment. *Aviat. Space Environ. Med.* 73, 85–90.

**Krins, P. W. (2009). *Beyond the "right stuff": The Role of Group Processes in Isolated Confined Extreme Environments.* Unpublished doctoral dissertation, The Australian National University, Australia.

Landon, L. B., Vessey, W. B., and Barrett, J. D. (2015). *Risk of Performance and Behavioral Health Decrements due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation Within a Team.* Technical Report. Houston, TX: Johnson Space Center, National Aeronautics and Space Administration.

**Le Scanff, C., Bachelard, C., Cazes, G., Rosnet, E., and Rivolier, J. (1997). Psychological study of a crew in long-term spaceflight simulation. *Int. J. Aviat. Psychol.* 7, 293–309. doi: 10.1207/s15327108ijap0704_3

**Leon, G. R., Atlis, M. M., Ones, D. S., and Magor, G. (2002). A 1-year, three-couple expedition as a crew analog for a Mars mission. *Environ. Behav.* 34, 672–700. doi: 10.1177/0013916502034005006

**Leon, G. R., Kanfer, R., Hoffman, R. G., and Dupre, L. (1994). Group processes and task effectiveness in a Soviet-American expedition team. *Environ. Behav.* 26, 149–165. doi: 10.1177/0013916594026002 01

Leon, G. R., List, N., and Magor, G. (2004). Personal experiences and team effectiveness during a commemorative trek in the High Arctic. *Environ. Behav.* 36, 386–401. doi: 10.1177/0013916503262215

Leon, G. R., Sandal, G. M., Fink, B. A., and Ciofani, P. (2011). Positive experiences and personal growth in a two-man North Pole expedition team. *Environ. Behav.* 43, 710–731. doi: 10.1177/0013916510375039

LePine, J. A., Piccolo, R. F., Jackson, C. L., Mathieu, J. E., and Saul, J. R. (2008). A meta-analysis of teamwork processes: tests of a multidimensional model and relationships with team effectiveness criteria. *Pers. Psychol.* 61, 273–307. doi: 10.1111/j.1744-6570.2008.00114.x

*Lim, B. C., and Klein, K. J. (2006). Team mental models and team performance: a field study of the effects of team mental model similarity and accuracy. *J. Organ. Behav.* 27, 403–418. doi: 10.1002/job.387

*Lim, B. C., and Ployhart, R. E. (2004). Transformational leadership: relations to the five-factor model and team performance in typical and maximum contexts. *J. Appl. Psychol.* 89, 610–621. doi: 10.1037/0021-9010.89.4.610

**Luger, T. J., Stadler, A., Gorur, P., Terlevic, R., Neuner, J., Simonsen, O., et al. (2014). Medical preparedness, incidents, and group dynamics during the analog MARS2013 mission. *Astrobiology* 14, 438–450. doi: 10.1089/ast.2013.1128

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manag. Rev.* 26, 356–376. doi: 10.2307/259182

**Mizuno, K., Inoue, N., Kraft, N., Ohshima, H., and Sekiguchi, C. (2001). "Relationship between aerobic work capacity and mood during SFINCSS-99 project," in *Simulation of Extended Isolation: Advances and Problems*, ed V. M. Baranov (Moscow: FirmSLOVO), 370–379.

Moher, D., Liberati, A., Tetzlaff, J., and Altman, D. G., The, P. R. I. S. M. A., Group (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* 6:e1000097. doi: 10.1371/journal.pmed.1000097

**Natani, K., Shurley, J. T., and Joern, A. T. (1973). "Interpersonal relationships, job satisfaction, and subjective feelings of competence: their influence upon adaptation to Antarctic isolation," in *Polar Human Biology,* eds O. G. Edholm and E. K. E. Gunderson (London: Heinemann), 384–400. doi: 10.1016/B978-0-433-08155-5.50041-8

*Nelson, P. D. (1964). *Compatibility Among Work Associates in Isolated Groups (No. NMNRU-64-13).* San Diego, CA: Navy Medical Neuropsychiatric Research Unit.

Newman, D. A., Jacobs, R. R., and Bartram, D. (2007). Choosing the best method for local validity estimation: relative accuracy of meta-analysis versus a local study versus Bayes-analysis. *J. Appl. Psychol.* 92, 1394–1413. doi: 10.1037/0021-9010.92.5.1394

**Nicolas, M., and Gushin, V. (2014). Stress and recovery responses during a 105-day ground-based space simulation. *Stress Health* 31, 403–410. doi: 10.1002/smi.2565

Nicolas, M., Sandal, G. M., Weiss, K., and Yusupova, A. (2013). Mars-105 study: time-courses and relationships between coping, defense mechanisms, emotions and depression. *J. Environ. Psychol.* 35, 52–58. doi: 10.1016/j.jenvp.2013.05.001

Oser, R. L., McCallum, G. A., Salas, E., and Morgan Jr, B. B. (1989). *Toward a Definition of Teamwork: An Analysis of Critical Team Behaviors (No. NTSC-89-004).* Orlando, FL: Naval Training Systems Center. doi: 10.21236/ADA212454

Palinkas, L. A., Gunderson, E. K., and Burr, R. G. (1989). *Psychophysiological Correlates of Human Adaptation in Antarctica (No. NHRC-89-5).* San Diego, CA: Naval Health Research Center.

**Palinkas, L. A., and Houseal, M. (2000). Stages of change in mood and behavior during a winterover in Antarctica. *Environ. Behav.* 32, 128–141. doi: 10.1177/00139160021972469

**Paul, F. J., Mandal, M. K., Ramachandran, K., and Panwar, M. R. (2010). Interpersonal behavior in an isolated and confined environment. *Environ. Behav.* 42, 707–717. doi: 10.1177/0013916509336889

**Paul, F. U., Mandal, M. K., and Ramachandran, K. (2013). Interpersonal feelings of personnel in polar environment. *Int. J. Res. Soc. Sci.* 3, 265–277. Available online at: http://www.indianjournals.com/ijor.aspx?target=ijor:ijrss&volume=3&issue=4&article=017.

**Roma, P. (2015). *[Team Cohesion in Analog Environments]*. Unpublished raw data.

**Rosnet, E., Cazes, G., and Vinokhodova, A. (1998). Study of the psychological adaptation of the crew during a 135 days space simulation. *Acta Astronaut.* 42, 265–272. doi: 10.1016/S0094-5765(98)00123-4

Salas, E., Grossman, R., Hughes, A. M., and Coultas, C. W. (2015a). Measuring team cohesion observations from the science. *Hum. Factors* 57, 365–374. doi: 10.1177/0018720815578267

Salas, E., Tannenbaum, S. I., Kozlowski, S. W., Miller, C. A., Mathieu, J. E., and Vessey, W. B. (2015b). Teams in space exploration: A new frontier for the science of team effectiveness. *Current Directions in Psychological Science*, 24, 200–207. doi: 10.1177/0963721414566448

**Sandal, G. M. (2001). Crew tension during a space station simulation. *Environ. Behavior*, 33, 134–150. doi: 10.1177/00139160121972918

**Sandal, G. M. (2004). Culture and crew tension during an International Space Station simulation; results from SFINCSS'99. *Aviat. Space Environ. Med.* 75, 44–51.

**Sandal, G. M., and Bye, H. H. (2015). Value diversity and crew relationships during a simulated spaceflight to Mars. *Acta Astronaut.* 114, 164–173. doi: 10.1016/j.actaastro.2015.05.004

**Sandal, G. M., Endresen, I. M., Vaernes, R., and Ursin, H. (1999). Personality and coping strategies during submarine missions. *Militar. Psychol.* 11, 381–404. doi: 10.1207/s15327876mp1104_3

**Sandal, G. M., Vaernes, R., and Ursin, H. (1995). Interpersonal relations during simulated space missions. *Aviat. Space Environ. Med.* 66, 617–624.

Schmidt, F. L., and Hunter, J. E. (2015). *Methods of Meta-Analysis: Correcting Error and Bias in Research Findings, 3rd Edn*. Thousand Oaks, CA: Sage. doi: 10.4135/9781483398105

Schmidt, L. L. (2015). *A Model of Psychosocial Factors for Long-Duration Spaceflight Exploration Missions (NASA/TM-2015-218582)*. Houston, TX: Johnson Space Center, National Aeronautics and Space Administration.

*Seymour, G. E. (1970). *The Concurrent Validity of Unobtrusive Measures of Conflict in Small Isolated Groups (Report No. 71-16)*. San Diego, CA: Navy Medical Neuropsychiatric Research Unit.

Shacham, S. (1983). A shortened version of the profile of mood states. *J. Personal. Assess.* 47, 305–306. doi: 10.1207/s15327752jpa4703_14

Shea, C., Slack, K. J., and Keeton, K. E., Palinkas, L. A., Leveton, L. B. (2011). *Antarctica Meta-Analysis: Psychosocial Factors Related to Long-Duration Isolation and Confinement (NASA/TM-2011-216148)*. Houston, TX: Johnson Space Center, National Aeronautics and Space Administration.

Smith-Jentsch, K. A. (2015). *On Shifting From Autonomous to Interdependent Work: What We Know and What We Need to Learn (NASA/TM-2015-218563)*. Houston, TX: Johnson Space Center, National Aeronautics and Space Administration.

**Šolcová, I., Gushin, V., Vinokhodova, A., and Lukavský, J. (2013). Emotional energy, work self-efficacy, and perceived similarity during the Mars 520 study. *Avi. Space Environ. Med.* 84, 1186–1190. doi: 10.3357/ASEM.3679.2013

**Šolcová, I. P., Lačev, A., and Šolcová, I. (2014). Study of individual and group affective processes in the crew of a simulated mission to Mars: positive affectivity as a valuable indicator of changes in the crew affectivity. *Acta Astronaut.*100, 57–67. doi: 10.1016/j.actaastro.2014.03.016

**Steel, G. D. (2001). Polar moods third-quarter phenomena in the Antarctic. *Environ. Behav.* 33, 126–133. doi: 10.1177/00139160121972909

**Steel, G. D., and Suedfeld, P. (1991). Temporal patterns of affect in an isolated group. *Environ. Behav.* 23, 749–765. doi: 10.1177/0013916591236006

Stuster, J. (2010). *Behavioral Issues Associated with Long-duration Space Expeditions: Review and Analysis of Astronaut Journals (Experiment 01-E104)*. Houston, TX: National Aeronautics and Space Administration.

**Tafforin, C. (2013). The Mars-500 crew in daily life activities: an ethological study. *Acta Astronaut.* 91, 69–76. doi: 10.1016/j.actaastro.2013.05.001

**Tafforin, C. (2015). Comparison of spatiotemporal adaptive indicators in isolated and confined teams during the Concordia stay, Tara Drift and Mars-500 experiment. *J. Hum. Perform. Extreme Environ.* 12:2. doi: 10.7771/2327-2937.1062

**Tafforin, C., Vinokhodova, A., Chekalina, A., and Gushin, V. (2015). Correlation of etho-social and psychosocial data from "Mars-500" interplanetary simulation. *Acta Astronaut.* 111, 19–28. doi: 10.1016/j.actaastro.2015.02.005

Totterdell, P., Kellett, S., Teuchmann, K., and Briner, R. B. (1998). Evidence of mood linkage in work groups. *J. Personal. Soc. Psychol.* 74, 1504–1515. doi: 10.1037/0022-3514.74.6.1504

Tyerman, A., and Spencer, C. (1983). A critical test of the Sherifs' robber's cave experiments: intergroup competition and cooperation between groups of well-acquainted individuals. *Small Group Behav.* 14, 515–531. doi: 10.1177/104649648301400407

**Ushakov, I. B., Morukov, B. V., Bubeev, Y. A., Gushin, V. I., Vasil'eva, G. Y., Vinokhodova, A. G., and Shved, D. M. (2014). Main findings of psychophysiological studies in the Mars 500 experiment. *Herald Russian Acad. Sci.* 84, 106–114. doi: 10.1134/S1019331614020063

**van Baarsen, B. (2013). Person autonomy and voluntariness as important factors in motivation, decision making, and astronaut safety: first results from the Mars500 LODGEAD study. *Acta Astronaut.* 87, 139–146. doi: 10.1016/j.actaastro.2013.02.006

**Vinokhodova, A. G., Bystritskaya, A. F., and Eskov, K. N. (2001). "Influence of intergroup relations on group effectiveness and interpersonal relations under long-term isolation conditions," in *Simulation of Extended Isolation: Advances and Problems*, ed V. M. Baranov (Moscow: FirmSLOVO), 100–116.

**Vinokhodova, A. G., Bystritskaya, A. F., and Eskov, K. N. (2002). Inter-group relationship under simulated long-term isolation conditions. *Space Technol.* 22, 103–111.

**Vinokhodova, A. G., Gushin, V. I., Eskov, K. N., and Khananashvili, M. M. (2012). Psychological selection and optimization of interpersonal relationships in an experiment with 105-days isolation. *Hum. Physiol.* 38, 677–682. doi: 10.1134/S0362119712070262

**Wang, Y., Jing, X., Lv, K., Wu, B., Bai, Y., Luo, Y., et al. (2014). During the long way to Mars: effects of 520 days of confinement (Mars500) on the assessment of affective stimuli and stage alteration in mood and plasma hormone levels. *PLoS ONE* 9:e87087. doi: 10.1371/journal.pone.0087087

Watson, D., Clark, L. A., and Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS Scales. *J. Personal. Soc. Psychol.* 54, 1063–1070. doi: 10.1037/0022-3514.54.6.1063

**Wood, J., Lugg, D. J., Hysong, S. J., and Harm, D. L. (1999). Psychological changes in hundred-day remote Antarctic field groups. *Environ. Behav.* 31, 299–337. doi: 10.1177/0013916599313001

*References marked with one asterisk indicate effect size data set studies.

**References marked with two asterisks indicate benchmark data set studies.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Bell, Brown and Mitchell. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

ORIGINAL RESEARCH
published: 11 June 2019
doi: 10.3389/fpsyg.2019.01322

A Bottom Up Perspective to Understanding the Dynamics of Team Roles in Mission Critical Teams

C. Shawn Burke[1], Eleni Georganta[1,2] and Shannon Marlow[3]*

[1] The Institute for Simulation and Training, University of Central Florida, Orlando, FL, United States, [2] Department of Psychology, Ludwig-Maximilians-Universität München, Munich, Germany, [3] Department of Management, The University of Texas at San Antonio, San Antonio, TX, United States

There is a long history, dating back to the 50 s, which examines the manner in which team roles contribute to effective team performance. However, much of this work has been built on *ad hoc* teams working together for short periods of time under conditions of minimal stress. Additionally, research has been conducted with little attention paid to the importance of temporal factors, despite repeated calls for the importance of considering time in team research (e.g., Mohammed et al., 2009). To begin to understand team roles and how temporal aspects may impact the types of team roles employed when teams are working in extreme mission critical environments, the current manuscript uses a data-driven, bottom-up approach. Specifically, we employ the use of retrospective historical data as our input and a historiometric approach (Simonton, 2003). Source documents consist primarily of autobiographies, memoires, biographies, and first-hand accounts of crew interaction during spaceflight. Critical incidents regarding team interaction were extracted from these source documents and independently coded for team roles by two trained raters. Results of the study speak to the importance of task and social roles within teams that are predominantly intact and operating in extreme environments where mistakes can be life threatening. Evidence for the following task (i.e., coordinator, boundary spanner, team leader, evaluator, critic, information provider, team player, and innovator) and social roles (i.e., team builder, nurturer, harmonizer, entertainer, jokester, and the negative roles of attention seeker and negativist) were found. While it is often task roles that receive the greatest attention, results point to the importance of not neglecting the socioemotional health of the team (and the corresponding roles). Results also indicated that while some roles were consistently enacted independent of temporal considerations (e.g., mission length), the degree to which others were enacted varied across missions of differing lengths. Additionally, based on the current sample we see the following trends: (1) increased enactment of the team builder role as mission duration increases, (2) prominence of the entertainer role, and (3) increased emphasis on the visionary/problem solver role on missions over 2 years.

Keywords: teams and groups, team roles, team performance, time, temporal and contextual factors

OPEN ACCESS

Edited by:
Marissa Shuffler,
Clemson University, United States

Reviewed by:
Esther Sackett,
Northwestern University,
United States
Suzanne Bell,
DePaul University, United States

****Correspondence:***
C. Shawn Burke
sburke@ist.ucf.edu

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *09 December 2018*
Accepted: *21 May 2019*
Published: *11 June 2019*

Citation:
Burke CS, Georganta E and Marlow S (2019) A Bottom Up Perspective to Understanding the Dynamics of Team Roles in Mission Critical Teams. Front. Psychol. 10:1322. doi: 10.3389/fpsyg.2019.01322

INTRODUCTION

It has often been said that a team of experts does not make an expert team. Although different conceptualizations of teams have been introduced within the literature, one prevalent definition stipulates that teams consist of two or more individuals who interact dynamically, adaptively, and interdependently; share common goals or purposes; and have specific roles or functions to perform (Salas et al., 1992). Teams represent a prevalent approach to structuring work, with a majority of employees reporting spending at least some part of their day within a team setting (Ken Blanchard Companies, 2006). In this vein, there is a long history of research that has sought to examine the factors that contribute to team effectiveness within a variety of contexts and much has been learned (Mathieu et al., 2008).

Despite the long history of research on team effectiveness, much of this work has been built on *ad hoc* teams working together for short periods of time within laboratory or organizational settings. Additionally, much of this work is primarily static in nature despite repeated arguments for the importance of considering temporal factors in team research (e.g., Mohammed et al., 2009). This, in turn, has led to minimal guidance for those individuals tasked with staffing, developing, and assessing teams that operate over longer periods of time as intact teams or operate within mission critical, extreme contexts. Teams that operate in these environments are often referred to as "extreme teams." According to Bell et al. (2018), extreme teams are those which are embedded in environments whereby one or more contextual features exist that are atypical in level or kind.

While understanding the factors that facilitate team effectiveness and how these may change over time is an important and difficult endeavor due to the complexity of collecting longitudinal data on teams, facilitating this understanding is of even greater importance for teams operating in extreme contexts. Extreme teams are not only exposed to stressors that are atypical in level, but stressors often occur simultaneously and oscillate between chronic and acute duration levels (Bell et al., 2018). Teams operating under these conditions have been shown to be more likely to have decrements in performance due to the effects of stress on team process (and correspondingly performance, Driskell et al., 1999).

In seeking to understand the factors that facilitate the effectiveness of such teams and how these factors may change based on temporal factors (e.g., team duration), we focus on team roles. Research on team roles has a rich history dating back to Bales (1950). Roles have been defined as a "set of behaviors that are interrelated with the repetitive activities of others and characteristic of the person in a particular setting" (Stewart et al., 2005, p. 344). Throughout the years, many taxonomies have been created to delineate the roles that facilitate performance in teams (e.g., Bales, 1950; Belbin, 1981; Mumford et al., 2006). While there are differences in the taxonomies created throughout the years, nearly all argue for the importance of both task and social roles. However, not much is known regarding the types of team roles needed within mission critical, extreme contexts, or how team roles in this context vary based on temporal factors (e.g., team/mission duration).

Therefore, the goal of the current study is to move the literature forward in two thrusts: (1) understanding the team roles needed within extreme environments and (2) examining how the instrumentality of specific team roles may vary based on temporal factors in extreme environments. These advancements meet a critical need in better understanding the dynamic nature of teams and consequently the roles that are enacted, but also begin to highlight the importance of context.

To achieve our goals, we employ historiometry (Simonton, 2003) as a methodology to analyze archival documentation of crew interaction, with a particular emphasis on role enactment in extreme teams using spaceflight crews as an exemplar. In the following, we first present background on team roles, extreme teams, and highlight a set of hypotheses that serve to drive our approach. Next, we summarize our methodology including the nature of our sample and procedure. Finally, we describe our results, extract the implications for understanding the dynamic nature of team roles within the context of extreme teams, and highlight future research needs.

TEAM ROLES

Team roles have been defined as different functions and responsibilities team members must assume to enable smooth team functioning (Stewart et al., 1999, 2005). In this vein, a number of taxonomies have been created that argue for those roles that must be enacted to facilitate team performance (Benne and Sheats, 1948; Belbin, 1993; Mathieu et al., 2015; Driskell et al., 2017). The manner in which taxonomies have described team roles has varied, ranging from descriptions involving: (1) high overarching categories consisting of 2–3 dimensions, (2) nuanced categories consisting of 5–12 dimensions, and (3) those focusing on a set of core characteristics (see **Table 1** for exemplars). Early work tended to describe team roles primarily in terms of broad overarching roles (e.g., Bales, 1950). Evidence of this research stream can still be seen in work on team roles for despite many role taxonomies becoming more nuanced, there is now general agreement on two broad classes of team roles: task roles (those behaviors that further task completion and fulfillment of the team's objectives) and social roles (those behaviors that maintain the team's social environment and the socioemotional health of the team).

As the literature progressed, taxonomies began to become more nuanced, accounting for a more varied set of roles (e.g., Margerison and McCann, 1985; Belbin, 1993; Parker, 1994, 1996; DuBrin, 1995). Perhaps most recent in this steam of work are role taxonomies put forth by Mumford et al. (2006) and Mathieu et al. (2015). Mumford et al. (2006) synthesized the previous literature on roles and delineated a set of ten roles, five task roles (i.e., contractor, creator, contributor, completer, critic) and five social roles (i.e., communicator, cooperator, calibrator, consul, coordinator, see **Table 1**). Mathieu et al. (2015) suggest that one of the key theoretical contributions of this work is integrating Ancona and Caldwell's (1988, 1992) work on roles with additional theoretical frameworks to include the

TABLE 1 | Example team role taxonomies.

Source	Description	Dimensions
Bales, 1950	Task roles Socioemotional roles	• Asking for/giving orientation, opinion, suggestions • Positive – show solidarity, tension release, agrees, negative – antagonism, tension, disagrees
Benne and Sheats, 1948	Task roles Group building/ maintenance roles Individual roles	• Initiator-contributor, information seeker, opinion seeker, information giver, opinion giver, elaborator, coordinator, orienter, evaluator-critic, energizer, procedural technician, recorder • Encourager, harmonizer, compromiser, gate-keeper, standard setter, group-observer, follower • Aggressor, blocker, recognition-seeker, self-confessor, playboy, dominator, help-seeker, special interest pleader
Belbin, 1993	No specification	• Completer-finisher, implementer, specialist, monitor-evaluator, coordinator, plant, shaper, resource investigator • Team worker
Mumford et al., 2006	Task roles Social roles	• Contractor (organize, coordinate), creator (promote innovative approaches), contributor (provides pertinent information), completer (foster task completion) critic (promote open discussion of potential issues) • Communicator (promote healthy social environment/collaboration), cooperator (conforms to others expectations), calibrator (observe/change team social processes), consul (gather information from outside sources), coordinator (coordinates team efforts with outside)
Mathieu et al., 2015	Task roles Socio-emotional roles Change-orientated roles	• Organizer, doer, challenger, innovator • Team builder, connector • Challenger, innovator
Driskell et al., 2017	Focus on dimensions which underly all roles in varying degrees	• Dominance • Sociability • Task orientation

notion of boundary spanning. Work by Mathieu et al. (2015) attempted to find a middle ground between high overarching taxonomies of team roles and those taxonomies with many nuanced team roles. Mathieu et al. (2015) proposed and validated the Team Role Experience and Orientation (TREO), that includes six team roles. The six roles consist of the organizer (i.e., structures the team and task to ensure goals are being met), doer (i.e., completes taskwork), challenger (i.e., challenges the team to question assumptions and approaches to the task), innovator (i.e., generates ideas and solutions), team builder (i.e., maintains a positive atmosphere within the team, establishes norms, and supports team decisions), and connector (i.e., connects the team with outside entities). Taken as a whole, the research provides compelling evidence to support the validity of the six roles introduced within this theoretical framework.

Representing the last category of role taxonomies is the work of Driskell et al. (2017). Building upon previous work, Driskell et al. (2017) delve deeper into roles and argue that there are three characteristics (i.e., dominance, sociability, task orientation, see **Table 1**) that can be used to describe all team roles based on the degree to which each characteristic is present. This three-dimensional model is labeled TRIAD or Tracking Roles in and Across Domains. Its usefulness lies in helping to understand how team roles might covary with one another based on their underlying characteristics.

Each of these approaches has expanded an understanding of the team roles needed for successful teamwork. However, there remains a gap in the literature regarding the influence of context. Researchers have sought to create team role taxonomies that are comprehensive and generalize across samples and conditions. Yet, we suggest that the prevalence and necessity of team roles may be contingent upon the demands of the situation. Therefore, we draw from a taxonomy introduced to describe team roles in extreme environments to further understanding in this area. In particular, Burke et al. (2016) developed a taxonomy which utilized existing literature and interviews with domain experts to form an initial set of team roles grounded in the context of teams operating in extreme environments. The taxonomy depicts a set of eleven roles consisting of five social roles (three functional, two dysfunctional) and six functional task roles. Social roles include: contribution seeker, team builder, jokester/entertainer, attention seeker, and negativist. In contrast, task roles consist of the following: team player, evaluator, information provider, boundary spanner, visionary/innovator, coordinator (see **Table 2** for a full description of roles).

While the taxonomy put forth by Burke et al. (2016) provides initial input into the types of team roles that may appear, further research needs to be conducted to examine the degree to which these roles actually occur in teams operating in extreme contexts. Teams embedded within extreme environments are repeatedly faced with strong situations which present unique demands, and each demand may require a different team role. Consequently, a more precise theoretical model explicating the roles needed for success, depending upon the various demands of the situation, is required. To address this gap, we leverage the taxonomy described by Burke et al. (2016) along with the literature on extreme teams (below) to foster our understanding of how different conditions faced by spaceflight teams influence the necessity of specific team roles.

TABLE 2 | Team role taxonomy (Burke et al., 2016).

Team role	Description
Social roles	
Contribution seeker	Behaviors that seek to ensure that all members are contributing to the task, are recognized for their contribution, and feel their contribution is valued.
Team builder	Behaviors that seek to improve and maintain the social structure, motivation, and team well-being. This includes sub-roles: harmonizer, motivator, and nurturer.
Entertainer	Behaviors which serve to maintain cohesion and emotional well-being through humor and other active public forms of artistic expression targeted at the team. Subdimension: jokester.
Attention seeker	Behaviors that serve to consistently call attention to oneself. This attention seeking is self-initiated.
Negativist	Behaviors which reflect an explicit negative outlook, are toxic in nature, and serve to degrade the social emotional environment within the team. This includes sub-roles: complainer and aggressive arguer.
Task roles	
Team player	Behaviors which reflect a willingness to pitch in wherever is needed and being prepared to help. This includes sub-roles: task completer, mission support, and social loafer (negative instance).
Evaluator	Behaviors aimed at questioning and ensuring the best use of team ideas and information. This includes sub-roles: critic and analyzer/synthesizer.
Information provider	Behaviors which serve to transmit information within the team serving to create shared mental models. This includes the sub-roles of clarifier, facilitator, note taker, power seeker (negative role).
Boundary spanner	Behaviors which represent someone who is managing the relationship of the team with outside entities as well as gathering/sending information outside the team to bring back in.
Visionary/innovator	Behaviors which are oriented toward coming up with new and creative ideas and approaches to the task.
Coordinator	Leadership-oriented behaviors focused on the processes involved in task completion. The includes sub-roles: team leader, project manager.

ROLE ENACTMENT IN EXTREME TEAMS

As the predominant amount of work on team roles has been conducted within the context of teams operating in non-extreme environments, those charged with composing, managing, or developing teams that operate in extreme environments have little guidance upon which to rely; this is despite the mission critical nature of the teams that operate within these types of environments. Extreme environments have been described as ones in which "one or more extreme events are occurring or are likely to occur that may exceed the organization's capacity to prevent and result in an extensive and intolerable magnitude of physical, psychological, or material consequences to – or in close physical or psycho-social proximity to – organization members" (Hannah et al., 2009, p. 898). Teams that operate within extreme environments often face stressors that are atypical in kind or level (Bell et al., 2018); this culmination of stressors may drive the instrumentality of the various task and social roles that have been argued for within the broader literature.

While there are a number of team types that operate in extreme environments, perhaps the most commonly referenced are those operating within the context of polar exploration, firefighting, spaceflight, and some military environments. In investigating role enactment within these more extreme teams, we utilize teams involved in space exploration/spaceflight. Teams operating within the context of spaceflight face a number of potential stressors that are atypical in terms of kind and level. For example, research has identified at least four different classes of stressors often present in this environment: physiological/physical, habitability, taskwork, and psychosocial (see Dietz et al., 2017). In terms of physiological/physical stressors the following have been identified: decreased exposure to sunlight, circadian rhythm disruption, and sleep deprivation. Stressors related to habitability have been argued to include things such as a lack of privacy, noise/vibrations, and cooking/eating restrictions. Crews also face task related stressors such as: scheduling, variations in task autonomy, periods of monotomy/boredom, shiftwork, time pressure, and high workload. Finally, there are a myriad of psychosocial stressors which may occur, including but not limited to family life disruption, multicultural issues, task and relationship conflict, communication delays, and isolation/confinement (Dietz et al., 2017). These stressors often occur in conjunction with one another and serve as a source of threat to the crews embedded within this environment. As such, space exploration, and the teams therein, provide an exemplar of teams that operate in extreme environments and can be categorized along the set of characteristics argued by Hannah et al. (2009) to define extreme environments (i.e., location in time, magnitude of consequences, probability of consequences, physical/psychosocial proximity, and form of threat).

In seeking to understand the team roles that must be enacted within extreme environments, such as spaceflight, we can leverage work conducted on how teams respond when under stress. In this vein, early work by Sorokin (1943) found that groups involved in catastrophic events tended to become overly aroused and emotional which consequently impacted the way they processed information and made decisions. Similarly, work conducted by Driskell and Salas (1991) found stress impacts the degree to which members are receptive to informaton offered by team members. Specifically, replicating previous findings (Foushee and Helmreich, 1988), Driskell and Salas (1991) found

that under stress low status members became more willing to defer to high status members. However, contrary to previous findings, results indicated that high status members were more likely to attend to the task contributions of others. In these cases the team is in a situation in which the high status member is willing to accept task input, yet lower status members may be less willing to provide such input. This drives a need for task related roles which seek to proactively elicit information from relevant team members. While this role primarily serves to facilitate task accomplishment, it does have a social component by providing a sense of meaning and value to team members indicating that their contributions are valued.

Extending this work are findings by researchers indicating that stress leads to a loss of team perspective whereby an individual member's breadth of attention narrows and they become more self-focused, less group identity is reported, and members have less of a collective representation of the task (Driskell et al., 1999). Similarly, stress has been argued to increase distraction and decrease attentional focus, increase team members' cognitive load, increase negative emotion (e.g., frustration, fear, anxiety), and increase social impairment (e.g., reduce back-up behavior, increased interpersonal conflict/aggression, failure to appropriately read social cues, and less cooperative behavior as seen through attentional narrowing) (Driskell et al., 2018). Given the impact that stress has on both task and psychosocial aspects of the team, in line with prior research, we would expect that both task and social roles would be present (Prichard and Stanton, 1999; Chong, 2007) and fairly equally distributed when looked at across the lifecycle of the team.

> *Hypothesis 1: The distribution of task and social roles will be fairly equally represented in extreme teams.*

The taxonomy put forth by Hannah et al. (2009) along with the types of stressors often experienced within spaceflight can be used to further make predictions regarding the specific types of task and social role behaviors that might be evidenced. Hannah et al. (2009) delineates five dimensions of extreme environments: location in time/temporal ordering, magnitude of consequences, probability of consequences, form of threat, and physical or psychosocial proximity. For the current effort, the first four of these are perhaps the most relevant in delineating the types of roles needed within the context of spaceflight (and other teams operating in similar extreme contexts). As such, these will be briefly discussed next.

Location in Time

The types of threat that are present within the predominant number of extreme environments are ones which oscillate over time (e.g., at certain times being more of a concern). The temporal cycle of the impact of such threats will vary across extreme contexts and as such will drive the nature of the type of team processes required for teams to be resilient within such environments. With regard to spaceflight, the threat is primarily located in the situation although some physiological effects can persist beyond the immediate situation. While there are always low intensity chronic stressors that exist within spaceflight due to the mission criticality of the environment and distance of the crew from earth, there are periods of high intensity, acute stressors which may occur in combination as unexpected or off-nominal events occur. In this vein, Hannah et al. (2009) argue for the importance of the management of transitions between these periods of nominal and off-nominal events. With regard to roles, this drives the need for the sets of behavioral activities which will facilitate team and leader transition phase behaviors as seen in the work of Marks et al. (2001) and Morgeson et al. (2010). More specifically, role behaviors that facilitate structuring and planning of coordinative activities and points of transition, such that member cognitive and behavioral capacities are taken into account in order to ensure the capacity of any one individual member is not exceeded. This would, in turn, point to the importance of the coordinator role, information provider which serves to facilitate the exchange and clarification of information, boundary spanner to push and pull information in from outside the immediate team for use in planning, as well as the enactment of the evaluator role.

Magnitude/Probability of Consequences

The second and third factors that Hannah et al. (2009) argue as defining characteristics of extreme environments are the magnitude and probability of consequences. With respect to spaceflight, the magnitude and probability of consequences is high given the distance from earth, relative isolation, and the environmental characteristics of space. To better understand the impact on the crew and the roles that may be important, we leverage existing literature on the impact of stress on teams along with that on high reliability organizations. Extracting from the literature on stress and teams, stress has been shown to degrade team process by causing: a narrowing of attention, loss of team perspective, degradations in coordination, and tendency for groupthink with low status members more willing to defer to others and less likely to speak up (e.g., Janis, 1972; Callaway et al., 1985; Driskell and Salas, 1991; Burke et al., 2008; Ellis and Pearsall, 2011). This points to team roles such as the critic (to combat groupthink) and boundary spanner (to bring in alternative information from outside and serving to combat the narrowing of attention and in combination with the critic role serving to combat groupthink). The propensity for low status members to "go with the flow" and potentially not offer valuable information drives the need for the contribution seeker.

High reliability organizations (HROs) can be defined as organizations that operate within environments where the magnitude and probability of consequence of error is high, yet are able to minimize errors (Roberts, 1990). As such, HROs should provide some insight into the types of roles needed when magnitude and probability of consequence is high. Research has suggested that principles of collective mindfulness (i.e., preoccupation with failure, reluctance to simplify interpretations, sensitivity to operations, commitment to resilience, and underspecification of structures, Weick et al., 1999) are the mechanisms that allow HROs to effectively operate. Moreover, work has attempted to translate the above

organizational practices to the team level (e.g., Wilson et al., 2005; Baker et al., 2006). Wilson et al. (2005) argue that at the team level, these processes may be manifested through the following actions: sensitivity to operations (e.g., cross-lagged communication, information exchange, maintaining shared situation awareness), commitment to resilience (e.g., backup/monitoring, shared mental models), deference to expertise (e.g., assertiveness, collective orientation, expertise), reluctance to simplify (e.g., adaptability, flexibility, and planning), and preoccupation with failure (e.g., error management, feedback/team self-correction).

An examination of the HRO principles can provide insight into the types of team roles needed. For example, many of the principles speak to ensuring that information is being transmitted throughout the team (i.e., sensitivity to operations, preoccupation with failure) to maintain shared mental models and situation awareness (i.e., sensitivity to operations, commitment to resilience). This speaks to the need for team roles such as the information provider and contribution seeker to ensure relevant input is being gained no matter the status of the individual team member. The importance of members backing one another up (i.e., commitment to resilience) and maintaining a collective orientation (i.e., deference to expertise) drives the need for the team player, jumping in wherever needed. Finally, the requirement to be adaptive and flexible (i.e., reluctance to simplify, preoccupation with failure) drives the need of the critic who can combat against groupthink as well as the boundary spanner role to ensure that the team is maintaining an awareness of events outside the team that may impact their mission.

Hypothesis 2: The oscillations in stressor onset as well as the high magnitude and probability of consequences will drive the following task-orientated roles as being commonly seen: boundary spanner, team player, evaluator/critic, contribution seeker, and information provider.

Form of Threat

The fourth characteristic along which extreme environments can be characterized is the form of the threat(s) presented to the teams. Hannah et al. (2009) argue that threats can be physical, psychological, or material. In the case of spaceflight, while threats can exist on any of the three aforementioned dimensions, they are most often physical and psychological. Factors such as isolation, confinement, and disruption of family life drive the increased need for team roles that are targeted at maintaining the psychosocial health of the team, in addition to the physical health. Therefore, we predict that the enactment of behavioral sets of activities that serve to reduce interpersonal conflict (e.g., harmonizer), maintain team morale, redirect crew attention from the negative aspects (e.g., team builder, entertainer), and ensure that personal physical and space needs are met (e.g., nurturer) are the key social roles that will be seen within extreme environments. The latter set of roles (e.g., nurturer) arise to fulfill the gap created based on the confinement and isolation from loved ones who might otherwise ensure these basic needs are met.

Hypothesis 3: Social roles that will be most prominently seen in extreme teams (e.g., spaceflight crews) include: the harmonizer, nurturer, team builder, and entertainer.

ROLE ENACTMENT AND TEMPORAL CONSIDERATIONS

While the contextual nature of extreme teams is expected to drive the importance and/or frequency of enactment of particular roles as argued for above, it is also expected that team roles are dynamic and the degree to which specific roles are manifested within a team will vary based on several temporal factors. Below, we begin to set forth a series of propositions driven by the literature on team development, albeit manifested in two different ways. The literature on team development and team dynamics has a long history (e.g., Tuckman, 1965; Gersick, 1991; Salas et al., 1992; Hackman and Wageman, 2005; Kozlowski et al., 2009; Burke et al., 2017), yet in thinking about extreme teams we take a slightly different approach in that we couple team development with contextual factors due to their tightly linked nature in teams.

The context within which we are investigating extreme teams is one in which the team members tend to be task experts, co-located with fellow crew members, and highly driven individuals. These crews also tend to be intact, operate under varied stressors that occur simultaneously, and tend to have high level of isolation and confinement. Therefore, our propositions will touch less upon the team developmental needs as by the time the predominant number of these teams are on a mission, they have already been exposed to a wide variety of team building and training exercises and in most cases have prior knowledge of crew members (if not prior working experience with them). Instead, we focus predominantly on how team needs may change over time based on the temporal duration of the missions within which the team is operating.

Work by Salas et al. (1992) has argued, and later research has shown (e.g., Mathieu et al., 2008), that in order to be effective, teams must master two tracks of skills – taskwork and teamwork. Specifically, the taskwork track represents "task-orientated skills that members must understand and acquire for task performance" (Salas et al., 1992, p. 10). In contrast, the teamwork track refers to "the behavioral interaction and attitudinal responses that team members must develop before they can function effectively as a team" (p. 11). We expect that teams operating in extreme contexts are no different than most operational teams in this regard (i.e., both sets must be mastered, as indicated by Hypothesis 1). However, we do propose that teams operating in these extreme environments have different challenges that cause the instrumentality of roles related to the maintenance of these two tracks to differ over time.

Within the set of extreme teams under consideration, missions of shorter duration tend to be characterized by high operational tempo due to the high workload present as crew members strive to complete science payloads, engage in public outreach and educational efforts, adhere to exercise and diet schedules, and ensure the equipment in transport vehicles and the habitat are working properly. The degree of high operational tempo seen

in missions of short duration drives the crew into a very task-oriented mindset. Therefore, within these missions when the crew is together for shorter periods of time roles will tend to revolve around ensuring task needs are met. This is not to say that social roles are not important on the shorter duration missions, but the social stressors that the teams are exposed to on the short duration missions are not as salient as the task-orientated stressors. For these reasons, we would expect that in terms of frequency of enactment, there would be a greater proportion of task roles enacted on those missions that fall within the short duration category. The social stressors that the teams are presented with on short missions may be viewed as low level, while task stressors tend to be of higher levels and oscillate between acute and chronic in nature. Although not conducted with extreme teams, a review of team studies conducted by Bradley et al. (2003) revealed a pattern consistent with this expectation. They found that teams working on tasks of shorter duration, as compared to longer duration tasks, focused on "the task to the exclusion of efforts to form cohesive team norms that would only benefit the teams if they were going to remain together for the performance of future tasks" (p. 12). This evidence suggests that teams are less likely to invest in interpersonal relations and focus on fostering group norms via social roles when focused on tasks or missions of shorter duration (i.e., <=15 days).

> *Hypothesis 4: In shorter duration missions, task roles will be the driving factor in facilitating team performance, particularly those roles which foster the self-regulatory capacity of the team and facilitate collective mindfulness (e.g., boundary spanning, evaluator/critic).*

As the duration of the mission increases, and correspondingly the team is exposed to the extreme conditions for longer periods of time, we expect that the enactment of social roles will become more prominent. The task-based stressors do not disappear as many are defining features of the extreme environment; however, the perceptions of isolation and confinement increase and begin to take a socio-emotional toll on the team. This effect is commonly reported in literature with respect to teams that have been deployed within extreme conditions for long periods of time. This phenomena is known as the third-quarter effect whereby individuals within isolated extreme environments often experience a decrease in mood and affect during the third quarter of their deployment or mission (Evans et al., 1987; Bechtel and Berning, 1991; Steel, 2001). This, in turn, is expected to drive an increased focus on behaviors that are related to ensuring that the social needs of the team are being met as a way to combat this natural drop in affect and mood. Moreover, teams formed for a longer period of time, as compared to teams working on tasks of shorter duration, have been found to invest more effort in forming relationships with other team members because they are aware that the longer task duration makes it more beneficial to have these relationships (Bradley et al., 2003). In line with this evidence, we suggest this is another reason, in addition to contending with the extreme environment (e.g., Steel, 2001), that more social roles are likely to be enacted on longer duration missions. Team members may engage in more social roles with the underlying goal of forming close relationships with other team members due to the longer duration of the mission.

> *Hypothesis 5: As team duration increases within extreme contexts the enactment of social roles become more frequent. Particularly, those roles that foster the socioemotional health of the team such as behaviors which provide an escape from the stressors present as well as behaviors which seek to maintain the emotional and physical health of the team (e.g., entertainer/jokester, nurturer).*

MATERIALS AND METHODS

In order to test our assumptions and to gain a better understanding of team roles in extreme teams, with an emphasis on spaceflight crews, a historiometric approach (Simonton, 2003) was applied. Historiometry describes the systematic analysis of the content of past events and is defined as the "collection of methods in which archival data concerning historic individuals and events are subjected to quantitative analyses in order to test nomothetic hypotheses about human thought, feeling, and action" (Simonton, 1998, p. 269). This method is especially useful for exploring a relatively new research area, such as examining the dynamic nature of team roles in extreme environments, because it depends on data that were not explicitly collected for the research question of interest, thus limiting some bias. Further benefits of this approach include the contextual richness of the data and the corresponding external validity (Crayne and Hunter, 2018). Historiometry also enables the examination of complex constructs as expressed in behavior (e.g., team roles) during real situations, and the investigation of how such (team) constructs may differ depending on the type of situation (Antonakis et al., 2003). Recent studies have similarly applied historiometric analysis to explore topics such as team leadership in mission critical/isolated environments, successfully providing insight into other relatively new team-level research areas (e.g., DeChurch et al., 2011; Burke et al., 2018).

Sample

The final sample used to examine our hypotheses consisted of 525 roles extracted from 514 critical incidents describing collective team interaction within the context of spaceflight. The incidents and coded roles came from the following seven missions that varied in length, allowing an examination of how team roles may vary over time: Shuttle, Soyuz, Gemini, Skylab, Salyut, Mir, and Mars 500.

Procedure

Sources

The first step was to identify historical events (i.e., missions) that documented team interaction within the context of spaceflight. Sources were identified through the following databases: EBSCOhost, Google, and Google Scholar. Sources were also identified by searching the following websites: Amazon,

TABLE 3 | Sources and the respective spaceflight context.

Document title	Source	Author	Date	Spaceflight context
Flight: my life in mission control	Book (Autobiography)	Kraft C.	2001	Gemini
Of emergencies and Christmas trees – an exciting end to 2010	Diary (Mission Diary Entry)	Charles R.	12 January 2010	Mars 500
Goodbye Sun, goodbye Earth, we are leaving for Mars!	Diary (Mission Diary Entry)	Urbina D. and Charles R.	3 June 2010	Mars 500
Romain Charles completes the tour	Diary (Video Diary Entry)	Charles R.	21 June 2010	Mars 500
A dirty job but someone's gotta do it!	Diary (Video Diary Entry)	Urbina D.	30 June 2010	Mars 500
This is our home, our workplace, and our life	Diary (Mission Diary Entry)	Urbina D.	7 July 2010	Mars 500
It's housecleaning day	Diary (Video Diary Entry)	Urbina D.	14 July 2010	Mars 500
Smooth routine' and interplanetary birthday party	Diary (Mission Diary Entry)	Charles R.	22 July 2010	Mars 500
Romain collecting air samples	Diary (Video Diary Entry)	Charles R.	9 August 2010	Mars 500
Waste not – want not	Diary (Mission Diary Entry)	Urbina D.	18 August 2010	Mars 500
How supplies are rationed?	Diary (Video Diary Entry)	Charles R.	6 September 2010	Mars 500
Science and thoughts of Chilean miners	Diary (Mission Diary Entry)	Charles R.	10 September 2010	Mars 500
Thanks to Oliver and Cyrille!	Diary (Mission Diary Entry)	Urbina D. and Charles R.	15 September 2010	Mars 500
Diego and Romain answer your questions	Diary (Mission Diary Entry)	Urbina D. and Charles R.	24 September 2010	Mars 500
Preparing the meals (with a shaker)	Diary (Video Diary Entry)	Urbina D.	12 October 2010	Mars 500
Diego and Romain answer your questions 2	Diary (Mission Diary Entry)	Urbina D. and Charles R.	26 October 2010	Mars 500
The barber shop on the way to Mars	Diary (Video Diary Entry)	Urbina D. and Charles R.	3 November 2010	Mars 500
"Are we alone?"	Diary (Mission Diary Entry)	Urbina D.	10 November 2010	Mars 500
Approaching the Red Planet	Diary (Mission Diary Entry)	Urbina D.	26 January 2011	Mars 500
Unpacking the Lander and preparing for a hike on Mars	Diary (Mission Diary Entry)	Charles R.	9 February 2011	Mars 500
Celebrating Chinese New Year – even on Mars!	Diary (Mission Diary Entry)	Charles R.	2 February 2011	Mars 500
Greetings from Mars!	Diary (Mission Diary Entry)	Urbina D.	1 March 2011	Mars 500
Long trip without moving anywhere	Diary (Mission Diary Entry)	Charles R.	3 June 2011	Mars 500
"The best moments of our trip"	Diary (Mission Diary Entry)	Charles R.	17 August 2011	Mars 500
Earth approaching!	Diary (Mission Diary Entry)	Urbina D.	13 October 2011	Mars 500
Countdown is on	Diary (Mission Diary Entry)	Charles R.	25 October 2011	Mars 500
Way station to the Stars: the Story of Mir, Michael, and Me	Book (Autobiography)	Foale C.	1999	Mir
Diary of a Cosmonaut: 211 days in Space	Book (Autobiography)	Lebedev V.	1990	Salyut
Salyut – The First Space Station: Triumph and Tragedy	Book	Ivanovich G. S.	2008	Salyut
Space Shuttle Columbia (Her Missions and Crews)	Book	Evans B.	2003	Shuttle
Riding Rockets: The Outrageous Tales of a Space Shuttle Astronaut	Book (Autobiography)	Mullane M.	2007	Shuttle
Space Shuttle Challenger (Ten Journeys Into the Unknown)	Book	Evans B.	2007	Shuttle
The All-American Boys: An Insider's Candid Look at the Space Program and the Myth of the Super Hero	Book	Cunningham W.	2010	Shuttle
Homesteading Space: The Skylab Story	Book	Hitt D., Garriott O., Kerwin J., Bean A. L., and Hockam H.	2011	Shuttle
Wheels Stop: The Tragedies and Triumphs of the Space Shuttle Program, 1986–2011	Book	Houston R.	2014	Shuttle
Women in Space [Biography (Lerner Hardcover)]	Book	Gibson K. B.	2014	Shuttle
A House in Space	Book	Cooper H. S. F.	1976	Skylab
Around the World in 84 days: The Authorized Biography of Skylab Astronaut Jerry Carr	Book (Autobiography)	Shayler D. J.	2006	Skylab
Leaving Earth: Space Stations, Rival Superpowers, and the Quest for Interplanetary Travel	Book	Zimmerman R.	2003	Soyuz, Mir, and Salyut

Johnson Space Center, and European Space Agency. Both primary (e.g., diaries and autobiographies) and secondary sources (e.g., biographies and missions reports) (Simonton, 1990) were collected (see **Table 3** for complete list of final sources used). Sources were examined for the extent to which they described team interaction and corresponding behaviors whereby critical

incidents regarding team role enactment could be extracted. Of specific interest was task and social role enactment as evidenced within collaborative activities that occurred while members were engaged in their primary tasks (i.e., task execution) as well as those that occurred during off-task periods (i.e., downtime). Information related to duration of the spaceflight missions comprising our sample was also collected (**Table 4**). The missions identified fell into one of four durations: short (15 days or less), medium (greater than 15 days, maximum 6 months), long (greater than 6 months, maximum 1½ years), longest (longer than 1½ years, maximum 2 years).

Sampling

The initial search produced approximately 150 sources for further examination. Sources were then examined with respect to the following criteria: (a) sources must describe interdependent interaction among the crew/team; (b) sources must describe crew/team actions where team role behaviors (positive or negative) are present and described; (c) teams being described must be operating in a real or simulated spaceflight environment; and (d) source must be accessible. A group of psychologists with experience in team roles and historiometric analysis reviewed the suitability of all sources as described previously, while taking into consideration the representation of all different spaceflight contexts and missions durations. At the end of this stage, a set of 39 sources remained (i.e., 14 books and 25 diaries).

In order to systematically extract all relevant information from the final set of 39 sources, seven subject matter experts were trained on the critical incident technique and its application in the current context (Flanagan, 1954). The critical incident technique has been described as a set procedures that assist in the systematic extraction of human behavioral observation which may be "...adapted to meet the specific demands of the situation at hand" (p. 335). The first step in developing a critical incident is to understand the aim of the incident. For us, the aim is driven by our stated research questions. Therefore, the raters responsible for extraction of the critical incidents needed to understand what team roles were and how they manifest in teams. While all raters had a prior familiarity with team roles, ensuring their understanding was the initial part of our training. Next, training progressed to incident extraction. While the specific form a critical incident may take can vary based on the researcher's need, for the current project, extraction included a behavioral description of team interaction at a specific point in time during the team's mission as well as the consequence of that interaction (see **Table 5** for examples).

Coding

Once extracted, all incidents were double-coded by two SMEs with experience in teams (and more specifically team roles). The SMEs were asked to independently sort the identified roles into role type (i.e., social, task, or non-applicable), role category (e.g., team player, contribution seeker, or non-applicable), and if applicable into role subcategory. Raters utilized the Burke et al. (2016) taxonomy as a baseline for their coding, but were told not be restricted by the dimensions contained within that particular taxonomy. For some incidents, more than one role category was identified. For testing the interrater reliability among the SMEs, we calculated Krippendorff's alpha, a standard reliability measure regardless of the number of observers, levels of measurement, sample sizes, and presence or absence of missing data, by using the respective SPSS macro (Hayes and Krippendorff, 2007). The interrater agreement was excellent for role type (Krippendorff's $\alpha = 0.79$), role category (Krippendorff's $\alpha = 0.77$), and for role subcategory (Krippendorff's $\alpha = 0.75$) (Cicchetti, 1994). In the final step, a meeting was held where both SMEs came to consensus regarding any discrepancies in their codes.

TABLE 4 | Differentiating of spaceflight context based on mission duration.

Duration	Exemplar missions	Incidents extracted
Short (<=15 days)	Shuttle, Gemini	132
Medium (<=6 months)	Skylab/ISS, Soyuz	124
Long (<=1.5 years)	Salyut, Mir	197
Longer (<=2 years)	Mars 500	72

Data Analysis

Data analysis consisted of two primary foci. First, to examine the set of propositions pertaining to team role enactment within extreme teams (Hypotheses 1–3), the roles that emerged from the card sort were rank-ordered by their frequency of occurrence. The frequency of each role type (i.e., task, social), role category (e.g., jokester, critic) and role subcategory (if applicable) was calculated.

To examine the dynamic nature of the identified team roles, we differentiated between spaceflight contexts in terms of the mission's duration (i.e., short, medium, long, and longer duration, see **Table 5**). Specifically, we adopted a comparative method (e.g., Gardner, 1993) by comparing and contrasting the illustrated team roles, in order to extract the common and differing role characteristics between the various temporal durations.

RESULTS

Team Roles

One of the primary questions posed within the current study was with regard to the types of task and social roles exhibited in teams operating within extreme contexts, using spaceflight crews as an exemplar. Closely related to this question was an examination of how temporal factors (i.e., mission duration) impact the nature of team roles exhibited. In this vein, five hypotheses were put forth regarding the team roles expected to be the most prevalent based on the defining features of spaceflight crews operating in extreme contexts and the frequency of specific role enactment based on mission duration.

With respect to Hypothesis 1, as predicted, results indicate that in terms of frequency both task and social roles were enacted in nearly equal proportions. Specifically, collapsing across missions, results indicated that 51% of the roles witnessed were social roles, while 49% of the roles were task-related ($N = 267$ and 258, respectively). Additionally, results indicated that many of

TABLE 5 | Example statements and categorization.

Sample critical incidents	Role	Source
"We did some funny TV today. Bill made some large cardboard swim fins, and paddles for his hands, and I televised him in his crazy get-up trying to paddle from one end of the forward compartment to the other. He put lightning bolts on the helmet. I laughed so much I could hardly hold the camera. I made up the dialog to go with it – called him "William Pogue Aerospace Pioneer." Hope the folks on the ground get a kick out of it."	Entertainer/jokester	Shayler, 2006
"Thus at an early stage Michael was able to show hospitality to his commander and flight engineer by welcoming them to his quarters to watch a late-night film, after supper together in the Base Block. They were glad of this entertainment and crammed amiably close to each other to watch Michael's tiny movie theater. . . .In this way, almost by accident, he set up an early bond with his crewmates which presaged friendship and trust beyond anything normally required in the contracts or international agreements, or in previous binational crews' experience. This warmth of feeling led to Michael's first public support of his crewmates against their seemingly rather hard Ground Control taskmasters in Moscow."	Team builder	Foale, 1999
Jean-Loup said, "I was surprised and impressed by your work together and how you fought to save the experiment." He smiled and was also in a perfect mood.	Contribution seeker	Lebedev, 1990
"Carr complained that the soap was like dog shampoo. Pogue, the pilot, bitched that the towels–which were made of a synthetic material that was highly fire-resistant–were "sort of like drying off with padded steel wool." Gibson griped that "the fire-prevention guys really got away with something when they made us go with that kind of material; I don't think it's absorbent enough, and I think it's too hard."	Negativist	Cooper, 1976
"Garriott, a bemused-looking, thin-faced man with a distinctive mustache that made him look like a western cowpoke, was even more eager to do more. Not only did he urge his crewmates on, he continually requested more work from scientists on the ground. " "I was thrilled with my crew. Hoot Gibson was a natural-born leader. He didn't micromanage as some commanders did (one was known to reach completely across the cockpit to make a switch change rather than allow the crewmember at that position to do it.) Hoot gave each of us our duties and set us free to be creative to get the job done."	Team Player Coordinator	Zimmerman, 2003 Mullane, 2007
"This morning I suggested to Ground Control that we check the C-2 sextant and asked them to give us the location of three or four stars so that we could see one in the middle of the porthole."	Boundary spanner	Lebedev, 1990

the roles seen in previous taxonomies developed with respect to teams operating in more traditional, non-extreme environments also appeared in the current context (e.g., team builder, jokester, team player, information provider). However, at a global level there were some differences to note. First was the presence of the social role of "entertainer." While similar to the jokester role seen in many role taxonomies outside of extreme contexts, the entertainer role is broader. Specifically, we define it as behaviors which seek to maintain cohesion and emotional well-being of team members through humor and other active, public forms of artistic expression. Additionally, the role of "nurturer" was a prominent role that does not often appear outside this context. This role consists of behaviors primarily focused on the maintenance of the physical health and personal space of crew members. Finally, of note is the lack of enactment of what would traditionally be considered negative roles consisting of behaviors directed at fellow team members (e.g., attention seeking, social loafing, expression of negativity). While a negativist role was frequently seen in some contexts it tended to consist of negative affect (i.e., complaining) regarding environmental, contextual, or equipment difficulties; it did not tend to be directed toward fellow crew members. When it was directed at individuals, it was most often members of ground control.

Hypotheses 2–3 described the task and social roles that were believed to be the most critical to teams operating in extreme contexts, such as spaceflight. To examine the data in relation to the hypothesis presented herein, the team roles that emerged from the card sort were rank-ordered in terms of their frequency of occurrence with respect to task and social roles, respectively. With respect to the predictions set forth in Hypothesis 2, findings were mixed. In line with predictions, the roles of boundary spanner, team player, and information provider emerged within the top five most frequently occuring task roles (see **Table 6**). The team player role is comprised of behaviors that reflect a willingness to pitch in wherever help is needed. Whereas, the information provider is comprised of behaviors serving to transmit and gather informaton within the team and create shared mental models. Finally, the boundary spanning role involves those behaviors which serve to maintain a link between the team and external entities and may involve the pulling and pushing of information. However, also occuring within the top five, but not predicted, were the coordinator role (encompassing subroles of team leader and project management) and the visionary/innovator role. The later role involving behaviors related to problem solving and thinking outside the box. Finally, contrary to predictions, behaviors related to the analysis and evaluation of ideas (e.g., critic) did not appear within the top five enacted task roles.

TABLE 6 | Rank ordering of the top five task roles which emerged.

Team role	Rank order	% of comments supporting rank
Boundary spanner	1	55%
Team player	2	14%
Visionary/innovator	3	9%
Coordinator	4	5%
Information provider	5	4%

TABLE 7 | Rank ordering of the top five social roles which emerged.

Team role	Rank order	% of comments supporting rank
Team builder	1	37%
Negativist	2	27%
Entertainer	3	26%
Nurturer	4	3%
Harmonizer	5	2%

Hypothesis 3 pertained to the enactment of social roles. Similar to Hypothesis 2, results suggest partial support for this prediction. As expected, the team builder, entertainer, and nurturer roles were witnessed within the top five most enacted social roles (see **Table 7**). This reflects the importance of positive behaviors that improve the team's social structure and well-being. Specifically, the team builder reflects behaviors which seek to improve and maintain the social structure of the team, including behaviors that foster motivation and harmony. A subrole of this dimension is the nurturer role which primarily focuses on behaviors promoting the physical and emotional well-being of crew members, including personal space. However, the presence of behaviors reflecting an explicit negative outlook (i.e., the negativist) was unexpected. In further examining the results, these role behaviors primarily came from crews involved in the Skylab mission where relations between mission control and the crew degraded to such a point that the crew went on strike. Dropping the mission where the crew went on strike does drastically reduce the prevalence with which these behaviors are seen, but they would still appear within the top five. However, the focus then becomes negative comments related primarily to environmental and equipment conditions, with much less of a focus being on interpersonal negativity. **Table 8** contains a full listing of all team roles which emerged and the frequency with which emergence took place (both task and social).

Additionally, we conducted exploratory analyses to determine the five most commonly enacted roles when looking across the total set of task and social roles. As can be seen in **Tables 8**, **9**, results indicated the following five roles were the most frequently occurring, in order: boundary spanner, team builder, entertainer, negativist, and team player. This last role was closely followed by the presence of the visionary/innovator role. In essence this analysis pits social and task roles against one another to examine the most frequently occurring roles across the set of extreme contexts.

Roles Over Time

Another primary goal of our study was to investigate the degree to which roles may vary across spaceflight contexts in terms of mission duration. As is common with the exploration of phenomena on which there is not a large body of prior work upon which to build hypotheses (and one reason for the approach taken), the hypotheses concerning the specific task and social roles expected to be most prevalent based on temporal duration received mixed support. **Table 10** contains the full list of task and social team roles, their frequency counts and percentages as delineated by temporal duration.

TABLE 8 | Relative frequency of enactment of task and social roles (as compared to one another).

	Across all temporal contexts	
Roles	***n***	**%**
Task roles	258	49
Team player	38	7
Task completer	15	3
Mission support	1	0
Evaluator	6	1
Analyzer/synthesizer	9	2
Information provider	10	2
Clarifier	5	1
Facilitator	1	0
Power seeker	1	0
Boundary spanner	111	22
Visionary/innovator	24	5
Coordinator	15	3
Team leader	17	3
Project manager	5	1
Social roles	267	51
Contribution seeker	3	1
Team builder	88	17
Harmonizer	8	2
Motivator	5	1
Nurturer	12	2
Entertainer	74	14
Attention seeker	8	2
Negativist	25	5
Belittler	–	–
Complainer	44	8

TABLE 9 | Rank ordering of the top five team roles enacted across task and social categories.

Team role	Role type	Rank order	% of comments supporting rank
Boundary spanner	Task	1	22%
Team builder	Social	2	17%
Entertainer	Social	3	14%
Negativist	Social	4	8%
Team player	Task	5	7%

Results indicated that during short missions (i.e., less than 15 days), task team roles emerged twice as frequent (N = 84) as social roles (N = 48), while during medium duration missions (i.e., up to 6 months), the exact opposite role distribution was found between task (N = 44) and social (N = 80) team roles. During long (i.e., up to 1.5 years) and longer spaceflight missions (i.e., more than 2 years), the task (N = 98 in long missions, N = 32 in longer missions) and social (N = 99 in long missions, N = 40 in longer missions) team roles were evenly distributed. It seems that task roles are notably salient in very short missions, while social roles are gaining importance as the duration of the mission

TABLE 10 | Emergence of team roles by temporal duration of mission[4].

	Short duration		Medium duration		Long duration		Longer duration		Across contexts	
Roles	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	**n**	**%**
Task roles										
Team player	13	10	7	6	12	6	6	8	38	7
Task completer	12	9	–	–	–	–	3	4	15	3
Mission support	–	–	–	–	–	–	1	1	1	0
Evaluator	3	2	1	1	2	1	–	–	6	1
Analyzer/synthesizer	–	–	1	1	3	2	1	1	9	2
Information provider	3	2	1	1	3	2	3	4	10	2
Clarifier	2	2	2	2	1	1	–	–	5	1
Facilitator	–	–	–	–	–	–	1	1	1	0
Power seeker	–	–	–	–	1	1	–	–	1	0
Boundary spanner	15	11	24	19	67	34	5	7	111	22
Visionary/innovator	8	6	4	3	2	1	10	14	24	5
Coordinator	7	5	2	2	6	3	–	–	15	3
Team leader	13	10	1	1	1	1	2	3	17	3
Project manager	4	3	1	1	–	–	–	–	5	1
Social roles										
Contribution seeker	1	1			2	1			3	1
Team builder	7	5	22	18	32	16	27	38	88	17
Harmonizer	3	2	–	–	4	2	1	1	8	2
Motivator	2	2	1	1	2	1	–	–	5	1
Nurturer	5	4	1	1	5	3	1	1	12	2
Entertainer	18	14	18	15	30	15	8	11	74	14
Attention seeker	3	2	1	1	4	2	–	–	8	2
Negativist	3	2	8	7	14	7	–	–	25	5
Belittler	–	–	–	–	–	–	–	–	–	–
Complainer	6	5	29	23	6	3	3	4	44	8

[4]*Percentages contained in table are based on the total task and social roles enacted for a given mission.*

TABLE 11 | Frequencies of task and social roles identified for each mission duration.

	Short duration		Medium duration		Long duration		Longer duration	
Roles	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**
Task roles	84	64	44	36	98	50	32	44
Social roles	48	37	80	65	99	50	40	56

increases. At the same time, when the duration of the spaceflight missions exceeds a duration of 6 months both task and social team roles become equally frequent (see **Table 11**). The above set of results tends to support the primary tenets put forth in Hypotheses 4 and 5. Specifically, that the enactment of task roles are the most prominent within missions of short duration, while social roles gain more prominence as mission duration increases.

However, in looking at the predictions as to what particular task and social roles would appear most prominently, we received mixed results (see **Table 10**). One of the top task role categories, similarly frequent in all mission durations, was the team player, highlighting the importance of being willing and prepared to contribute and help whenever and wherever needed. The boundary spanner role also emerged as one of the top task roles in all mission durations, gaining frequence with increasing duration up to long duration missions; during the longer duration missions, the frequence of the boundary spanner was lower compared to the other mission durations. The opposite trend emerged for the third top task role for all mission durations – visionary/innovator; this social role decreased in frequency as mission duration was increasing, demonstrating its lowest frequency during long duration missions. For the longer mission duration, the visionary/innovator role emerged more frequently than in any other mission duration. The task role of team leader, highlighting the importance of leadership-oriented behaviors focusing on directing the teams toward mission completion, was identified as one of the top social roles only in short duration missions.

The entertainer role was one of the top social roles that similarly emerged in all mission durations, demonstrating the

relevance of positive behaviors that serve to bring humor into the team. The team builder was identified as one more top team role in almost all spaceflight contexts, gaining frequence with increasing mission duration. During short duration missions, the frequency of the team builder role was noticeably lower compared to the other mission durations. The complainer team role, reflecting negative behaviors of complaining and whining about social team issues, emerged as one further top social role only for medium mission duration.

DISCUSSION

The use of teams has become ubiquitous within organizations due to the potential for teams to accomplish complex and interdependent work within environments that are increasingly dynamic. A well coordinated team is not only a pleasure to watch, but can bring tremendous rewards to organizations by leveraging the combined intellectual strength of its individual members. However, more often is the case that teams are implemented, yet fail to fully capitalize on the potential synergy present in the team; when capitalized upon, this synergy allows teams to become more than the sum of their individual member contributions. In effort to facilitate the probability that teams can leverage this potential capacity, there has been a tremendous amount of research conducted on the factors that facilitate the ability for members to work in a coordinated and adaptive manner such that they are ready to respond to changes both internal and external to the team. Due to the tremendous growth in team research and the corresponding lessons learned, a great deal of guidance can be currently provided to organizations regarding team dynamics. However, as noted by the editors of this special issue, sorely lacking in the area of team research is guidance pertaining to how the instrumentality of processes, states, and facilitating factors seen in team effectiveness models and team taxonomic efforts may vary due to temporal factors.

Due to the complexity of teams there are a variety of ways that temporal factors could be operationalized within teams, including but not limited to: the moment to moment changes in team process dynamics, oscillations between transition and action phase while engaging in a performance episode, team developmental stage, and/or length of time the team has been together. Within the current study, we have begun to take initial steps to delineate how team roles may vary over time by examining teams operating within extreme environments over short, medium, and long durations. Given our interest in team roles and how they may change over time within extreme teams, we chose to initially investigate this phenomena at a more global level in terms of time. The path we chose was dictated by the fact that, while dynamic, the enactment and switching of roles is most likely not as dynamic as changes in team process, thereby pushing us initially toward a more global view of time. In addition, given the lack of research on team roles over time within teams operating in extreme conditions we did not feel the theory was yet there to begin to predict moment to moment changes at a fine-grained level.

Results of the study speak to the importance of task and social roles within teams that are predominantly intact and operating in extreme environments where mistakes can be life threatening. Additionally, our findings begin to highlight areas of commonality and distinction between these environments and the more traditional organizational environments in which teams have been studied. In essence, while there were many commonalities between the team roles seen in the context of spaceflight and those which appear in the team role taxonomies which appear in the broader literature on teams, there were also differences. In terms of commonalities, task roles such as the team player, coordinator, evaluator/synthesizer, information provider/facilitator were seen. However, far less commonly seen were task related roles that may be considered dysfunctional (e.g., social loafer, power seeker). The decreased prevalence of these roles may be due to the mission critical environment in which the teams in this sample (and many teams in extreme environments) are embedded. Mistakes in these environments can often be extremely costly not only in terms of material, but personal resources – in some cases life threatening.

Many of the differences seen in terms of role enactment dealt with aspects of the social roles. Perhaps most prevalent was the expansion of the traditional jokester role to encompass a more inclusive entertainer role. This role reflects the elevation of mood and team member bonding not only through humor, but also through competitive activities and coming up with novel ways to occupy "down time." Additionally, the team builder role incorporated the notion not only of behaviors which serve to reduce conflict and promote harmony among team members, but behaviors that serve to keep the team motivated, and behaviors that are more "nurturing" by nature. This later aspect of the team building role is one that is not often explicitly mentioned in the team taxonomies that appear in the broader literature. Finally, it is interesting to note that results did suggest a prevalence of behaviors related to negative affect; however, the predominant amount of these affective remarks were not directed at the immediate crew, but were either directed outside the immediate crew, or expressed in relation to conditions or equipment. This points to the fact that the atypical stressors present in the environment do serve to impact the affect of teams within extreme contexts; being resilient in these environments does not mean that negative affect does not occur. Future research should further investigate the mechanisms through which the team deals with the negativity when expressed. It is likely that some of the other social roles seen may serve as a buffer against the negativist comments, but this needs to be further investigated.

Furthermore, the exploration into how mission duration, or the degree of time that the team is embedded within the extreme environment, also revealed interesting findings. In particular, variation in the instrumentality of task role enactment on missions of shorter duration and the increased prevalence of social roles as mission duration increased. This points to the increased attention paid to the socioemotional impact that operating within extreme environments can have on the team and the types of social roles that teams utilize to mitigate some

of these negative effects and remain resilient to the multitude of stressors. Often when examining teams operating in extreme environments there is a tendency to focus on the task-related effects of the stressors, with less of a focus on the socioemotional aspects. The findings from the current study begin to highlight the increased importance of not neglecting the socioemotional health of the team. Additionally, based on the current sample we see the following trends: (1) increased enactment of the team builder role, (2) prominence of the entertainer role, and (3) increased emphasis on the visionary/problem solver role on missions over 2 years. Of additional interest is the continued prevalence of the boundary spanner role even though these teams were operating under conditions of isolation and confinement. In part the prevalence of this role may be an artifact of the sample itself reflecting the communication between the flight crew and mission control. However, the role of boundary spanner has also been seen in extreme teams outside the context of spaceflight (Burke et al., 2018). Future research should continue to investigate the nature and instrumentality of this role under varying levels of isolation and confinement.

Limitations

The examination of archival accounts of teams operating in extreme contexts provides a wealth of contextually rich information concerning real teams operating together over time. However, as with any method, it also has limitations. For example, it does not facilitate an understanding of the relationship of identified team roles to their impact on team processes and emergent states. Additionally, the source documents which were examined to pull critical incidents from were not written with our research questions in mind. While this may be considered a strength, as it may serve to eliminate biases concerning social desirability, given the archival nature it does not negate the possibility that the individual accounts themselves are biased. We attempted to mitigate this possibility to the extent it was possible by collecting information from multiple sources. Related to the fact that the source documents were not written for our specific purposes is the fact that while they were contextually rich they do not provide the level of detail needed in order to investigate team roles at a finer grained temporal level to capture more moment-to-moment changes. Future research should continue to explore these questions using a cross-section of methodologies as each method has its own strengths and weaknesses and it is only through a combination of methodologies that confidence will grow and theory will move forward.

Future Research

The results herein begin to highlight those task and social roles that are important within extreme teams. While we did not explicitly compare high and low performing teams in the current study at some level the teams contained within could be considered effective in that the missions were accomplished without serious bodily harm. Future research should more explicitly investigate differences between high and low performing teams to more finely delineate areas in which team roles are likely to falter as this could point to potential countermeasures. Moreover, investigation into the temporal dynamics relating to team roles is an area that is wide open. We have begun to provide some initial findings herein as to how time may impact the type of team roles which are enacted. However, future research could begin to examine how often the informally defined team roles examined herein are associated with team enactment of action and transition phases during performance episodes. Leveraging work by Marks et al. (2001), one could imagine that the enactment of particular team roles could be used to drive the efficiency and effectiveness of the phases of cyclical activity which comprise performance episodes. Additionally, future research could begin to highlight those roles that are essential to move teams along different phases of the developmental continuum.

Up to this point, team roles and many other team factors have tended to primarily been examined at a single point in time (usually at the end of the mission), with little attention paid to how the myriad of temporal factors present may impact how they evolve and change with regard to their implementation or instrumentality. It is our hope that the findings presented here and the many new questions that emerge will serve to spur future research in this area.

AUTHOR CONTRIBUTIONS

All authors contributed to the writing and assisted in the theoretical development of the manuscript. CB was responsible for conceptualization of the manuscript.

FUNDING

This work was supported by funding from the National Aeronautics and Space Administration (Grant NNX16AB08G). The views expressed in this work are those of the authors and do not necessarily reflect the organizations with which they are affiliated or their sponsoring institutions.

REFERENCES

Ancona, D. G., and Caldwell, D. F. (1988). Beyond task and maintenance: defining external functions in groups. *Group Organ. Manag.* 13, 468–494. doi: 10.1177/105960118801300405

Ancona, D. G., and Caldwell, D. F. (1992). Bridging the boundary: external activity andperformance in organizational teams. *Adm. Sci. Q.* 37, 634–665.

Antonakis, J., Avolio, B. J., and Sivasubramaniam, N. (2003). Context and leadership: an examination of the nine-factor full-range leadership theory using the multifactor leadership questionnaire. *Leadersh. Q.* 14, 261–295. doi: 10.1016/S1048-9843(03)00030-4

Baker, D. P., Day, R., and Salas, E. (2006). Teamwork as an essential component of high-reliability organizations. *Health Serv. Res.* 41, 1576–1598. doi: 10.1111/j.1475-6773.2006.00566.x

Bales, R. F. (1950). A set of categories for the analysis of small group interaction. *Am. Sociol. Rev.* 15, 257–263.

Bechtel, R. B., and Berning, A. (1991). "The third-quarter phenomenon: do people experience discomfort after stress has passed?," in *From Antarctica to Outer Space*, eds A. A. Harrison, Y. A. Clearwater, and C. P. McKay (New York, NY: Springer), 261–265. doi: 10.1007/978-1-4612-3012-0_24

Belbin, R. M. (1993). *Team Roles At Work*. Oxford: Butterworth-Heinemann.

Belbin, R. M. (1981). *Management Teams: Why They Succeed or Fail*. London: Heinemann.

Bell, S. T., Fisher, D. M., Brown, S. G., and Mann, K. E. (2018). An approach for conducting actionable research with extreme teams. *J. Manag.* 44, 2740–2765. doi: 10.1177/0149206316653805

Benne, K. D., and Sheats, P. (1948). Functional roles of group members. *J. Soc. Issues* 4, 41–49. doi: 10.1111/j.1540-4560.1948.tb01783.x

Bradley, J., White, B. J., and Mennecke, B. E. (2003). Teams and tasks: a temporal framework for the effects of interpersonal interventions on team performance. *Small Group Res.* 34, 353–387. doi: 10.1177/1046496403034003004

Burke, C. S., Driskell, T., Driskell, J., and Salas, E. (2016). Moving towards a better understanding of team roles in isolated, confined environments. *Paper Presented at the 2016 Human Research Program Investigators Workshop (NASA)*, Galveston, TX.

Burke, C. S., Georganta, E., and Hernandez, C. (2017). "The importance of time in team leadership research," in *Team Dynamics Over Time Research on Managing Groups and Teams*, Vol. 18, eds E. Salas, W. B. Vessey, and L. B. Landon (London: Emerald Publishing), 95–122. doi: 10.1108/s1534-085620160000018005

Burke, C. S., Priest, H. A., Salas, E., Sims, D., and Mayer, K. (2008). "Stress and teams: how stress affects decision making at the team level," in *Making Decisions Under Stress: Implications for Individual and Team Training*, eds J. A. Cannon-Bowers and E. Salas (Washington, DC: American Psychological Association), 181–208.

Burke, C. S., Shuffler, M. L., and Wiese, C. W. (2018). Examining the behavioral and structural characteristics of team leadership in extreme environments. *J. Organ. Behav.* 39, 716–730. doi: 10.1002/job.2290

Callaway, M. R., Marriott, R. G., and Esser, J. K. (1985). Effects of dominance on group decision making: toward a stress-reduction explanation of groupthink. *J. Pers. Soc. Psychol.* 49, 949–952. doi: 10.1037/0022-3514.49.4.949

Chong, E. (2007). Role balance and team development: a study of team role characteristics underlying high and low performing teams. *J. Behav. Appl. Manag.* 8, 202–217.

Cicchetti, D. V. (1994). Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychol. Assess.* 6, 284–290. doi: 10.1037/1040-3590.6.4.284

Cooper, H. S. F. (1976). *A House in Space*. New York, NY: Holt, Rinehart and Winston.

Crayne, M. P., and Hunter, S. T. (2018). Historiometry in organizational science: renewed attention for an established research method. *Organ. Res. Methods* 21, 6–29. doi: 10.1177/1094428117731879

DeChurch, L. A., Burke, C. S., Shuffler, M. L., Lyons, R., Doty, D., and Salas, E. (2011). A historiometric analysis of leadership in mission critical multiteam environments. *Leadersh. Q.* 22, 152–169. doi: 10.1016/j.leaqua.2010.12.013

Dietz, A. S., Driskell, J. E., Sierra, M. J., Weaver, S. J., Driskell, T., and Salas, E. (2017). "Teamwork under Stress," in *The Wiley Blackwell Handbook of the Psychology of Team Working and Collaborative Processes*, eds S. Eduardo, P. Jonathan, and R. Ramon (Hoboken, NY: John Wiley & Sons Ltd), 297–315. doi: 10.1002/9781118909997.ch13

Driskell, J. E., and Salas, E. (1991). Group decision making under stress. *J. Appl. Psychol.* 76, 473–478. doi: 10.1037/0021-9010.76.3.473

Driskell, J. E., Salas, E., and Johnston, J. (1999). Does stress lead to a loss of team perspective? *Group Dyn.* 3, 291–302. doi: 10.1037/1089-2699.3.4.291

Driskell, T., Driskell, J. E., Burke, C. S., and Salas, E. S. (2017). Team roles: a review and integration. *Small Group Res.* 48, 482–511. doi: 10.1177/1046496417711529

Driskell, T., Salas, E., and Driskell, J. E. (2018). Teams in extreme environments: alterations in team development and teamwork. *Hum. Res. Manag. Rev.* 28, 434–449. doi: 10.1016/j.hrmr.2017.01.002

DuBrin, A. J. (1995). *The Breakthrough Team Player: Becoming the MVP on Your Workplace Team*. New York, NY: AMACOM. NASA technical report, NAG2-387.

Ellis, A. P., and Pearsall, M. J. (2011). Reducing the negative effects of stress in teams through cross-training: a job demands-resources model. *Group Dyn.* 15, 16–31. doi: 10.1037/a0021070

Evans, G. W., Stokols, D., and Carrére, S. (1987). *Human Adaptation to Isolated and Confined Environments*. Moffett Field, CA: NASA-Ames Research Center.

Flanagan, J. C. (1954). The critical incident technique. *Psychol. Bull.* 51, 327–358.

Foale, C. (1999). *Waystation to the Stars: The Story of Mir, Michael, and Me*. London: Headline Book Publishers, Ltd.

Foushee, H. C., and Helmreich, R. L. (1988). "Group interaction and flight crew performance," in *Academic Press Series in Cognition and Perception. Human Factors in Aviation*, eds E. L. Wiener and D. C. Nagel (San Diego, CA: Academic Press), 189–227. doi: 10.1016/b978-0-08-057090-7.50013-8

Gardner, H. (1993). *Creating Minds: An Anatomy of Creativity Seen Through the Lives of Freud, Einstein, Picasso, Stravinsky, Eliot, Graham, and Gandhi*. New York, NY: Basic Books.

Gersick, C. J. (1991). Revolutionary change theories: a multilevel exploration of the punctuated equilibrium paradigm. *Acad. Manag. Rev.* 16, 10–36. doi: 10.5465/amr.1991.4278988

Hackman, J. R., and Wageman, R. (2005). A theory of team coaching. *Acad. Manag. Rev.* 30, 269–287.

Hannah, S. T., Uhl-Bien, M., Avolio, B. J., and Cavarretta, F. L. (2009). A framework for examining leadership in extreme contexts. *Leadersh. Q.* 20, 897–919. doi: 10.1016/j.leaqua.2009.09.006

Hayes, A. F., and Krippendorff, K. (2007). Answering the call for a standard reliability measure for coding data. *Commun. Methods Meas.* 1, 77–89. doi: 10.1080/19312450709336664

Janis, I. L. (1972). *Victims of Groupthink: A Psychological Study of Foreign-Policy Decisions and Fiascoes*. Oxford: Houghton Mifflin.

Ken Blanchard Companies (2006). *The Critical Role of Teams*. Available at: http://www.kenblanchard.com/Leading-Research/Research/The-Critical-Role-of-Teams (accessed April 10, 2019).

Kozlowski, S. W. J., Watola, D. J., Jensen, J. M., Kim, B. H., and Botero, I. C. (2009). "Developing adaptive teams: a theory of dynamic leadership," in *Team Effectiveness in Complex Organizatons: Cross-Disciplinary Perspectives and Approaches*, eds E. Salas, G. F. Goodwin, and C. S. Burke (Mahwah, NJ: LEA), 113–156.

Lebedev, V. (1990). *Diary of a Cosmonaut: 211 Days in Space*. New York, NY: Bantam Books.

Margerison, C., and McCann, D. (1985). *How to Lead a Winning Team*. Bingley: MCB University Press.

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manag. Rev.* 26, 356–376. doi: 10.5465/amr.2001.4845785

Mathieu, J. E., Maynard, M. T., Rapp, T., and Gilson, L. (2008). Team effectiveness 1997-2007: a review of recent advancements and a glimpse into the future. *J. Manag.* 34, 410–476. doi: 10.1177/0149206308316061

Mathieu, J. E., Tannenbaum, S. I., Kukenberger, M. R., Donsbach, J. S., and Alliger, G. M. (2015). Team role experience and orientation: a measure and tests of construct validity. *Group Organ. Manag.* 40, 6–34. doi: 10.1177/1059601114562000

Mohammed, S., Hamilton, K., and Lim, A. (2009). "The incorporation of time in team research: past, current, and future," in *Team Effectiveness in Complex Organizations: Cross-Disciplinary Perspectives and Approaches (Society for Industrial and Organizational Psychology Frontier Series)*, eds E. Salas, G. F. Goodwin, and C. S. Burke (Mahwah, NJ: Erlbaum).

Morgeson, F. P., DeRue, D. S., and Karam, E. P. (2010). Leadership in teams: a functional approach to understanding leadership structures and processes. *J. Manag.* 36, 5–39. doi: 10.1177/0149206309347376

Mullane, M. (2007). *Riding Rockets: The Outrageous Tales of a Space Shuttle Astronaut*. New York, NY: Scribner.

Mumford, T. V., Campion, M. A., and Morgeson, F. P. (2006). "Situational judgment in work teams: a team role typology," in *Situational Judgment Tests: Theory, Measurement, and Application*, eds J. A. Weekley and R. E. Ployhart (Mahwah, NJ: Erlbaum), 319–343.

Parker, G. M. (1994). *Cross-Functional Teams*. San Francisco, CA: Jossey-Bass.

Parker, G. M. (1996). *Team Players and Teamwork*. San Francisco, CA: Jossey-Bass.

Prichard, J., and Stanton, N. A. (1999). Testing belbin's team role theory of effective groups. *J. Manag. Dev.* 18, 652–665. doi: 10.1108/02621719910371164

Roberts, K. H. (1990). Managing high reliability organizations. *Calif. Manage. Rev.* 32, 101–113. doi: 10.2307/41166631

Salas, E., Dickinson, T. L., Converse, S. A., and Tannenbaum, S. I. (1992). "Toward an understanding of team performance and training," in *Teams: Their Training and Performance*, eds R. W. Swezey and E. Salas (Norwood, NJ: Ablex).

Shayler, D. J. (2006). *Around the World in 84 Days: The Authorized Biography of Skylab Astronaut Jerry Carr*. Burlington, ON: Collector's Guide Publishing.

Simonton, D. K. (1990). *Psychology, Science, and History: An Introduction to Historiometry*. New Haven, CT: Yale University Press Psychology.

Simonton, D. K. (1998). Historiometric methods in social psychology. *Eur. Rev. Soc. Psychol.* 9, 267–293. doi: 10.1080/14792779843000108

Simonton, D. K. (2003). Qualitative and quantitative analyses of historical data. *Annu. Rev. Psychol.* 54, 617–640. doi: 10.1146/annurev.psych.54.101601.145034

Sorokin, P. A. (1943). *Sociocultural Causality, Space, Time*. Durham, N.C: Duke University Press.

Steel, G. D. (2001). Polar moods: third-quarter phenomena in the Antarctic. *Environ. Behav.* 33, 126–133. doi: 10.1177/00139160121972909

Stewart, G. L., Fulmer, I. S., and Barrick, M. R. (2005). An exploration of member roles as a multilevel linking mechanism for individual traits and team outcomes. *Pers. Psychol.* 58, 343–365. doi: 10.1111/j.1744-6570.2005.00480.x

Stewart, G. L., Manz, C. C. M., and Sims, H. P. (1999). *Team Work and Group Dynamics*. New York, NY: John Wiley & Sons.

Tuckman, B. W. (1965). Developmental sequence in small groups. *Psychol. Bull.* 63, 384–399. doi: 10.1037/h0022100

Weick, K. E., Sutcliffe, K. M., and Obstfeld, D. (1999). Organizing for high reliability: processes of collective mindfulness. *Res. Organ. Behav.* 21, 81–123.

Wilson, K. A., Burke, C. S., Priest, H. A., and Salas, E. (2005). Promoting health care safety through training high reliability teams. *Qual. Saf. Health Care* 14, 303–309. doi: 10.1136/qshc.2004.010090

Zimmerman, R. (2003). *Leaving Earth: Space Stations, Rival Superpowers, and the Quest for Interplanetary Travel*. Washington, DC: Joseph Henry Press.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Burke, Georganta and Marlow. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

REVIEW
published: 13 June 2019
doi: 10.3389/fpsyg.2019.01324

Advancing Teams Research: What, When, and How to Measure Team Dynamics Over Time

*Fabrice Delice[1], Moira Rousseau[1] and Jennifer Feitosa[2]**

[1] Brooklyn College, City University of New York, Brooklyn, NY, United States, [2] Claremont McKenna College, Claremont, CA, United States

Teams are complex and dynamic entities that face constant changes to their team structures and must simultaneously work to meet and adapt to the varying situational demands of their environment (Kozlowski and Ilgen, 2006). Agencies, industries, and government institutions are currently placing greater attention to the influence on team dynamics and teamwork as they are important to key organizational outcomes. Due to increased emphasis being placed upon the understanding the maturation of team dynamics, the incorporation of efficient methodological tools to understand how teams are being measured over time becomes critical. Thus, the purpose of this paper is to present a review of relevant academic articles detailing the science behind methodological tools and general approaches to study team dynamics over time. We provide an overview of the methodological tools used to understand team dynamics with accordance to specific temporal elements. Drawing from Kozlowski et al. (1999) process model of team development, we highlight relevant emergent team constructs within each stage. As well, for each stage, we discuss the what and how to measure team dynamics. Our analyses bring to light relevant, novel and complex approaches being used by researchers to examine specific constructs within different team developmental phases (e.g., agent-based simulations, computational modeling) and the importance of transitioning from a single source methodology approach. Implications and future research are also discussed.

Keywords: teamwork, temporal elements, methodological tools, team phases, measurement

OPEN ACCESS

Edited by:
Marissa Shuffler, Clemson University, United States

Reviewed by:
Jose Navarro, University of Barcelona, Spain
Lauren Blackwell Landon, KBRwyle, United States

***Correspondence:**
Jennifer Feitosa
jennfeitosa@outlook.com

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *03 December 2018*
Accepted: *21 May 2019*
Published: *13 June 2019*

Citation:
Delice F, Rousseau M and Feitosa J (2019) Advancing Teams Research: What, When, and How to Measure Team Dynamics Over Time. Front. Psychol. 10:1324. doi: 10.3389/fpsyg.2019.01324

INTRODUCTION

A variety of global forces have led to the continuous implementation of teams across all different areas of the modern work industry (Cross et al., 2016; O'Neill and Salas, 2018). Driven by competition and consolidation, the current workforce requires fast response time, increased levels of expertise, and shared pools of knowledge that only effective teams have the ability to bring forth (Kozlowski et al., 1999). Teams, which can be defined as "distinguishable sets of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective" (Salas et al., 1992, p. 4), possess different attitudes, behaviors, and cognitions that are constantly shaped and influenced by that of other team members, and vice-versa (Dyer, 1984; Kozlowski and Chao, 2018). Ernst & Young Global Limited (2013) found that over 90% of organizations believe that teams increase employee participation and performance and as a result,

they are adjusting accordingly to benefit the possibility of achieving these desired outcomes. For example, innovation and service-oriented organizations such as 3M and Nestlé have decentralized and instead use shared service and information centers, as well as implemented teams to maintain productivity and alignment with overall business strategies (McDowell et al., 2016).

Brought on by an influx of emphasis on teams within organizational settings, a considerable amount of research has been conducted in efforts to determine what specific characteristics actually lead to the most successful team outcomes (Humphrey and Aime, 2014). What is important to understand is that as extremely complex dynamic systems, teams consistently develop over time as members evolve and adapt to the varying situational demands they continuously face (Kozlowski and Ilgen, 2006). In addition, teams are also heavily influenced by a variety of other factors (e.g., individual personalities, working relationships amongst members of the team, roles, culture, external factors, and time) (Myers, 2013). Although researchers such as Arrow et al. (2000), have characterized teams as complex adaptive systems (CAS) and multiple theoretical frameworks have emerged to capture and explain this idea, relatively few empirical work have actually been able to examine how long it takes for teams to be effective and how these effects unfold and develop over time (Kozlowski and Bell, 2003; Ramos-Villagrasa et al., 2018; Devaraj and Jiang, 2019). In fact, most empirical studies that have incorporated the idea of emergent states within teams have mainly operationalized the various related constructs through the use of weak methodological tools, such as self-report measurements. These are often incapable of capturing temporal aspects that influence teams which only illustrate teams in a static nature (Carter et al., 2018). Therefore, though useful, self-report measures risk the creation of inaccurate conclusions, as team members may report inaccurate perceptions based on their limited ability to view all aspects of the perceived construct being measured.

Accordingly, in the past few decades, various amounts of team researchers have developed frameworks in efforts to illustrate the unpredictable course of team dynamics. However, the fact that teams are constantly and dynamically ever-changing in terms of their processes, tasks, and context makes this a very difficult task (Miller, 2003). For example, Tuckman's (1965) theory regarding the four developmental stages of small groups (e.g., forming, storming, norming, and performing), though important to teams literature as it explains that all teams go through phases as they grow, face challenges, find solutions, and deliver results, presents limitations to team's research because it is meant to be hierarchical in nature. In other words, teams are not able to reach the next stages unless the previous stage has been accomplished. Later developments have shown that this may not always be the case. In McGrath's (1984) input-process-output (I-P-O) model, which has had a large influence on team dynamics research, *process* signified how members are able to combine efforts and knowledge to complete a specific task. However, despite implying team interaction, much research pertaining to process assess them only "as static retrospective perceptions" (Kozlowski and Chao, 2018, p. 578). Moreover, the I-P-O model fails to take into account that all mediational factors are not necessarily processes (Ilgen et al., 2005). Marks et al. (2001) developed a temporally based framework and taxonomy of team processes, noting that many constructs presented by researchers trying to invoke the I-P-O actually invoke emergent cognitive or affective states. Most recently, Ramos-Villagrasa et al. (2018) conducted a systematic review of the science of teams, under the logic that teams operate as CAS. As CASs, teams constantly adapt to tackle environmental occurrences, and make decisions based on the team's history and expected outcomes of the future (Arrow et al., 2000). In examining teams through this lens, researchers are given the opportunity to view teams in a non-linear, more dynamic way. Such a method has been seen as crucial to teams research because in adapting a non-traditional lens to study teams, researchers are better able to deal with temporal issues and provide insight for better practical application (McGrath et al., 2000; Navarro et al., 2015).

All dynamic constructs are theorized to change over time, thus the use of inadequate methods of measurements often can result in inaccurate representations and unsubstantiated views of actual team dynamics. Given that no measure can ever be the perfect representation of the construct it is trying to represent and that some constructs surface and become more apparent at different stages within the team's lifespan, researchers must consider a wider array of options to actually achieve the optimal assessment. While theories and frameworks attempt to capture team dynamics in a non-static light, not only do gaps in the literature still remain present in terms of how these dynamics can be accurately measured over time, methods of actual implementation have not progressed at a similarly. Despite being in the era of teams, teams research has not given enough consideration to temporal issues that often arise (e.g., Argote and McGrath, 1993; Kozlowski and Bell, 2003; Ilgen et al., 2005; Mohammed et al., 2009), as it is often regarded as one of the most neglected critical issue in teams research (Kozlowski and Bell, 2003). Accordingly, time should not just be regarded as the backdrop of events, but rather the lens through which the emergence of different behaviors, attitudes, and cognitions are observed (Ancona et al., 2001).

Namely, in order to effectively understand team dynamics, it is critical to examine what team emergent states and processes are most important, highlighting the *when*, *what*, and *how* to measure team dynamics over time. More specifically, the key challenge is to not only recognize time and temporality, but the study's design, data collection, and the methodologies behind team dynamics (Stewart, 2010), allowing researchers to effectively replicate and understand states of team dynamics through organizational and team processes. The purpose of this current paper is to provide an overview of the methodological tools and general approaches used to understand team dynamics depending on the temporal elements. Drawing from Kozlowski et al. (1999) process model of team development in combination with an A-B-C (i.e., attitudes, behaviors, and cognitions) framework, we highlight measurement idiosyncrasies of team dynamics as the team develops. First, we conduct a systematic review of scientific articles that utilize methodological tools and general approaches to measuring team dynamics over time. Secondly, articles are

coded with the intent to extract themes regarding how team dynamics are measured at team formation, task compilation, role compilation, team compilation, and team maintenance. We then provide temporal considerations in which we identify the most efficient way to capture these. Lastly, we identify opportunities to further push more rigorous research and science in terms of team dynamics measurement.

METHODOLOGY

In these sections, we briefly summarize our theoretical and methodological approaches. Specifically, we define the scope of team dynamics and the A-B-C framework (Kozlowski et al., 1999) and describe the inclusion criteria and conceptual coding we used to inform the assumptions and their proposed revisions.

Theoretical Approach

A-B-C Framework

As developing and maintaining effective teams has become a crucial topic, a myriad amount of research has been developed in an attempt to explain what conditions actually contribute to its successes and failures (Salas et al., 2015b). In an effort to consolidate key findings regarding teamwork and offer a more overarching, practical, and concise means of understanding it, Salas et al. (2008) developed the A-B-C framework for understanding teamwork. Three important aspects to teamwork that the framework depicts include the attitudes, shared behaviors, and cognitions of the individuals that make up the team. Arrow et al. (2000) define the attitudes, behaviors, and cognitions among team members as local dynamics, as they exist within the context of that specific team. Conceptually, team dynamics are embedded within team performance and are comprised of a set of these interrelated attitudes, shared behaviors, and cognitions, all of which contribute to the dynamic processes of performance. Shared behaviors specifically describe what team members do (e.g., communication, collaboration, conflict, and leadership styles). Attitudes, or what team members believe or feel include openness, trust, cohesion, and team viability. Cognitions, which include transactive memory, shared mental models, information and knowledge exchange, are what team members think or know.

These behaviors, attitudes and cognitions are in part what makes teamwork an adaptive, dynamic, and episodic process that is instrumental toward being able to achieve a common goal. The combined efforts of teamwork are necessary for effective team performance and positive outcomes, as it defines how tasks and goals are accomplished in a team context. Research has shown that if team members are not able to successfully share knowledge, trust each other, be open, and coordinate behaviors, teams have an increased likelihood if failing, even if they possess an extensive amount of task relevant knowledge (Mathieu et al., 2008). The aforementioned constructs often act as "emergent states," which means they can become present as team members interact with one another across different performance episodes (Marks et al., 2001). The limited amount of research examining the emergent states of these constructs, likely due to logistical constraints put on researchers, complicates and restrains our understanding of their temporal nature (Salas et al., 2015a). Not all findings regarding different constructs can be generalized to all teams, especially when they are not measured over the same period of time, contexts or conditions. The A-B-C framework proves extremely useful in that it captures the elements that together shape team dynamics. In identifying these elements, researchers are able to take steps to better develop practices that can promote optimal teamwork, but only when contextual and temporal aspects are also taken into account. Research has shown that to fully understand teams, how they develop and change over time must be examined as well (Gully, 2000).

Temporal Frameworks

It is widely understood that teams possess a past, present and future (McGrath et al., 2000). To thoroughly understand team dynamics, it is important that researchers expand our understanding of how teams develop over time. Several temporal frameworks have been developed in an effort to address the need. As discussed by Luciano et al. (2018), different temporal frameworks should be considered when examining dynamic constructs, as different forms and varieties of time can have substantial implication for our understanding of teams. Namely, developmental theories (e.g., Tuckman and Jensen, 1977; Ford, 2014) suggest that all teams change as a function of their development over time. A frequent occurrence within developmental theories is that stages build over each other at qualitatively different stages, thus suggesting that when measured it must be taken into account that different teams may develop at dramatically different paces. Further, episodic models (e.g., McGrath, 1991; Marks et al., 2001; Jarvenpaa and Majchrzak, 2016) suggest that teams can complete different tasks within different time frames, all whilst being directed at the same goal. In other words, a common theme amongst episodic models and theories is that different processes are activated at different times based on the specific demands of the team's tasks, implying that in order to measure dynamic constructs more accurately, they must be measured at different times as they relate to the cyclical patterns of team activity (Luciano et al., 2018). Other temporal frameworks (e.g., Barley, 1986; Weiss and Cropanzano, 1996; Park, 2010) dictate that external stimuli, such as environmental events also influence internal team processes. This implicates that research should also focus on assessing constructs before, during, and after the occurrence of such environmental events as a way to fully understand the dynamic nature of teams (Luciano et al., 2018).

Methodological Approach

Literature Search and Inclusion Criteria

This review collected and examined relevant articles that presented methodological tools and general approaches in measuring team dynamics overtime. Articles were accumulated through the use of research database sources. Searches were utilized through the electronic search engines EBSCOhost with PsycINFO and Business Source Complete being the main electronic databases. In order to generate a targeted collection of findings, we had to undergo a number of steps to find emergent

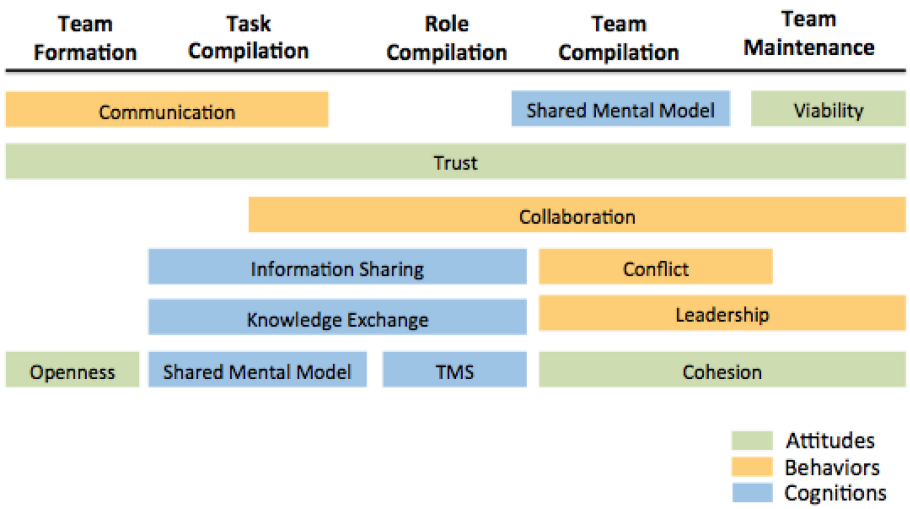

FIGURE 1 | Model illustrating constructs present during team developmental stages.

processes within team development. First, we explored team emergent processes in regards to team attitudes, behavior, and cognition by examining a literature review on the role of intra-team state profiles by Shuffler et al. (2018). Second, two of the authors garnered a list of specific constructs that develop within intra-team development by examining Kozlowski and Bell (2003), who wrote an extensive review chapter on the creation, development, and operation of work teams within the different phases of team's life cycle. As well, Taras et al. (2010) meta-analysis was also used as a reference for team emergent processes (e.g., group cohesiveness, trust, and conflict). Two of the authors held a meeting to discuss the most prominent team constructs by using the three articles to cross reference and come to a consensus. In all, four constructs across the attitude, behavior, and cognition model were developed as illustrated by **Figure 1**.

Our next step involved conducting a computerized search for each construct within the research database EBSCOhost. Using PsycINFO and Business Source Complete, we reviewed relevant articles through the combination of teams and the four emergent processes within the conceptual categorization of attitudinal, behavioral, and cognitive team constructs (see **Table 1** for a list of the final constructs). For instance, within EBSCOhost, researchers applied transactive memory system (TMS) within the first field option and teams within the second field option. As mentioned, only relevant articles were used with each search item displaying the title, authors, keywords, and abstracts. Two authors coded 50 articles for each search item in order to extract the most significant studies as well as keep the searches consistent. In all, 600 articles were examined.

Our literature analysis consisted of all source types as we did not limit our examinations to any publication dates. The selection process involved scanning the abstract and text for empirical studies as our main concern was to examine the methodological tools that team researchers are using to measure team dynamic processes. Articles were pulled if they presented sufficient information as to the approach in which teams were being studied and if team process was measured within collective team behaviors. Theoretical studies were not included as our main focus was toward empirical team studies. With a consistent and thorough inspection, 303 articles remained for analysis. Of these 303 articles, 51 were found to use novel methodology in their examination of team dynamics (see **Table 1** for details).

Conceptual Coding and Literature Linking

Once the remaining articles were identified, two of the authors undertook the process of coding each study into an Excel sheet. Over 20 articles were coded together and discussed. The other remaining articles were then independently coded. For each search item (e.g., cohesion and teams), the excel sheet contained the articles abstracts, methodology/general approaches, the study type (e.g., laboratory/survey, field study/focus group, etc.), types of teams (e.g., virtual, managers), construct measured input, measured used, and how the team data was analyzed. Coders also examined the mediators, moderators and construct measured outputs of each article. A final verdict for each article measurement in regards to whether being a novel tool or what can be considered as new or improved techniques that allow for innovation in assessing team process dynamics (e.g., virtual experimentation) was also established. Classic methods, on the other hand, were classified as such if they were done through self-reported questionnaires, focus groups, case studies, or interviews. Although more articles fell within the realm of attitudinal and cognitive emergent states, novel measures are being mostly applied to either these cognitive emergent states or behavioral team processes.

ROLE OF TEAM DYNAMICS IN TEAM DEVELOPMENT

In the section that follows, relevant literature is compared on the basis of the most common forms of team measurements

TABLE 1 | Summary of literature search findings.

Constructs	Relevant articles pulled	Novel measurements
Attitudes		
Openness	25	• **Mind game lab experiment:** tested the interactions between cultural intelligence and openness on the perception of task performance (Duff et al., 2012). • **Distributed Dynamic Decision-Making Simulation:** used to examine how the performance of diverse teams is affected by member openness to experience and the extent to which team reward structure emphasizes intragroup differences (Homan et al., 2008). • **Strategic Decision-Making Simulation:** participants practiced decision-making and leadership skills in team contexts (Quigley, 2013).
Trust	28	• **Longitudinal experiment:** used repeated investigations of the same participants over three stages of collaboration to measure the influence of facilitated collaboration principles on trust development in global virtual collaboration (Cheng et al., 2016). • **Collaborative experiential learning approach:** tested the effects of collaborative learning on the development of cultural intelligence, trust, and global and local identity in virtual multicultural teams (Erez et al., 2013). • **High-fidelity simulation task:** participants completed a sequence of performance episodes to study the temporal variations in the buffering effect of trust in teammates (Burtscher et al., 2018).
Cohesion	28	• **Team laboratory experiment:** used team task involving analyzing a business case to examine the role of team political skill in predicting team effectiveness (Lvina et al., 2018). • **Comparative Performance Assessment:** used to test the antecedents and performance outcomes of social cohesion across three levels (e.g., within team cohesion, between team cohesion, and between firm cohesion (Shaner et al., 2016). • **Experiential team learning:** team members engaged in various team-based tasks and activities with their fellow teammates to understand how and in what conditions team charter quality affects team performance (Courtright et al., 2017). • **Longitudinal laboratory experiment:** used to examine the effects of intervention strategies combining team feedback and guided reflexivity on virtual teams' affective outcomes and the mediating role of perceived social loafing in this relationship (Peñarroja et al., 2017). • **Three-wave longitudinal organizational simulation:** Participants were charged with three creativity tasks to examine the role of collective engagement in the relationship between team cohesion and team creative performance (Rodríguez-Sánchez et al., 2017). • **Dynamic Decision-Making Simulation:** Teams participated in firefighting scenarios to examine the relationships between coordination, action processes and trust and team performance (Hagemann and Kluge, 2017). • **Time series analysis:** Used temporal properties to examine the way changes in task-cohesion and shared understanding were experienced over time in sports teams (Bourbousson and Fortes-Bourbousson, 2017).
Team Viability	21	• **Computer game based simulation:** Examined the relationship between leadership and team viability, mediated by task cohesion through team based game that required team to run a fictional city (Curral et al., 2017). • **Computer game based simulation:** Participants performed simulated search and capture tasks to understand the relationship between team cognitive ability and personality composition (Resick et al., 2010).
Behaviors		• **Videotape and software coding:** Developed a temporal account of team interaction by recording team meetings and coding agreement and disagreement behaviors (Lehmann-Willenbrock and Chiu, 2018).
Collaboration	16	• **Concept mapping:** Examined the impact of learners' conflict resolution on deeper learning as measured by knowledge convergence in teams (Chen et al., 2018). • **Cross-border e-business website analysis:** incorporated collaboration engineering techniques to examine how team collaboration and trust develops in globally distributed teams (Cheng et al., 2016). • **Role-play simulation:** Helped understanding of an unfamiliar and challenging situation that require cooperation and collaboration amongst teams to improve outcomes (Hayes et al., 2018). • **Synthetic task environment:** Allowed the examination of the effect of group-level information-pooling bias on collaborative incident correlation (Rajivan and Cooke, 2018)
Communication	17	• **Temporal distance lab experiment:** used objective speed and product quality completion tasks to examine the direct associations between temporal distance and team performance as well as the mediating role of team interaction (Espinosa et al., 2015). • **Enterprise Social Media (ESM) task:** Online discussion threads were collected with unbounded and bounded visibility to examine communication ties as conduits to critical external resources (Van Osch and Steinfield, 2018).

(Continued)

TABLE 1 | Continued

Constructs	Relevant articles pulled	Novel measurements
Conflict	24	• **Scenario based study:** Helped studied how nationality composition (size of national diversity or number of nationalities) and context (nature of national diversity or types of nationalities) affects perceived conflict and expected performance (Ayub and Jehn, 2018). • **IMEx Business Simulation:** Used as a tool to study the consequences of relational conflicts and conflict asymmetry experienced by team members (Boroş et al., 2017). • **Critical Incident Technique:** Helped examine cultural challenges and benefits, sources of learning, and value-based differences in critical events (Brunton and Cook, 2018). • **Concept mapping:** Used as a tool to examine the impact of learners' conflict resolution on their learning as measured by knowledge convergence (Chen et al., 2018). • **Glo-Bus business simulation:** Used as a tool to examine team performance in relations to how teams handle friendship and conflicts (Hood et al., 2017). • **Team paintball game:** Help asses coalitional aggression through a simulated coalitional combat paradigm (Pollack et al., 2018). • **Video-coding and team decision task (intra-team negotiation):** Used as a tool to measure team members power struggles through team decision task in intra-team negotiations (Van Bunderen et al., 2018).
Leadership	30	• **Video recorder-eye scanning:** Help observers examine the eye gazing patterns of project teams in a meeting (Gerpott et al., 2018). • **Leadership Development Simulation (LDS):** Help examine team members risk preferences, team performance, aspirational behavior, and unwarranted risk behaviors (Lanaj et al., 2018).
Cognition		
Transactive Memory System	40	• **Blog tool and statement Q-sort:** Blog tool allowed the study of virtual teams communication, coordination, and the development of TMS (Bastida et al., 2017). • **Video game:** Examine role of relational communication within the development of TMS (Kahn and Williams, 2016). • **StarJet Airways Management Simulator:** "Study role-specific versus cross-role preparation on subsequent team-level performance in a complex decision-making task" (Linton et al., 2018. p. 45). • **Audio-video recording and Hidden profile task:** Study team discussions to assess the team process through transactive retrieval and information processing (Mell et al., 2014).
Shared Mental Model	27	• **Traditional ICT (synchronous text-chat):** Examine team interaction and collective mindfulness behaviors (Curtis et al., 2017). • **Face-to-face or virtual (via chat):** Examine team reflections between face-to-face interactions versus virtual chats (Konradt et al., 2015). • **hboxQ-methodology (sort photographs):** Examine participants' cognitive structures, attitudes, and perceptions (Lingard et al., 2015). • **Dynamic team task and simulated partial system failure:** Helped examine team adaptation and performance through studying a team's shared knowledge and standardized communication with an unforeseen change (Sander et al., 2015). • **Business simulation the Global Management Challenge:** Allowed for the examination of team performance in a fictitious business through company's' financial indicators, shared price and ranking relative to the other teams (Santos et al., 2015). • **Computer-based Networked Fire Chief (NFC) simulation task:** Help examine team effectiveness, team mental models, and team action patterns in the scenario of extinguishing fires (Uitdewilligen et al., 2018). • **Computer-based Networked Fire Chief (NFC) simulation task:** Used to study teams in a collaborative scenario in an emergent and dynamic environment consisting of extinguishing fires (Zhou, 2018).
Information Sharing	20	• **Naturalistic decision-making (NDM)- Simulation-based training**: "Examine the cognitive process that is associated with failures to execute action when a decision-maker struggles to choose between equally perceived aversive outcomes" (Alison et al., 2015, p. 295). • **Employee profile configurator:** Identify characteristics of team member and place in specific clusters to examine factors affecting trust, information sharing and communication, in virtual teams (Bhat et al., 2017). • **Mechanism design-approach:** "Mechanism selects a project, recommends (privately) to each member an individual effort level, and specifies the team members' outcome-contingent compensation." (Blanes i Vidal and Möller, 2016, p. 171) • **NeoCITIES- Crisis simulation:** Examine how cultural composition of teams have an impact on information sharing behaviors (Endsley, 2018) • **Synthetic task environment:** Allowed the examination of the effect of group-level information-pooling bias on collaborative incident correlation (Rajivan and Cooke, 2018) • **Crisis management simulation:** Used as a tool to investigate information processing and decision-making behaviors in multidisciplinary crisis management teams' members participating in a crisis management training (Uitdewilligen and Waller, 2018)
Knowledge Exchange	27	• **WhatsApp- Information and Communication Technology (ICT):** Used to study knowledge exchange and knowledge development between team members (Priyono, 2016)

and the new approaches that are being developed by researchers to better understand team dynamics within the different phases of team development as proposed by Kozlowski et al. (1999) team development process model. In **Figure 1**, we illustrate the placement of the 12 constructs in the most appropriate phase for measurements in either team formation, task compilation, role compilation, team compilation, or team maintenance.

Team Formation

Team formation, often characterized by high ambiguity and self-awareness, is known to have a great impact on performance and therefore is a critical period for modern organizations (Sorkhi and Hashemi, 2015). Moreover, during team formation, through observation and exploration, team members become more familiar with each other as they start to learn and develop within their roles. This first stage within team development can often be characterized by concerns of safety and inclusion as well as high dependency on designated leaders to provide direction during this ambiguous time (Wheelan, 2003) Similarly, members also learn the goals of their team and begin to strategize how these goals can be accomplished (Kozlowski et al., 1999; Feitosa et al., 2017). In many instances, team formation can be a difficult stage because individual differences may contribute to resistance when it comes to working together with dissimilar others to achieve these common goals. Often, individuals are attracted to similar others and therefore create distinctions between in-groups and out-groups based on perceived similarities in order to reduce ambiguity (Tajfel and Turner, 1985; Turner, 1987; Ashforth and Mael, 1989). Such behaviors have the ability to impact trust, communication, information sharing, and conflict throughout the entirety of the team's life span (Jehn and Bezrukova, 2010).

Key Constructs to Measure

Considering how crucial a role perception plays within team formation, an important construct used to measure teams in this phase is openness. Costa and McCrae (1992) highlight the importance of member reactions to different ideas, actions, and values in defining openness. Individuals who exhibit high openness, especially to experience, tend to be less dogmatic and rigid in their beliefs and ideas. Instead, they are more willing to consider different opinions, are more open to new situations, and are less likely to deny conflicts compared to people who low in openness (McCrae, 1987; LePine, 2003). Moreover, openness will allow individuals to get to know each other's strengths. These aspects of openness are very much closely related to the essence of working with new team members who more often than not, are likely to have different perspectives, attitudes, and thoughts (Cox et al., 1991; Van Knippenberg et al., 2004). Openness, though often studied at the individual-level, can have the ability to set the tone for whether or not individuals will be able to trust one another and communicate differing opinions when in the context of a team throughout the developmental stages of a team.

Relatedly, trust is often initially established through self-categorization as individuals, affected by their openness, will try to identify with other team members as a means to reduces ambiguity (Turner, 1987). Team trust refers to a party's willingness to be vulnerable to the actions of another based on positive expectations that others will perform a certain action important to the trusting party (Mayer et al., 1995). When trust is present, team members are open to taking risk, enhancing collaboration and co-operation effectiveness (Costa, 2003). Team trust has progressively been recognized as pivotal to team processes. Although little is known about how trust develops and evolves over a team's duration cycle (Grossman and Feitosa, 2018), evidence shows that trust is present and effects teams throughout all of the different stages of the team's life cycle (Harrison et al., 1998, 2002). It is with time and continuous interactions, verbal and non-verbal communication, and different behavioral patterns, different personal traits will reveal themselves and become the true basis for trust among individuals (Harrison et al., 1998, 2002).

How Constructs Are Measured

Out of the articles pulled as a result of our literature search, the most common methodological tools during the team formation used was through the forms of self-reported survey questionnaires. For example, a study by Lu et al. (2018) on openness, using a two-wave multi-source online survey with responses from 30 teams from different multicultural organizations in China, found that reduced openness hinders a diverse team's ability to generate innovative solutions. Especially in diverse teams, a lack of communication openness can have an impairing impact on team member information elaboration and creativity, later on. Bond-Barnard et al. (2018) conducted a self-reported survey of 151 project practitioners to assess the link between trust and collaboration. Results from the study indicated that high level of trust leads to stronger collaboration between group members. Moreover, the link between high level of trust and collaboration was more likely to predict project team success. However, being that self-report measures only provide a glimpse at static individual perception and may not even accurately reflect the behaviors of team members, the use of novel methods could prove useful in understanding the dynamic nature of teams.

With a more novel approach, Erez et al. (2013) used novel methodology in examining team trust in virtual multicultural teams with a 4-week project designed around principles of collaborative experiential learning, where trust was found to strongly moderate the project's effect on team member cultural intelligence and global identity. Participants were put through phases to get to know each other, and prepare for the virtual team project they would be participating in. In phase one, which mimics real world team formation, participants interacted in team chat rooms where they go to know each other, introducing themselves, sharing personal information, and photos of themselves. At the end of this process, participants were then given individual feedback regarding pre-project cultural values as they related to the purpose of the study. Phase two was meant to prepare participants for the team project they would be participating in later on. Phase three was described as a post experiment wrap up, where team members received feedback on their contributions to the team's processes. This virtual team simulation proves useful in understanding the various aspects of team formation in that it touches on the outcomes of working within diverse teams at formation, team building, and task

interdependence, all of which are not only of great importance to team formation, but also to the other stages of development as well. The novelty of this study lies in the fact the researchers developed and implemented a new program for acquiring global skills regarding trust, especially for virtual multicultural teams, where such individual differences could hinder trust. In these instances, simulations can be particularly informative during the team formation stage when it comes to dealing with teams in the real-world.

How Constructs Are Analyzed

The examination of various articles presented an assortment of relevant team measurements that are applied during the phase of team formation. Furthermore, it is also important to take consideration of how researchers analyze items within their applied measurements. Besides the typical analysis of descriptive statistics (e.g., means and standard deviation) and correlations, the most common types of analyzing tools that were assessed between the three main constructs of team formation (i.e., openness, trust, and communication) were regression analysis, mediation, and analysis of variance (ANOVA). Researchers use regression analysis to calculate the effects of casual variables and ANOVA to determine the amount of variation in the dependent variable score within the experimental conditions (Rutherford, 2001). Moreover, mediation holds great importance as an analytical tool due to its ability to examine whether these team constructs can serve as explanatory mechanisms between team inputs and outputs (Hayes, 2012). This is extremely beneficial when understanding how teams are becoming familiar with each other during this particular phase of team formation.

Task Compilation

Once a team has formed, individuals will begin to shift their attention toward their own individual tasks and focus on individual task mastery to develop the necessary skills required of them (Kozlowski et al., 1999). Though members will already have specialized knowledge and training in different areas, it is within this stage that team members will learn how to practice and apply their knowledge and skills within the context of the team. Moreover, in task compilation, members will seek out information and feedback from other members. Because team cognition plays a crucial role for task compilation, it is very important to understand the ways in which teams will share, exchange, and organize knowledge and how these processes occur over time (Gibson, 2001). Often characterized as a period of counter-dependency and conflict, two inevitable aspects of this stage, members can find themselves disagreeing about team goals and proper procedures. By combining their pools of knowledge and expertise, members must develop a unified understanding of how to execute the teams goals. Though conflict may arise, it is necessary for the development of trust and a more open climate, as members will be open to each other's ideas, even if it means they might disagree with one another (Wheelan, 2003). Teams who are able to develop effective systems for information sharing and knowledge exchange have been shown to experience greater performance outcomes (Wegner, 1987).

Key Constructs to Measure

One of the most studied constructs within this phase is information and knowledge sharing. Knowledge distribution across teams occurs within a variety of complex paths. Therefore, the team process of knowledge sharing is an aspect that tends to hold a great importance in the progression of team performance. Knowledge sharing is defined as "team members sharing task-relevant ideas, information, and suggestions with each other" (Srivastava et al., 2006, p. 1239). Existing knowledge within teams serves as a cognitive resource to be utilized for knowledge sharing (Argote, 1999). For knowledge sharing to occur, information that is applicable to the team's goal must be communicated with hopes of a successful collaboration between team members. In this way, communication, the act of transferring information from one place to another, among team members plays a crucial role in team functioning (Keyton et al., 2010; Beck and Keyton, 2011). Knowledge sharing also emphasizes the exchange and combination of relevant knowledge to then be applied to specific work task (Pennington, 2008). Knowledge sharing can contribute to the creation of shared mental models, which helps explain the ability of teams to cope with difficult and changing task conditions and requirements (Cannon-Bowers et al., 1993). Cannon-Bowers et al. (1993) assert that to adapt effectively, especially within the task compilation phase, team members must be able to predict what other team members are going to do and what steps are necessary to complete those tasks. Moreover, not only is it crucial for team members to engage in effective communication with each other to produce optimal outcomes, but they must also they must be able to trust that the information they provide to one another is truthful, honest and accurate. When trust is not present within the task compilation phase, teams can face a plethora of damaging effects such as lack of cooperation and resentment (McQuerrey, 2017). Understanding the emergence of constructs such as openness, communication, and trust as they relate to teams and how they are measured proves great importance to understanding team dynamics.

How Constructs Are Measured

The most common way knowledge and information sharing are measured are through the use of surveys and interviews (14 out of the 20 pulled). For example, in an article by Li et al. (2018), required participants to complete a survey where information sharing as measured in relation to perceived team performance outcomes. While surveys and other self-report measurements can provide useful insight to perceptions, their use also risks biases, over-exaggeration, or low response rate. However, the use of novel measurements, that often will take temporal considerations into account, may prove more useful in capturing team dynamics in a more accurate way. For example, in a cybersecurity threat detection task simulation using, Rajivan and Cooke (2018) sought to understand the effect of group-level information-pooling bias on collaborative incident correlation analysis in a synthetic task environment and revealed that participant teams were more likely to share information commonly known to the majority rather than not. However, unaided team collaboration was inefficient in finding associations between security incidents uniquely available to each member of the team. The present

study helps illustrate the effectiveness of novel methodological tools in that they have the ability to present the dynamism of complex teams. Synthetic task environments are "simulation environments purposed to recreate real-world tasks and cognitive aspects of the task with the highest fidelity possible" (Rajivan and Cooke, 2018, p. 628). The researchers used information distribution processes that mimicked processes found in real-world defense environments. Important to the task compilation stage, members were assigned ownership of specific duties, but also required to discuss and correlate information related to their team task. Lingard et al. (2015) used novel methodology in their research when they employed the use of photographic q-methodology to explore shared mental models in occupational health and safety. Q-methodology has been identified as an ideal tool to study shared mental models because they reveal member cognitions, attitudes, and perceptions and reflect their subjective views of what construct or variable is being studied (Anandarajan et al., 2006). Results give important insight into the types of team shared mental models may or may not exist in and therefore how knowledge and task related activities should be examined differently for different types of teams.

From the research presented, the task compilation phase involves behavioral and attitudinal, and cognitive constructs of great importance to team functioning. Understanding the way in which team members are able to communicate information with their peers can play an integral role in predicting how members will perform, not only in this stage but also throughout the development of the team. Thus, we recommend that both behaviorally, cognitively, and attitudinally rated anchored scales, as well as simulation/lab experiments where these constructs can be assessed, are implemented to accurately depict workplace behaviors.

How Constructs Are Analyzed

From the collection of relevant articles within this stage, there is a salient shift in how measurements are analyzed. For instance, coding and categorization allows for the culmination of themes within interviews and text-based documents, enabling researchers to better grasp information processing; a key element within task compilation (Swanson and Holton, 2005). Partial least squares (PLS) is a preferred method over multiple regression as it does not only allow for the combination of regression and factor analysis within similar statistical procedure, but also produces a variety of reliability and validity statistics within a theoretical model (Wold, 1982; Chin and Newsted, 1999; Konradt et al., 2015). However, a key limitation with the use of PLS is that its focus is much more geared toward prediction and not theoretical fit (Akgün et al., 2012). This is not surprising as PLS is more favorable for smaller sample size (Xiang et al., 2016), and team research often struggles with sample size issues. Structural equation modeling (SEM), on the other hand, is a preferred method over regression analysis due to the fact that it allows for the investigation of two independent variables while regression does not detect interfering effects between those two independent variables. As well, SEM is useful in research that involves latent constructs or variables that cannot be directly observed (Dao et al., 2017). In order to enhance analysis, researchers would greatly benefit in using a PLS-SEM technique as it has been found to be beneficial in predication-orientated research due to its ability to strengthen explained variance and independent variables (Dao et al., 2017). Although this method is not perfect, the use of PLS in SEM undoubtedly advances research. PLS-SEM allows for more predictors to be examined as well as shortening research time frame due to the fact that only a small sample size is needed to reflect a population.

Role Compilation

The development of a network of role exchanges, routines, and a set of roles for team members is of accordance to the information that is shared in the role compilation phase (Kozlowski and Bell, 2008). Thus, the next phase, role compilation, ensues emergent team processes of individual inputs and team-level outcomes become more focused on the overall team's performance outcome (Kozlowski et al., 1999; Stewart et al., 2005). Some of the most dominant constructs that are measured due to its emergence within the role compilation phase fall under team cognition known as TMSs and information sharing (Ilgen et al., 2005; Pearsall et al., 2010).

Key Constructs to Measure

To reiterate, the role compilation phase involves the exchange, sharing and seeking out information with relations to each team member specialized capabilities, knowledge and responsibilities within a team (Pearsall et al., 2010). These role identification behaviors relate to the different constructs involving trust (i.e., a party's willingness to be vulnerable to the actions of another based on positive expectations; Mayer et al., 1995), collaboration (i.e., shared decision making and collective responsibility amongst interdependent parties; Liedtka, 1996), information sharing (i.e., exchanging ideas amongst members; Hu et al., 2018), and knowledge exchange (i.e., transaction of information; Bullock et al., 2013). Role identification behaviors has also been shown to be a strong predictor of TMS, or who knows what (Wegner, 1987), within the role compilation phase through team discussion of each members relevant knowledge of the task (Austin, 2003; Pearsall et al., 2010). Therefore, cognitive emergent construct is a key component within the role compilation developmental phase. Hence, we further explored the approaches researchers are taking to study such cognition within teams.

How Constructs Are Measured

According to the literatures pulled for TMS, 38 of the 45 empirical articles measured TMS through the use of self-reported survey studies (e.g., web-based structured questionnaires). TMS has been linked to enhancing team innovation and performance (Wegner, 1987; Choi et al., 2010) and is commonly used as a mediator (i.e., the underlying mechanism that explains a relationship) (Baron and Kenny, 1986; Howell et al., 1986). For instance, an internet-based study conducted at a Finnish research organization was used to examine if TMS would mediate the relationships between task orientation and team innovation within team members (Peltokorpi and Hasu, 2016). Results illustrated how TMS mediated the relationship between task orientation and team motivation due to team members being

able to explore and refine different ideas in order to update and collaborate their specialized expertise. Chiang et al. (2014), also provided a self-reported survey to a Taiwanese electrical product manufacturing company where it was TMS had a positive mediating effect on the relationship between high commitment work systems and new product performance.

Self-reported surveys are ideal for capturing perception but vary when measuring behavior as they tend to suffer from response bias and low response rates (Jones et al., 2013; Young-Hyman, 2017). Thompson (1967) found that novel and more complex tasks increases information exchange among participants when solutions are not familiar. For instance, a business stimulation was presented to individuals at an university community after being randomly assigned to a role-specific preparation team or a cross-role preparation team in order to examine the effectiveness of different types of self-preparations on subsequent team-level performance (Linton et al., 2018). Participants were primed with role-specific preparation by being randomly assigned to one of the three director titles; marketing director, operation director, and financial director. Cross-role preparation team rotated between the three roles. Results showed that role-specific preparation in teams effectively set up the preconditions for TMS, performing better on objective measures of business performance (e.g., generating profit).

There has been a steady transition into novel approaches when studying information sharing as six out of 20 articles pulled displayed some sort of novel methodology. For example, a 2-day simulation-based training exercise of an aeroplane crash over a major city was provided to a large-scale multi agency. Researchers analyzed the frequency, type, audience, and type of communication through five subject matters to examine the cognitive processes that leads to failure of executing actions of decision-making struggles during equally perceived aversive outcomes (Alison et al., 2015). Using the novel 'hydra' system (i.e., immersive simulated learning platform), data was collected through communication logs coordinating decisions and actions between agencies and from within by marking communication as (1) information seeking, (2) a decision, or (3) an action. Results revealed that decision making was non-time bound, involved a multiple of agencies, subordinate goals lack identification, and information sharing of communication decreased as agencies communicated from within; distracting efficient discussions and action execution. The simulation allowed researchers to examine team decision making within different points of workplace time pressure, enhancing the relevance of the data collected to accurately display real-world contextual situations. Another novel approach involved a hidden profile task presented to teams consisting of students at a Dutch University (Mell et al., 2014). Researchers found a predicted interaction effect between TMS structure and the distribution of the task information due to TMS structure being more centralized within the disparity of metaknowledge (i.e., knowledge of who knows what), allowing for more information elaboration and team performance. This study addresses the importance of fostering meta knowledge within teams as TMS knowledge decays over time; especially after group knowledge changes (Ren and Argote, 2011). From the studies presented, there is evidence of novel approaches providing in depth analysis of team shared knowledge. This is extremely beneficial during the role compilation phase as members are exchanging knowledge and roles.

It is important to realize the effectiveness of using behaviorally-anchored rating scales (BARS) to measure team effectiveness through (1) coordination, (2) cooperation, and (3) communication during role compilation, a phase where communication in regards to role exchange and developing behavioral routines is important (Kozlowski and Bell, 2003, 2008). BARS are used to measure performance dimensions in a set of incidents that represents actual behaviors which job incumbents presented in the past (Atkin and Conlon, 1978). There is a conceptual advantage of using the BARS approach as it focuses on behaviors that differentiate successful performance as well as the increase in perceived objectivity of the rater (McIntyre and Gilbert, 1994). Hence, the integration of behaviorally anchored scales can be used to set an accurate representation of behaviors as they present "less method variance, less halo, and less leniency in ratings" in replicable task duplication of real-world organizational climates which constantly deals with complex team task (Landy and Farr, 1980, p. 18).

How Constructs Are Analyzed

To the role compilation phase introduces the development of role exchanges ad setting of roles through the information that is shared between team members (Kozlowski and Bell, 2008). Understanding how that information is passed is important to researchers within this particular phase. Mediation and regression analysis showed to be the most common tools for analyzing within this phase to understand the relationships between constructs and how that relationship is occurring. However, researchers would benefit by switching their focus toward PLSs analysis as it has been considered to be a powerful data analytic approach in advancing the knowledge and understanding of group development (Sosik et al., 2009). It not only allows for the combination of regression and factor analysis but also mediating effects of constructs through minimal demand of sample size (Wold, 1982; Chiang et al., 2014). SEM is considered as the best method of "confirming theoretical models within a quantitative fashion" (Schumacker and Lomax, 2010, p. 7). When researchers are developing theory in exploratory research, a PLS-SEM is considered to be the preferred method (Sarstedt et al., 2014). Hence, there are many benefits for researchers in transitioning form a mediation and regression analysis as analytical tools such as PLS-SEM are able to perform such analysis within a combination saving researchers time and allowing greater advancement in the team research phenomena.

Team Compilation

As individuals become more familiar with team member roles and each other's specialized knowledge or abilities, the team thus enters the phase of team compilation. Team compilation involves the process of individuals of a learning, adapting, and performing their roles due to the interdependence and role distribution amongst the team (Kozlowski et al., 1999; Feitosa et al., 2017). Due to the emergence of such behaviors, relying on their behavior and cognition allows for coordination within the team to run

smoothly (Pearsall et al., 2010). However, this is dependent on the success of an accurate development of role identification within the role compilation phase (Edwards et al., 2006).

Key Constructs to Measure

As stated, team compilation phase involves team members becoming associated with their team members and their knowledge/abilities. During this phase, the cohesion emerges as it is considered to be a relational emergent state or developing over time (Marks et al., 2001; Salas et al., 2015a). Team research focusing on the emergent process of team cohesion is important as the social integration process of team cohesion stimulates creativity, innovation, and positive team interactions (Taggar, 2002; Hülsheger et al., 2009). However, due to lack of sufficient team cognition development in the role compilation phase, team conflict becomes a major issue that hinders information processes and team member satisfaction (Bell et al., 2012). Conflict is considered to be a multidimensional construct involving task or relationship (Jehn and Mannix, 2001; Jehn and Bendersky, 2003). While relationship conflict represents the individual's perception of the incompatibility of their teams, task conflict is the disagreement among group members at to viewpoints and ideas about their collective task decisions but with moderate levels can help teams avoid groupthink and enhance performance (Jehn, 1995; Simons and Peterson, 2000; Bell et al., 2012). Hence, we further examine the general approaches that researchers are undergoing to measure team compilation phase of the level of team adaptation through cohesion and conflict.

How Constructs Are Measured

After a review of the 50 most relevant studies in regards to conflict, 24 empirical articles were pulled. The most common form of measurements for conflict was self-reported surveys for 16 articles. A myriad of research studies has found strong correlation between team conflict and team performance (De Dreu and Weingart, 2003). For instance, two self-reported questionnaires were provided to United Kingdom healthcare teams and their leaders to examine how task conflict moderates the mediated relationship between professional commitment and team effectiveness in accordance to cognitive diversity (Mitchell et al., 2018). In other words, the experience of task related disagreements between members on perspective and positions showed an increase in team members effectiveness of using such knowledge. Another example of conflict being a link to the effectiveness of team output was through a survey-based study of student teams at a large university in Western Canada (O'Neill et al., 2017). Teams were examined to understand the effects of a new team-training system for postsecondary teaching and learning activities. By implementing productive conflict or teams openly discussing disagreements about task (Jehn, 1995), students with different levels of training performance would vary. Results showed that productive conflict in teams that experience full training outperformed those with partial to no-training, as productive conflict in regards to task conflict helped improve team functioning. For these reasons, self-reported surveys can be beneficial to study team perceptions.

From the 28 articles pulled in regards to team cohesion, there was a noticeable trend of researchers incorporating advancements into methodological tools to examine the cohesive nature of teams and their performance. For example, teams consisting of students at a University were provided a simulation task of the game Sim City 4 and a questionnaire on task cohesion (i.e., collective commitment and to complete a group's task; Beal et al., 2003; Curral et al., 2017). Researchers predicted that task cohesion would lead to a positive relationship of team performance. Interestingly, when teams had perceived a maximum amounts of team cohesion, there was a decrease in team performance. The incorporation of behaviorally anchored rating scale through the use of simulation was beneficial during this study as teams are not obstructed from completing their task which thus lead to maximum cohesion, a detrimental effect that decreases performance due to the production of groupthink (Langfred, 2004). Transitioning out of single source methodologies does indeed have its perks.

Although conflict does involve the perception of team compatibility and difference of opinions, much of the research is focused on the examination of their effects on team performance (Bell et al., 2012). Agent-based simulation (ABS) or software-based simulation to mimic the behavior of interest (Kozlowski and Chao, 2018) was presented through most of the articles pulled. For instance, data was collected from business students at a large public university in the United States through a team-based business stimulation for 4-month to test a multiplex view of how friends or non-friends and intra-team conflict (task or relationship) has different effects on team performance (Hood et al., 2017). Participants participated in a 10 weekly decision rounds which they modified and acted on new strategies based on prior performance and their own competitive positions. Conflict network was measured through the respondent's perception of the frequency of interpersonal task conflict and relationship conflict amongst the team. Results indicated that relationship conflicts among team members of friends had a negative impact on team performance compared to non-friends who had a positive impact. This article contributed to the study of performance within teams change over time as in the accordance to changes in team conflict. Boroş et al. (2017), presented a 5-day business simulation to students enrolled in a Management Integration course to explore the effects of relational conflicts and conflict asymmetry (i.e., group members holding different perception of team conflict in their group (Jehn et al., 2010). Researchers also performed computational modeling to measure the personal and direct experiences of conflict in teams as opposed to the conflict within a group. Results indicated that some team members elicit more conflict than others which affected the evolution of team dynamics and performance; even more than the high levels of conflict together (Boroş et al., 2017). These studies present evidence of ABS and computational modeling ability to provide understanding of team emergent processes per the emulation of human behavior using a virtual system.

For the most part, behaviorally anchored rating scales are a beneficial assessment tool within the team compilation phase as researchers' study how individuals adapt and learn within

a team structure in order to perform their roles, correlating with the significance of behaviorally anchored rating scales (Campbell et al., 1973; Kozlowski et al., 1999; Feitosa et al., 2017). Especially with ABSs, agent-based modeling provides advantages to conventional simulation during situations of dynamic relationships with other agents form or dissolve (Macal and North, 2006). Interestingly, the studies presented illustrated the effectiveness of novel methodological tools as they present complex systems increasing the interaction between team members, supporting Jin and Levitt (1996) view of complex team task having correlations with increasing coordination between team members. Thus, the implementation of complex and innovated novel approaches exposes researchers to real world team measures that inadequate methodological tools lack to supply within team's research.

How Constructs Are Analyzed

Through the collection of articles within the team compilation phase, there were a large number of articles using mediation and regression analysis are their main analytical tool to examine the attitudinal, behavioral and cognitive constructs that are most common within this phase. Assessing how team members are building a form of interdependence between each other and associating with each other's knowledge and abilities is determined by using these analytical tools. However, through PLSs, this job can be done simultaneously. Indeed, PLS does have its faults as it is most concerned with prediction than a test for theoretical fit and there must be careful interpretation of estimates and as they tend to increase (Akgün et al., 2012). With careful consideration, however, PLS can provide stronger "estimates of standardized regression coefficients for model paths, which can then be used to measure the relationship between latent variables" (Huang and Chen, 2018, p. 102). As researchers gear predictive research toward PLS analytical tool, the advancement of team research can greatly benefit with this practice.

Team Maintenance

As team members have begun to fully develop a team identity, collaborative goals, and a sense of team cohesion, the process of maintaining such team behaviors becomes a critical task. Research has shown team proficiency levels decay over time; continuous behavioral success pertaining to team compilation is at risk (Feitosa et al., 2017). Therefore, team maintenance becomes a significant phase of team development. Team maintenance behavior is interpreted as "group member behavior required for maintaining the group as a working unit" (i.e., encouraging, expressing group feelings, harmonizing, gate-keeping, setting standards) (Neufeld and Haggerty, 2001, p. 37).

Key Constructs to Measure

Leadership is a construct that is significant with maintenance behavior as a leaders purpose is to develop expert teams, regulate activities, and help members adapt to the ever-changing environment (Kozlowski et al., 2010). Beginning at the formation stage, members often seek guidance from leaders to provide direction for the team (Wheelan, 2003). Being that teams today often exist over long periods of time, must coordinate to perform tasks, and are subject to dynamic change over time (i.e., in terms of context, task demands, and membership), team viability must also be considered within this stage of team development. Team viability refers to the "capacity for growth and sustainability required for success in future performance episodes" (Bell and Marentette, 2011, p. 276). Despite team viability being deemed an important construct for examining team maturation, this construct is understudied. As a result, construct confusion and inconsistencies in terms of how researchers have conceptualized and operationalized the construct have actually stifled its usefulness. Thus, we further expand on the emergence of leadership and team viability to present how they are being measured within relevant studies.

How Constructs Are Measured

A vast amount of research has shown that leadership has a high level of influence toward employee's enthusiasm and vitality at work (Bakker et al., 2007; Atwater and Carmeli, 2009; Perry et al., 2010; Carnevale et al., 2018). Kozlowski et al. (1996a,b) stated that leaders are the prime developers of team coherence as they lead their team within a four-step learning cycle; (1) goal-setting, (2) performance monitoring, (3) error diagnosis, and (4) process feedback. From the 33 articles pulled, each study examined leadership within these four-step learning cycles through self-administered questionnaires due to it being a great indicator of perspective behaviors (Young-Hyman, 2017). For example, in a study of Ethiopian Electric Utility employees, a self-administered questionnaire was provided to examine transformational leadership behavior (i.e., leaders inspiring and intellectually stimulating their team members) on the collective efficacy of employees (Jung and Sosik, 2002; Getachew and Zhou, 2018). Results revealed that transformational leadership had a significant impact on the collective efficacy of team members as those who were high in transformational leadership behaviors were able to boost the confidence level of their followers. Due to participants expressing their sense of confidence in the team to complete extended goals because of transformational leadership, the study allows this behavior to be linked to Neufeld and Haggerty (2001) description of team maintenance behavior as a phase of expressing group feelings (Langfred, 2000; Young-Hyman, 2017). Hence, survey design would be very beneficial in studying such behaviors of a leadership.

In another article, project teams at a software firm in India were examined through how perceived time pressures affect the team process and performance on either strong or weak temporal leadership or "the degree to which team leaders schedule deadlines, synchronize team member behaviors, and allocate temporal resource" (Mohammed and Nadkarni, 2011, p. 490). Temporal leadership was assumed as a moderator of the relationship between perceived time pressure and team performance. Results showed strong temporal leadership had an indirect effect on perceived time pressure and team performance while weak temporal leadership had an indirect effect on levels of perceived time pressure and team performance (Maruping et al., 2015). These findings display a strong link to how researchers study team leadership behaviors through the four-step learning

cycle. These involved perceived behaviors by team members, considering survey-based questions being an effective tool to use during this stage.

From the 21 articles pulled in our review, team viability displayed the use of three novel methodologies, while the other 18 used self-report surveys. It is understandable as team viability is based off of team members' perception of their effectiveness based on past experiences. One novel methodology was used by Curral et al. (2017). Two hundred individuals were divided into 40 teams of five. Participants were asked to engage in a simulation experiment using a PC game SimCity 4, a city building game used in past research involving work teams. This specific version was chosen because members could act more autonomously in making decisions regarding the city they chose. Participants were then asked to complete a survey involving team viability measures, among other constructs. Results from coding game play and survey responses suggest that the mediating role of viability plays in understanding team effectiveness, especially in relation to leadership and task cohesion. Lehmann-Willenbrock and Chiu (2018) also took a novel approach in developing their multi-study longitudinal research program. Two hundred and fifty-nine employees in 43 teams participated in monthly team meetings where they discussed their workflow, problems they faced, and ways to improve as a team. These team meetings were videotaped and subsequently software coded to distinguish the difference among problem solving, off-task, and agreement behaviors. Team members were then surveyed through self-report assessments. Their methodology and findings present important implications for both teams research and practical application. Namely, this research indicates that disagreements within teams actually can enhance team learning and promote effective methods of problem solving.

Although 31 out of 33 articles pulled measured leadership through the lens of self-reported survey questionnaires or in some cases interviews, the novel measurement of simulation (i.e., agent-based simulation) does have a place in studying leadership behaviors within teams. For example, in a study of multi-team systems of United States Air Force officers, convergent (i.e., single solution) versus divergent (i.e., as many alternative solutions) risk preferences expressed during planning by the leadership was believed to affect multi-team behavior and performance (Gilhooly et al., 2007; Lanaj et al., 2018). Through the use of Leadership Development Simulation, researchers examined the risk preference, multi-team system performance, and unwarranted risk behaviors within teams. From the results, divergence of risk preferences between leadership and team's component benefited the performance and aspirational behaviors of the multi-team system due to their ability to handle risk behaviors and task time pressure overtime. In another novel measurement study, 18 observers examined 42 zero-history teams of three who collaborated for 7 weeks at a large automotive consultant project company. The observers were examined through an eye-tracking experiment to detect leadership signals within individuals as researchers argue humans possess an automated mechanism for providing higher visual attention to emergent leaders as opposed to non-leaders (Gerpott et al., 2018). First data was collected by video recording meetings of project teams and providing teams with a peer rating questionnaire on who they thought emerged as an informal leader. Observers gazes were then measured through an eye-tracking experiment after they watched 42 brief videos of the project teams. Results indicated that observers not only gazed at emergent leaders but spent longer time periods providing their attention as opposed to non-leaders. The novelty and complexity of implementing behaviorally anchored scales for leadership, a construct revolved around behaviors of individuals influencing other team members, is undoubtedly beneficial. The two novel methodological approaches of measurement presented, agent-based simulation and eye-tracking, allowed for a broader understanding of leadership as opposed to only focusing on perception through self-reported assessments.

From the research presented, the phase of team maintenance involves a multitude of aspects as the study of behavioral and attitudinal constructs are of great importance. Understanding how group members feel about their peers and organization will have a strong prediction upon the maintenance of team behavior (Neufeld and Haggerty, 2001). Thus, both behaviorally anchored scales and self- and peer evaluation scales being implemented would allow researchers to broaden their collection of data through team perspective while accurately designing workplace behaviors. Moreover, such implementations have the ability of increasing the accuracy of research on efficient team maintenance practices through an accurate work depiction during the specific developmental stage. Thus, once researchers begin to fully accommodate complex and advance methodological approaches, then team research would notice a enhanced validity in accurately depicting organizational practice and issues.

How Constructs Are Analyzed

Once a team has developed a firm and stable cognitive structure of each other roles and what is needed to complete the task at hand, team maintenance is critical in order to continue behavior of a working unit. Attitudinal and behavioral constructs are thus relevant to examine within this certain phase. After assessing the most common forms of analytical tools within this particular phase, coding was one of the most widely used analytical tool by researchers as they were able to assess common themes of how teams were maintaining a cohesive working relationship in order to successfully hold group structure over time and achieve a certain team goal. Regression analysis and mediation were heavily used by researchers to test the relationship between variables and why an outcome has occurred. Although we mention path analysis in previous phases, there was a lack of usage within this phase. Henceforth, this may signal that path analysis is more widely used during research involving cognitive measure as opposed to attitudinal and behavioral constructs. Lehmann-Willenbrock and Chiu (2018) provided novel modes of analysis in that they used a statistical discourse analysis to analyze the social interactions that were recorded in their longitudinal research program. Using a multilevel, time series, explanatory models approach, researchers may be better able to capture member perceptions of team viability, as well as other constructs, crucial to team effectiveness.

THE ROAD AHEAD

This paper summarizes the state of the science regarding team dynamics measurement allowing for a more sensitive approach to temporal components. At the present time, the most commonly used form method to examine team dynamics across a multitude of constructs and team developmental phases is through the lens of self-reported surveys. However, research has taken strides in finding new ways to obtain more efficient and descriptive results with regards to team dynamic link to team efficiency (e.g., Prochazka et al., 2018). Fortunately, the study of team emergent constructs such as team conflict, cohesion, and shared mental models are noticeably incorporating more advanced and novel methodologies within the use of complex task. From the articles pulled, it is apparent that research on team cognition constructs has seen a steady influx of novel approaches conducted under team dynamic studies. However, there is a clear gap of novelty measurement across attitudinal constructs such as trust which has been found to be important within the five stages of team development (see **Figure 1**).

Regarding these more novel methodologies, we highlight two that are particularly promising: ABSs and computational modeling. Specifically, these methods can address sample size issue that most teams research face. Moreover, Macal and North (2006) argue that ABSs provide an advantage in understanding the interactions of agents within dynamic relationships with other agents, as well as situations of agent relationships forming or dissolving. Computational modeling uses mathematical relationships (e.g., equations) to incorporate large numbers of process mechanisms that affect behaviors simultaneously, giving researchers an advantage of analyzing a larger scope of multilevel emergence of team dynamic processes (Kozlowski et al., 2016). However, self-reported assessments hold some advantage within research as they are able to analyze larger populations, great indicators of perspective views, as well as provide insight on team interactions. Unfortunately, they suffer from low response rates, response bias, and are obtrusive by interrupting ongoing interactions between team members (Thompson, 1967; Jones et al., 2013; Feitosa et al., 2018; Golden et al., 2018; Kozlowski and Chao, 2018). More importantly, asking participants to remember certain experiences involving attitude, behavioral, and cognitive interactions over time is detrimental to the validity and acquiring of big data (Luciano et al., 2018). Salas et al. (2018) argue that relying on more than one method of measurement can reduce single-source bias as well as reduce survey respondents' fatigue. Hence, we call forth further team dynamic research to examine the impact factor and difference of implanting novel measures as opposed to using a single source self-reported assessment in accordance to the A-B-C framework.

Although classical methods such as self-reported survey, observations, focus groups, and interviews are commonly used by researchers, traditional measurement methods are unfortunately plagued by various challenges. What sets apart articles that followed traditional method approaches as opposed to those classified as novel approaches is the way the studies model team tasks and context. Novel studies held an advantage as to the validity and reliability of their data due to team tasks and conflict vary over time (Hinsz et al., 2009). Research has called for the consideration of dynamics and contextual features through operationalizing team environments and task in order to influence the changes of behaviors that are relevant within that workplace context (Mathieu et al., 2019). This consideration will not only allow researchers to explore emergent states of team processes but analyze emergent behaviors across varying degrees of complex research design. For instance, virtual experimentation triggers environmental events, providing more validity and reliability when assessing how team members adapt and interact within those certain situation. Such advancements in complexity of relevant research design will not only increase accuracy with measuring teams within there are different phases of team development but will strengthen the understanding of group dynamics over time.

Despite multi-method research being recommended for expanding a larger scope of team interactions and reducing data bias, it is unfortunately an expensive method and somewhat difficult to practice within organizational field studies (Kim et al., 2012). Obtained data, however, has become fairly easy as digital traces such as e-mails, smart phones, and video surveillance. They provide ongoing and unobtrusive data that can be used to adapt technology to simulate real-world complex simulations while targeting emergent team processes (Kozlowski et al., 2015; Kozlowski and Chao, 2018). Furthermore, Waber et al. (2008) discuss how team interactions sensors such as sociometric badges, a smart phone device, have been developed to accumulate data involving "bluetooth to detect people in proximity with one another, infrared to detect closer face-to-face interactions, accelerometers to assess movement, and microphones to detect vocalization" (Kozlowski and Chao, 2018, p. 581). These sociometric badges are unobtrusive, provided to large numbers of participants, and have the ability to obtain real-world data over long periods of time that can subsequently be incorporated as a source for advancing ABSs and computational modeling, avoiding multiple data collection points and ultimately minimizing the use of self-reported surveys. As well, sociometric badges are much easier to compute as they take couple of minutes to input data recorded from every hour into a spreadsheet, limiting the preparation of observation notes and coding analysis (Kim et al., 2012). This holds many opportunities for future research as laboratories that may not have access to ABS or computational modeling programs would still have the ability to capture real-world team interaction behaviors over time. Thus, we call forth future research upon the use of sociometric badges as this data collection method provides a strong positive outlook for researchers to gain knowledge upon team dynamics.

To reiterate, digital traces such as e-mails, smart phones, and video surveillance is at researchers' disposal for unobtrusive data. Luciano et al. (2018) discuss how big data is generated through three general types of data streams: (a) behaviors, (b) words, and (c) physiological responses. Sociometric badges is a perfect example of behavior-related data streams due to its ability to measure proximity, movement, or interactions with other team members (Waber et al., 2008). When analyzing word-related data streams, Luciano et al. (2018) discuss computer-aided text analysis (CATA) and Hidden Markov Model (HMM)

(Pentland, 2007). CATA allows for researchers to infer what is being said through the quantifying of word use and pattern, while HMM analyzes how things are being said in accordance to the inter-relationship speech patterns (e.g., frequency, amplitude, or amount) over time (e.g., turn-taking, interruptions, variation of speaking time). Physiological data streams, such as brain activity, can be analyzed through the use of quantitative electroencephalography (QEEG; Waldman et al., 2015). Researchers are able to examine group dynamics by placing this portable hardware with sensors on an individual scalp and record electrical activities that signify human interactions such as leader emergence, collective cognition, and team members engagement. By incorporating such innovative tools, different streams of interpersonal interactions data through teams affect, behavior, and cognition can be obtained, broadening the scope of what we understand about team dynamics and emergent team processes. Thus, we call forth for their incorporation within future teams research as a way to measure naturally occurring individual and collective processes activities.

Besides the advancement in methodological tools and approaches in measuring emergent team process across a different periods of team developmental stages, analysis tools should also be a concern. We touched upon the many advantages of using PLSs within SEM. PLS-SEM is an approach that seeks to maximize the explained variance of dependent constructs through a causal modeling technique (Hair et al., 2011). PLS-SEM is beneficial in circumstances of prediction, theory development, and research involving a limited number of participants (Wong, 2013). Although PLS-SEM analytic tool is promising and holds potential for business research, there is a noticeable gap in research as it was most noticeable within studies pertaining to cognitive constructs. Due to its predictive nature, it is recommended that future research begin implementing PLS-SEM within studies involving regression-based approaches as there is much benefits in using this SEM approach as opposed to the traditional regression and mediation analysis. Especially in the process of studying relationships between latent constructs (i.e., not directly observed but inferred from other variables), researchers are able to calculate estimates of factor scores latent variable in relations to the observed indicator variable more precisely (Hair et al., 2011). Thus, in order for team research advancement, it is imperative that researchers continue to adopt innovative novel methods in order to obtain more accurate data of emergent team process across different team developmental phases and context.

There is a need for more research to examine the effects of new methodological approaches to better cultivate team research on emergent constructs in each developmental team stage. Researchers must continue transitioning to real-time measurement that is provided through innovative technological. With the application of methodological approaches that trigger relevant workplace situations accompanied by strong analytical tools in assessing these measures, research will be gifted with new found accurate measurements that will set forth new heights for understanding teams research. Unfortunately, there is a lack of meta-analyses that focused on examining a variety of team processes across different stages of team development. As well, our research could have also benefited from a meta-analysis that also addressed team process change within different types of teams. Thus, examination of team processes can change over time and type of team through a meta-analytical approach by assessing their effect sizes is recommended in order for researchers to fully examine the strength of the relationship between type of team and temporal dynamics. Researchers would be able to perceive the relationship between team dynamic changes overtime and the type of teams these changes are more likely salient within. These future recommendations will allow the progression of team research to set forth and continually adapt to the use of emerging methodologies/approaches, obtaining and analyzing team dynamic workplace data with precision; revolutionizing methodological assessments.

CONCLUSION

Within the past few decades, organizations have made a salient and ongoing shift from individual-work organized jobs to a more team-centric worked based structure (Kozlowski and Bell, 2003). Accordingly, research on how individual personalities and behaviors interact in working relationships to effect teams, roles, culture, and the organizational structure comes into play within the form of team dynamics research (Myers, 2013). In this article, we address the question of how team research is conducting empirical studies to better understand the development of teams through the lens of team dynamic constructs. Through the examination of common attitudinal, behavioral, and cognitive emergent team constructs, we explore the different methodological tools/approaches being applied by team research in accordance to the developmental stages as specified within Kozlowski et al. (1999) team developmental model.

From the myriad of articles collected, researchers are taking the necessary steps by incorporating new, improved, and innovative methodological approaches to better conceptualize relationships between team emergent constructs and team developmental stages. The present work illustrates the importance of simulation-based studies as they are beneficial in cultivating a relevant working environment due to the triggering of situational based context. These situations can be done through behaviorally anchored rating scales geared toward ABSs which allows researchers to closely examine team dynamic relations within complex systems. Although these tools are available, majority of relevant studies within the past decade are relying on traditional methodological approaches, showing signs of a reliance and comfortability to outdated methods. This article is not specifically telling future research to leave traditional methodological tools (i.e., surveys, interviews, case studies, and focus groups) behind, as these methods do have beneficial factors. For instance, there is much work to be done in advancing behaviorally anchored rating scales.

Future recommendations are addressed for incorporating multi-method measurements, specifically combining traditional methodological tools with ABSs or computational modeling in order to enhance the relevance of data obtained. As well, sociometric badges, computer-aided text analysis, HMM,

and quantitative electroencephalography are also expanded on as tools to measure behavioral, word, and physiological data streams for obtaining real-world unobtrusive data. These tools are advantageous in providing a stronger source of interpersonal behaviors for advancing behaviorally anchored rating scales. Especially with a shift into incorporating PLS-SEM for predictive and theory development, future teams research will benefit with more accurate score values of latent constructs through the use of smaller sample sizes. Following our recommendation to incorporate innovative approaches such as multimethod modeling and novel methodological/analytical approaches, new found team dynamic information can surely impact teams research, opening doors for better comprehension of replicating workplace environment and accumulating more accurate measurements of team processes. Although these approaches are not perfect, the steps team research should continue to take to advance our insight of team dynamics through innovative methodological and analytical practices should not go without notice as they are establishing a new scope built around the successful outlook of future team research.

AUTHOR CONTRIBUTIONS

FD and MR provided substantial contributions to the conception or design of the work. JF drafted the initial outline, set-up the methodological plan, and revised the manuscript critically for important intellectual content. All authors have provided approval for publication of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

REFERENCES

Akgün, A. E., Keskin, H., Lynn, G., and Dogan, D. (2012). Antecedents and consequences of team sensemaking capability in product development projects. *R D Manag.* 42, 473–493. doi: 10.1111/j.1467-9310.2012.00696.x

Alison, L., Power, N., van den Heuvel, C., Humann, M., Palasinksi, M., and Crego, J. (2015). Decision inertia: deciding between least worst outcomes in emergency responses to disasters. *J. Occup. Organ. Psychol.* 88, 295–321. doi: 10.1111/joop.12108

Anandarajan, M., Paravastu, N., and Simmers, C. A. (2006). Perceptions of personal web usage in the workplace: AQ-methodology approach. *Cyberpsychol. Behav.* 9, 325–335. doi: 10.1089/cpb.2006.9.325

Ancona, D. G., Goodman, P. S., Lawrence, B. S., and Tushman, M. L. (2001). Time: a new research lens. *Acad. Manag. Rev.* 26, 645–663. doi: 10.5465/amr.2001.5393903

Argote, L. (1999). *Organizational Learning: Creating, Retaining, and Transferring Knowledge*. Boston, MA: Kluwer Academic Publishers.

Argote, L., and McGrath, J. E. (1993). Group processes in organizations: continuity and change. *Int. Rev. Ind. Organ. Psychol.* 8, 333–389.

Arrow, H., McGrath, J. E., and Berdahl, J. L. (2000). *Small Groups as Complex Systems: Formation, Coordination, Development, and Adaptation*. Thousand Oaks, CA: SAGE Publications, Inc.

Ashforth, B. E., and Mael, F. (1989). Social identity theory and the organization. *Acad. Manag. Rev.* 14, 20–39. doi: 10.5465/amr.1989.4278999

Atkin, R. S., and Conlon, E. J. (1978). Behaviorally anchored rating scales: some theoretical issues. *Acad. Manag. Rev.* 3, 119–128. doi: 10.5465/amr.1978.4297058

Atwater, L., and Carmeli, A. (2009). Leader–member exchange, feelings of energy, and involvement in creative work. *Leadersh. Q.* 20, 264–275. doi: 10.1016/j.leaqua.2007.07.009

Austin, J. R. (2003). Transactive memory in organizational groups: the effects of content, consensus, specialization, and accuracy on group performance. *J. Appl. Psychol.* 88, 866–878. doi: 10.1037/0021-9010.88.5.866

Ayub, N., and Jehn, K. A. (2018). Exploring diversity effects: nationality composition and nationality context in workgroups. *Eur. J. Work Organ. Psychol.* 27, 616–628. doi: 10.1080/1359432x.2018.1502173

Bakker, A. B., Hakanen, J. J., Demerouti, E., and Xanthopoulou, D. (2007). Job resources boost work engagement, particularly when job demands are high. *J. Educ. Psychol.* 99, 274–284. doi: 10.1037/0022-0663.99.2.274

Barley, S. (1986). Technology as an occasion for structuring: evidence from observations of CT scanners and the social order of radiology departments. *Adm. Sci. Q.* 31, 78–108.

Baron, R. M., and Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *J. Pers. Soc. Psychol.* 51, 1173–1182. doi: 10.1037//0022-3514.51.6.1173

Bastida, R., Gupta, H., and Wingreen, S. C. (2017). Exploring blog usage in virtual teams: discovering social media utility. *J. Inf. Technol. Manag.* 28, 15–27.

Beal, D. J., Cohen, R. R., Burke, M. J., and McLendon, C. L. (2003). Cohesion and performance in groups: a meta-analytic clarification of construct relations. *J. Appl. Psychol.* 88, 989–1004. doi: 10.1037/0021-9010.88.6.989

Beck, S. J., and Keyton, J. (2011). "Team cognition, communication, and message interdependence," in *Theories of Team Cognition: Cross-Disciplinary Perspectives*, eds E. Salas, S. M. Fiore, and M. P. Letsky (New York, NY: Routledge), 471–494.

Bell, B. S., Kozlowski, S. W. J., and Blawath, S. (2012). "Team learning: a theoretical integration and review," in *The Oxford Handbook of Organizational Psychology*, Vol. 2, ed. S. W. J. Kozlowski (Oxford: Oxford University Press), 859–909.

Bell, S. T., and Marentette, B. J. (2011). Team viability for long-term and ongoing organizational teams. *Organ. Psychol. Rev.* 1, 275–292. doi: 10.1177/2041386611405876

Bhat, S. K., Pande, N., and Ahuja, V. (2017). Employee profile configurator: a tool to improve effectiveness of a virtual team. *Int. J. Netw. Virtual Organ.* 17, 392–409.

Blanes i Vidal, J., and Möller, M. (2016). Project selection and execution in teams. *RAND J. Econ.* 47, 166–185. doi: 10.1111/1756-2171.12122

Bond-Barnard, T. J., Fletcher, L., and Steyn, H. (2018). Linking trust and collaboration in project teams to project management success. *Int. J. Manag. Projects Bus.* 11, 432–457. doi: 10.1108/ijmpb-06-2017-0068

Boroş, S., Van Gorp, L., Cardoen, B., and Boute, R. (2017). Breaking silos: a field experiment on relational conflict management in cross-functional teams. *Group Decis. Negot.* 26, 327–356. doi: 10.1007/s10726-016-9487-5

Bourbousson, J., and Fortes-Bourbousson, M. (2017). Fluctuations of the experience of togetherness within the team over time: task-cohesion and shared understanding throughout a sporting regular season. *Ergonomics* 60, 810–823. doi: 10.1080/00140139.2016.1229041

Brunton, M., and Cook, C. (2018). Dis/integrating cultural difference in practice and communication: a qualitative study of host and migrant Registered Nurse perspectives from New Zealand. *Int. J. Nur. Stud.* 83, 18–24. doi: 10.1016/j.ijnurstu.2018.04.005

Bullock, A., Morris, Z. S., and Atwell, C. (2013). Exchanging knowledge through healthcare manager placements in research teams. *Serv. Ind. J.* 33, 1363–1380. doi: 10.1080/02642069.2013.815739

Burtscher, M. J., Meyer, B., Jonas, K., Feese, S., and Tröster, G. (2018). A time to trust? The buffering effect of trust and its temporal variations in the context of high-reliability teams. *J. Organ. Behav.* 39, 1099–1112. doi: 10.1002/job.2271

Campbell, J. P., Dunnette, M. D., Arvey, R. D., and Hellervik, L. V. (1973). The development and evaluation of behaviorally based rating scales. *J. Appl. Psychol.* 57, 15–22. doi: 10.1037/h0034185

Cannon-Bowers, J. A., Salas, E., and Converse, S. (1993). "Shared mental models in expert team decision making," in *Individual and Group Decision Making: Current Issues*, ed. N. J. Castellan Jr. (Hillsdale, NJ: Lawrence Erlbaum Associates, Inc), 221–244.

Carnevale, J., Huang, L., and Harms, P. (2018). Speaking up to the "emotional vampire": a conservation of resources perspective. *J. Bus. Res.* 91, 48–59. doi: 10.1016/j.jbusres.2018.05.041

Carter, N. T., Carter, D. R., and DeChurch, L. A. (2018). Implications of observability for the theory and measurement of emergent team phenomena. *J. Manag.* 44, 1398–1425. doi: 10.1177/0149206315609402

Chen, W., Allen, C., and Jonassen, D. (2018). Deeper learning in collaborative concept mapping: a mixed methods study of conflict resolution. *Comput. Hum. Behav.* 87, 424–435. doi: 10.1016/j.chb.2018.01.007

Cheng, X., Fu, S., and Druckenmiller, D. (2016). Trust development in globally distributed collaboration: a case of US and Chinese mixed teams. *J. Manag. Inf. Syst.* 33, 978–1007. doi: 10.1080/07421222.2016.1267521

Chiang, Y. H., Shih, H. A., and Hsu, C. C. (2014). High commitment work system, transactive memory system, and new product performance. *J. Bus. Res.* 67, 631–640. doi: 10.1016/j.jbusres.2013.01.022

Chin, W. W., and Newsted, P. R. (1999). Structural equation modeling analysis with small samples using partial least squares. *Stat. Strategies Small Sample Res.* 1, 307–341.

Choi, S., Lee, H., and Yoo, Y. (2010). The impact of information technology and transactive memory systems on knowledge sharing, application, and team performance: a field study. *MIS Q.* 34, 855–870.

Costa, A. C. (2003). Work team trust and effectiveness. *Pers. Rev.* 32, 605–622. doi: 10.1108/00483480310488360

Costa, P. T., and McCrae, R. R. (1992). Four ways five factors are basic. *Pers. Individ. Dif.* 13, 653–665. doi: 10.1016/0191-8869(92)90236-i

Courtright, S. H., McCormick, B. W., Mistry, S., and Wang, J. (2017). Quality charters or quality members? A control theory perspective on team charters and team performance. *J. Appl. Psychol.* 102, 1462–1470. doi: 10.1037/apl0000229

Cox, T. H., Lobel, S. A., and McLeod, P. A. (1991). Effects of ethnic group cultural differences on cooperative and competitive behavior on a group task. *Acad. Manag. J.* 34, 827–847. doi: 10.5465/256391

Cross, R., Rebele, R., and Grant, A. (2016). Collaborative overload. *Harv. Bus. Rev.* 94, 74–79.

Curral, L. A., Leitão, P., Gomes, C., Silva, P. M. Q. F. D., and Lind, P. G. (2017). How complexity leadership and cohesion influence team effectiveness. *Rev. Psicol. Organ. Trab.* 17, 243–251.

Curtis, A. M., Dennis, A. R., and Hilmer, K. M. (2017). From monologue to dialogue: performative objects to promote collective mindfulness in computer-mediated team discussions. *MIS Q.* 41, 559–581. doi: 10.25300/misq/2017/41.2.10

Dao, M. A., Strobl, A., Bauer, F., and Tarba, S. Y. (2017). Triggering innovation through mergers and acquisitions: the role of shared mental models. *Group Organ. Manag.* 42, 195–236. doi: 10.1177/1059601117696573

De Dreu, C. K., and Weingart, L. R. (2003). Task versus relationship conflict, team performance, and team member satisfaction: a meta-analysis. *J. Appl. Psychol.* 88, 741–749. doi: 10.1037/0021-9010.88.4.741

Devaraj, S., and Jiang, K. (2019). It's about time – A longitudinal adaptation model of high-performance work teams. *J. Appl. Psychol.* 104, 433–447. doi: 10.1037/apl0000372

Duff, A. J., Tahbaz, A., and Chan, C. (2012). The interactive effect of cultural intelligence and openness on task performance. *Res. Pract. Hum. Resour. Manag.* 20, 97–113.

Dyer, L. (1984). Studying human resource strategy: an approach and an agenda. *Ind. Relat. J. Econ. Soc.* 23, 156–169. doi: 10.1186/1744-8603-8-11

Edwards, B. D., Day, E. A., Arthur, W. Jr., and Bell, S. T. (2006). Relationships among team ability composition, team mental models, and team performance. *J. Appl. Psychol.* 91, 727–736. doi: 10.1037/0021-9010.91.3.727

Endsley, T. C. (2018). *An Examination of Cultural Influences on Team Cognition and Information Sharing in Emergency Crisis Management Domains: A Mixed Methodological Approach*. Ann Arbor, MI: ProQuest.

Erez, M., Lisak, A., Harush, R., Glikson, E., Nouri, R., and Shokef, E. (2013). Going global: developing management students' cultural intelligence and global identity in culturally diverse virtual teams. *Acad. Manag. Learn. Educ.* 12, 330–355. doi: 10.5465/amle.2012.0200

Ernst & Young Global Limited (2013). *How Companies use Teams to Drive Performance*. Available at: https://www.ey.com/Publication/vwLUAssets/EY-The-power-of-many/\protect\T1\textdollarFILE/EY-The-power-of-many.pdf (accessed March 27, 2019).

Espinosa, J. A., Nan, N., and Carmel, E. (2015). Temporal distance, communication patterns, and task performance in teams. *J. Manag. Inf. Syst.* 32, 151–191. doi: 10.1080/07421222.2015.1029390

Feitosa, J., Grossman, R., and Salazar, M. (2018). Debunking key assumptions about teams: the role of culture. *Am. Psychol.* 73, 376–389. doi: 10.1037/amp0000256

Feitosa, J., Solis, L., and Grossman, R. (2017). "The influence of culture on team dynamics," in *Team Dynamics over Time*, eds E. Salas, W. B. Vessey, and L. B. Landon (Bingley: Emerald Publishing Limited), 209–230. doi: 10.1108/s1534-085620160000018009

Ford, J. K. (2014). *Improving Training Effectiveness in Work Organizations*. New York, NY: Psychology Press.

Gerpott, F. H., Lehmann-Willenbrock, N., Silvis, J. D., and Van Vugt, M. (2018). In the eye of the beholder? An eye-tracking experiment on emergent leadership in team interactions. *Leadersh. Q.* 29, 523–532. doi: 10.1016/j.leaqua.2017.11.003

Getachew, D. S., and Zhou, E. (2018). Multilevel organizational change readiness: towards comprehensive view in developing countries context. *Int. J. Organ. Innov.* 10, 201–220.

Gibson, C. B. (2001). From knowledge accumulation to accommodation: cycles of collective cognition in work groups. *J. Organ. Behav.* 22, 121–134. doi: 10.1002/job.84

Gilhooly, K. J., Fioratou, E., Anthony, S. H., and Wynn, V. (2007). Divergent thinking: strategies and executive involvement in generating novel uses for familiar objects. *Br. J. Psychol.* 98, 611–625. doi: 10.1111/j.2044-8295.2007.tb00467.x

Golden, S. J., Chang, C. H., and Kozlowski, S. W. (2018). Teams in isolated, confined, and extreme (ICE) environments: review and integration. *J. Organ. Behav.* 39, 701–715. doi: 10.1002/job.2288

Grossman, R., and Feitosa, J. (2018). Team trust over time: modeling reciprocal and contextual influences in action teams. *Hum. Resour. Manag. Rev.* 28, 395–410. doi: 10.1016/j.hrmr.2017.03.006

Gully, S. (2000). "Work teams research: recent findings and future trends," in *Work Teams: Past, Present and Future*, ed. M. M. Beyerlein (Dordrecht: Kluwer Academic), 25–44. doi: 10.1007/978-94-015-9492-9_2

Hagemann, V., and Kluge, A. (2017). Complex problem solving in teams: the impact of collective orientation on team process demands. *Front. Psychol.* 8:1730. doi: 10.3389/fpsyg.2017.01730

Hair, J. F., Ringle, C. M., and Sarstedt, M. (2011). PLS-SEM: indeed a silver bullet. *J. Mark. Theory Pract.* 19, 139–152. doi: 10.2753/mtp1069-6679190202

Harrison, D. A., Price, K. H., and Bell, M. P. (1998). Beyond relational demography: time and the effects of surface-and deep-level diversity on work group cohesion. *Acad. Manag. J.* 41, 96–107. doi: 10.5465/256901

Harrison, D. A., Price, K. H., Gavin, J. H., and Florey, A. T. (2002). Time, teams, and task performance: changing effects of surface-and deep-level diversity on group functioning. *Acad. Manag. J.* 45, 1029–1045. doi: 10.5465/3069328

Hayes, A. F. (2012). *PROCESS: A Versatile Computational Tool for Observed Variable Mediation, Moderation, and Conditional Process Modeling*. Available at: http://is.muni.cz/el/1423/podzim2014/PSY704/50497615/hayes_2012_navod_process.pdf (accessed March 31, 2019).

Hayes, C., Power, T., Davidson, P. M., Daly, J., and Jackson, D. (2018). Learning to liaise: using medication administration role-play to develop teamwork in undergraduate nurses. *Contemp. Nurse* [Epub ahead of print].

Hinsz, V. B., Wallace, D. M., and Ladbury, J. L. (2009). Team performance in dynamic task environments. *Int. Rev. Ind. Organ. Psychol.* 24, 183–216. doi: 10.1002/9780470745267.ch6

Homan, A. C., Hollenbeck, J. R., Humphrey, S. E., Knippenberg, D. V., Ilgen, D. R., and Van Kleef, G. A. (2008). Facing differences with an open mind: openness to experience, salience of intragroup differences, and performance of diverse work groups. *Acad. Manag. J.* 51, 1204–1222. doi: 10.5465/amj.2008.35732995

Hood, A. C., Cruz, K. S., and Bachrach, D. G. (2017). Conflicts with friends: a multiplex view of friendship and conflict and its association with performance in teams. *J. Bus. Psychol.* 32, 73–86. doi: 10.1007/s10869-016-9436-y

Howell, J. P., Dorfman, P. W., and Kerr, S. (1986). Moderator variables in leadership research. *Acad. Manag. Rev.* 11, 88–102. doi: 10.5465/amr.1986.4282632

Hu, J., Erdogan, B., Jiang, K., Bauer, T. N., and Liu, S. (2018). Leader humility and team creativity: the role of team information sharing, psychological safety, and power distance. *J. Appl. Psychol.* 103, 313–323. doi: 10.1037/apl0000277

Huang, C. C., and Chen, P. K. (2018). Exploring the antecedents and consequences of the transactive memory system: an empirical analysis. *J. Knowl. Manag.* 22, 92–118. doi: 10.1108/jkm-03-2017-0092

Hülsheger, U. R., Anderson, N., and Salgado, J. F. (2009). Team-level predictors of innovation at work: a comprehensive meta-analysis spanning three decades of research. *J. Appl. Psychol.* 94, 1128–1145. doi: 10.1037/a0015978

Humphrey, S. E., and Aime, F. (2014). Team microdynamics: toward an organizing approach to teamwork. *Acad. Manag. Ann.* 8, 443–503. doi: 10.5465/19416520.2014.904140

Ilgen, D. R., Hollenbeck, J. R., Johnson, M., and Jundt, D. (2005). Teams in organizations: from input-process-output models to IMOI models. *Annu. Rev. Psychol.* 56, 517–543. doi: 10.1146/annurev.psych.56.091103.070250

Jarvenpaa, S. L., and Majchrzak, A. (2016). Interactive self-regulatory theory for sharing and protecting in interorganizational collaborations. *Acad. Manag. Rev.* 41, 9–27. doi: 10.5465/amr.2012.0005

Jehn, K. A. (1995). A multimethod examination of the benefits and detriments of intragroup conflict. *Adm. Sci. Q.* 40, 256–282.

Jehn, K. A., and Bendersky, C. (2003). Intragroup conflict in organizations: a contingency perspective on the conflict-outcome relationship. *Res. Organ. Behav.* 25, 187–242. doi: 10.1016/s0191-3085(03)25005-x

Jehn, K. A., and Bezrukova, K. (2010). The faultline activation process and the effects of activated faultlines on coalition formation, conflict, and group outcomes. *Organ. Behav. Hum. Decis. Process.* 112, 24–42. doi: 10.1016/j.obhdp.2009.11.008

Jehn, K. A., and Mannix, E. A. (2001). The dynamic nature of conflict: a longitudinal study of intragroup conflict and group performance. *Acad. Manag. J.* 44, 238–251. doi: 10.2307/3069453

Jehn, K. A., Rispens, S., and Thatcher, S. M. (2010). The effects of conflict asymmetry on work group and individual outcomes. *Acad. Manag. J.* 53, 596–616. doi: 10.5465/amj.2010.51468978

Jin, Y., and Levitt, R. E. (1996). The virtual design team: a computational model of project organizations. *Comput. Math. Organ. Theory* 2, 171–195. doi: 10.1007/bf00127273

Jones, T. L., Baxter, M. A. J., and Khanduja, V. (2013). A quick guide to survey research. *Ann. R. Coll. Surg. Engl.* 95, 5–7. doi: 10.1308/003588413X13511609956372

Jung, D. I., and Sosik, J. J. (2002). Transformational leadership in work groups: the role of empowerment, cohesiveness, and collective-efficacy on perceived group performance. *Small Group Res.* 33, 313–336. doi: 10.1177/10496402033003002

Kahn, A. S., and Williams, D. (2016). We're all in this (game) together: transactive memory systems, social presence, and team structure in multiplayer online battle Arenas. *Commun. Res.* 43, 487–517. doi: 10.1177/0093650215617504

Keyton, J., Beck, S. J., and Asbury, M. B. (2010). Macrocognition: a communication perspective. *Theor. Issues Ergon. Sci.* 11, 272–286. doi: 10.1080/14639221003729136

Kim, T., McFee, E., Olguin, D. O., Waber, B., and Pentland, A. S. (2012). Sociometric badges: using sensor technology to capture new forms of collaboration. *J. Organ. Behav.* 33, 412–427. doi: 10.1002/job.1776

Konradt, U., Schippers, M. C., Garbers, Y., and Steenfatt, C. (2015). Effects of guided reflexivity and team feedback on team performance improvement: the role of team regulatory processes and cognitive emergent states. *Eur. J. Work Organ. Psychol.* 24, 777–795. doi: 10.1080/1359432x.2015.1005608

Kozlowski, S. W., and Bell, B. S. (2003). "Workgroups and teams in organizations," in *Handbook of Psychology: Industrial and Organizational Psychology*, Vol. 12, eds W. C. Borman, D. R. Ilgen, and R. J. Klimoski (New York, NY: Wiley-Blackwell), 333–375.

Kozlowski, S. W., and Chao, G. T. (2018). Unpacking team process dynamics and emergent phenomena: challenges, conceptual advances, and innovative methods. *Am. Psychol.* 73, 576–592. doi: 10.1037/amp0000245

Kozlowski, S. W., Chao, G. T., Chang, C. H., and Fernandez, R. (2015). "Team dynamics: using "big data" to advance the science of team effectiveness," in *Big Data. (at)Work: The Data Science Revolution and Organizational Psychology*, eds S. Tonidandel, E. B. King, and J. M. Cortina (New York, NY: Routledge), 273–309.

Kozlowski, S. W., Chao, G. T., Grand, J. A., Braun, M. T., and Kuljanin, G. (2016). Capturing the multilevel dynamics of emergence: computational modeling, simulation, and virtual experimentation. *Organ. Psychol. Rev.* 6, 3–33. doi: 10.1177/2041386614547955

Kozlowski, S. W. J., Gully, S. M., McHugh, P. P., Salas, E., and Cannon-Bowers, J. A. (1996a). A dynamic theory of leadership and team effectiveness: developmental and task contingent leader roles. *Res. Pers. Hum. Resour. Manag.* 14, 253–306.

Kozlowski, S. W. J., Gully, S. M., Salas, E., and Cannon-Bowers, J. A. (1996b). "Team leadership and development: theory, principles, and guidelines for training leaders and teams," in *Advances in Interdisciplinary Studies of Work Teams; Team Leadership*, Vol. 3, eds M. M. Beyerlein, D. A. Johnson, and S. T. Beyerlein (New York, NY: Elsevier Science), 253–291.

Kozlowski, S. W., Gully, S. M., Nason, E. R., and Smith, E. M. (1999). "Developing adaptive teams: a theory of compilation and performance across levels and time," in *The Changing Nature of Work Performance: Implications for Staffing, Personnel Actions, and Development*, eds D. E. Ilgen and E. D. Pulakos (San Francisco, CA: Jossey-Bass), 240–292.

Kozlowski, S. W., and Ilgen, D. R. (2006). Enhancing the effectiveness of work groups and teams. *Psychol. Sci. Public Interest* 7, 77–124. doi: 10.1111/j.1529-1006.2006.00030.x

Kozlowski, S. W. J., and Bell, B. S. (2008). "Team learning, development, and adaptation [Electronic version]," in *Work Group Learning*, eds V. I. Sessa and M. London (Mahwah, NJ: Lawrence Erlbaum Associates), 15–44.

Kozlowski, S. W. J., Chao, G. T., and Jensen, J. M. (2010). "Building an infrastructure for organizational learning: a multilevel approach," in *Learning, Training, and Development in Organizations*, eds S. W. J. Kozlowski and E. Salas (New York, NY: Routledge), 363–403.

Lanaj, K., Foulk, T. A., and Hollenbeck, J. R. (2018). The benefits of not seeing eye to eye with leadership: divergence in risk preferences impacts multiteam system behavior and performance. *Acad. Manag. J.* 61, 1554–1582. doi: 10.5465/amj.2015.0946

Landy, F. J., and Farr, J. L. (1980). Performance rating. *Psychol. Bull.* 87, 72–107.

Langfred, C. W. (2000). The paradox of self-management: individual and group autonomy in work groups. *J. Organ. Behav.* 21, 563–585. doi: 10.1002/1099-1379(200008)21:5<563::aid-job31>3.0.co;2-h

Langfred, C. W. (2004). Too much of a good thing? Negative effects of high trust and individual autonomy in self-managing teams. *Acad. Manag. J.* 47, 385–399. doi: 10.5465/20159588

Lehmann-Willenbrock, N., and Chiu, M. M. (2018). Igniting and resolving content disagreements during team interactions: a statistical discourse analysis of team dynamics at work. *J. Organ. Behav.* 39, 1142–1162. doi: 10.1002/job.2256

LePine, J. A. (2003). Team adaptation and postchange performance: effects of team composition in terms of members' cognitive ability and personality. *J. Appl. Psychol.* 88, 27–39. doi: 10.1037/0021-9010.88.1.27

Li, J., Li, A., Chattopadhyay, P., George, E., and Gupta, V. (2018). Team emotion diversity and performance: the moderating role of social class homogeneity. *Group Dyn. Theory Res. Pract.* 22, 76–92. doi: 10.1037/gdn0000083

Liedtka, J. M. (1996). Collaborating across lines of business for competitive advantage. *Acad. Manag. Exec.* 10, 20–34. doi: 10.5465/ame.1996.9606161550

Lingard, H., Peihua Zhang, R., Blismas, N., Wakefield, R., and Kleiner, B. (2015). Are we on the same page? Exploring construction professionals' mental models of occupational health and safety. *Constr. Manag. Econ.* 33, 73–84. doi: 10.1080/01446193.2015.1016541

Linton, R. K., Critch, S., and Kehoe, E. J. (2018). Role-specific versus cross-role preparation for decision-making teams. *Group Dyn. Theory Res. Pract.* 22, 45–60. doi: 10.1037/gdn0000081

Lu, L., Li, F., Leung, K., Savani, K., and Morris, M. W. (2018). When can culturally diverse teams be more creative? The role of leaders' benevolent paternalism. *J. Organ. Behav.* 39, 402–415. doi: 10.1002/job.2238

Luciano, M. M., DeChurch, L. A., and Mathieu, J. E. (2018). Multiteam systems: a structural framework and meso-theory of system functioning. *J. Manag.* 44, 1065–1096. doi: 10.1177/0149206315601184

Lvina, E., Johns, G., and Vandenberghe, C. (2018). Team political skill composition as a determinant of team cohesiveness and performance. *J. Manag.* 44, 1001–1028. doi: 10.1177/0149206315598371

Macal, C. M., and North, M. J. (2006). "Introduction to agent-based modeling and simulation," in *MCS LANS Informal Seminar*, eds M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines (Argonne, IL: Argonne National Laboratory).

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manag. Rev.* 26, 356–376. doi: 10.5465/amr.2001.4845785

Maruping, L. M., Venkatesh, V., Thatcher, S. M., and Patel, P. C. (2015). Folding under pressure or rising to the occasion? Perceived time pressure and the moderating role of team temporal leadership. *Acad. Manag. J.* 58, 1313–1333. doi: 10.5465/amj.2012.0468

Mathieu, J., Maynard, M. T., Rapp, T., and Gilson, L. (2008). Team effectiveness 1997-2007: a review of recent advancements and a glimpse into the future. *J. Manag.* 34, 410–476. doi: 10.1177/0149206308316061

Mathieu, J. E., Gallagher, P. T., Domingo, M. A., and Klock, E. A. (2019). Embracing complexity: reviewing the past decade of team effectiveness research. *Annu. Rev. Organ. Psychol. Organ. Behav.* 6, 17–46. doi: 10.1146/annurev-orgpsych-012218-015106

Mayer, R. C., Davis, J. H., and Schoorman, F. D. (1995). An integrative model of organizational trust. *Acad. Manag. Rev.* 20, 709–734. doi: 10.5465/amr.1995.9508080335

McCrae, R. R. (1987). Creativity, divergent thinking, and openness to experience. *J. Pers. Soc. Psychol.* 52, 1258–1265. doi: 10.1037//0022-3514.52.6.1258

McDowell, T., Agarwal, D., Miller, D., Okamoto, T., and Page, T. (2016). *Organizational Design: The Rise of Teams*. Westlake, TX: Deloitte University Press.

McGrath, J. E. (1984). *Groups: Interaction and Performance*. Englewood Cliffs, NJ: Prentice-Hall.

McGrath, J. E. (1991). Time, interaction, and performance (TIP). *Small Group Res.* 22:147. doi: 10.1177/1046496491222001

McGrath, J. E., Arrow, H., and Berdahl, J. L. (2000). The study of groups: past, present, and future. *Pers. Soc. Psychol. Rev.* 4, 95–105.

McIntyre, F. S., and Gilbert, F. W. (1994). Improving performance in case courses: an argument for behaviorally anchored rating scales. *Mark. Educ. Rev.* 4, 51–58. doi: 10.1080/10528008.1994.11488442

McQuerrey, L. (2017). *How Does Trust Affect Teamwork? AZ Central*. Available at: https://yourbusiness.azcentral.com/trust-affect-teamwork-17383.html (accessed March 31, 2019).

Mell, J. N., Van Knippenberg, D., and Van Ginkel, W. P. (2014). The catalyst effect: the impact of transactive memory system structure on team performance. *Acad. Manag. J.* 57, 1154–1173. doi: 10.5465/amj.2012.0589

Miller, D. L. (2003). The stages of group development: a retrospective study of dynamic team processes. *Can. J. Adm. Sci.* 20, 121–134. doi: 10.1111/j.1936-4490.2003.tb00698.x

Mitchell, R., Boyle, B., and Von Stieglitz, S. (2018). Professional commitment and team effectiveness: a moderated mediation investigation of cognitive diversity and task conflict. *J. Bus. Psychol.* 1–13. doi: 10.1007/s10869-018-9550-0 (accessed October 29, 2018).

Mohammed, S., Hamilton, K., and Lim, A. (2009). "The incorporation of time in team research: past, current, and future," in *The Organizational Frontiers Series. Team Effectiveness in Complex Organizations: Cross-Disciplinary Perspectives and Approaches*, eds E. Salas, G. F. Goodwin, and C. S. Burke (New York, NY: Routledge), 321–348.

Mohammed, S., and Nadkarni, S. (2011). Temporal diversity and team performance: the moderating role of team temporal leadership. *Acad. Manag. J.* 54, 489–508. doi: 10.5465/amj.2011.61967991

Myers, S. P. (2013). *Definition of Team Dynamics*. Available at: http://www.teamtechnology.co.uk/team/dynamics/definition/ (accessed April 5, 2019).

Navarro, J., Roe, R. A., and Artiles, M. I. (2015). Taking time seriously: changing practices and perspectives in Work/Organizational Psychology. *J. Work Organ. Psychol.* 31, 135–145. doi: 10.1016/j.rpto.2015.07.002

Neufeld, D. J., and Haggerty, N. (2001). Collaborative team learning in information systems: a pedagogy for developing team skills and high performance. *J. Comput. Inf. Syst.* 42, 37–43.

O'Neill, T. A., Hoffart, G. C., McLarnon, M. M., Woodley, H. J., Eggermont, M., Rosehart, W., et al. (2017). Constructive controversy and reflexivity training promote effective conflict profiles and team functioning in student learning teams. *Acad. Manag. Learn. Educ.* 16, 257–276. doi: 10.5465/amle.2015.0183

O'Neill, T. A., and Salas, E. (2018). Creating high performance teamwork in organizations. *Hum. Resour. Manag. Rev.* 28, 325–331. doi: 10.1016/j.hrmr.2017.09.001

Park, C. L. (2010). Making sense of the meaning literature: an integrative review of meaning making and its effects on adjustment to stressful life events. *Psychol. Bull.* 136, 257–301. doi: 10.1037/a0018301

Pearsall, M. J., Ellis, A. P., and Bell, B. S. (2010). Building the infrastructure: the effects of role identification behaviors on team cognition development and performance. *J. Appl. Psychol.* 95, 192–200. doi: 10.1037/a0017781

Peltokorpi, V., and Hasu, M. (2016). Transactive memory systems in research team innovation: a moderated mediation analysis. *J. Eng. Technol. Manag.* 39, 1–12. doi: 10.1016/j.jengtecman.2015.11.001

Peñarroja, V., Orengo, V., and Zornoza, A. (2017). Reducing perceived social loafing in virtual teams: the effect of team feedback with guided reflexivity. *J. Appl. Soc. Psychol.* 47, 424–435. doi: 10.1111/jasp.12449

Pennington, D. D. (2008). Cross-disciplinary collaboration and learning. *Ecol. Soc.* 13:8.

Pentland, A. (2007). Automatic mapping and modeling of human networks. *Phys. A Stat. Mech. Appl.* 378, 59–67. doi: 10.1016/j.physa.2006.11.046

Perry, S. J., Witt, L. A., Penney, L. M., and Atwater, L. (2010). The downside of goal-focused leadership: the role of personality in subordinate exhaustion. *J. Appl. Psychol.* 95, 1145–1153. doi: 10.1037/a0020538

Pollack, J., Holbrook, C., Fessler, D. M. T., Sparks, A. M., and Zerbe, J. G. (2018). May God guide our guns: visualizing supernatural aid heightens team confidence in a paintball battle simulation. *Hum. Nat.* 29, 311–327. doi: 10.1007/s12110-018-9320-8

Priyono, A. (2016). The use of ICT platforms to promote knowledge exchange in project-based organisations. *Int. J. Entrepreneurial Knowl.* 2, 5–21. doi: 10.1515/ijek-2016-0010

Prochazka, J., Vaculik, M., Smutny, P., and Jezek, S. (2018). Leader traits, transformational leadership and leader effectiveness: a mediation study from the Czech Republic. *J. East Eur. Manag. Stud.* 23, 474–501. doi: 10.5771/0949-6181-2018-3-474

Quigley, N. R. (2013). A longitudinal, multilevel study of leadership efficacy development in MBA teams. *Acad. Manag. Learn. Educ.* 12, 579–602. doi: 10.5465/amle.2011.0524

Rajivan, P., and Cooke, N. J. (2018). Information-pooling bias in collaborative security incident correlation analysis. *Hum. Factors* 60, 626–639. doi: 10.1177/0018720818769249

Ramos-Villagrasa, P. J., Marques-Quinteiro, P., Navarro, J., and Rico, R. (2018). Teams as complex adaptive systems: reviewing 17 years of research. *Small Group Res.* 49, 135–176. doi: 10.1177/1046496417713849

Ren, Y., and Argote, L. (2011). Transactive memory systems 1985–2010: an integrative framework of key dimensions, antecedents, and consequences. *Acad. Manag. Ann.* 5, 189–229. doi: 10.5465/19416520.2011.590300

Resick, C. J., Dickson, M. W., Mitchelson, J. K., Allison, L. K., and Clark, M. A. (2010). Team composition, cognition, and effectiveness: examining mental model similarity and accuracy. *Group Dyn. Theory Res. Pract.* 14, 174–191. doi: 10.1037/a0018444

Rodríguez-Sánchez, A. M., Devloo, T., Rico, R., Salanova, M., and Anseel, F. (2017). What makes creative teams tick? Cohesion, engagement, and performance across creativity tasks: a three-wave study. *Group Organ. Manag.* 42, 521–547. doi: 10.1177/1059601116636476

Rutherford, A. (2001). *Introducing ANOVA and ANCOVA: a GLM Approach*. Thousand Oaks, CA: Sage.

Salas, E., Cooke, N. J., and Rosen, M. A. (2008). On teams, teamwork, and team performance: discoveries and developments. *Hum. Factors* 50, 540–547. doi: 10.1518/001872008x288457

Salas, E., Dickinson, T. L., Converse, S. A., and Tannenbaum, S. I. (1992). "Toward an understanding of team performance and training," in *Teams: Their Training and Performance*, eds R. W. Swezey and E. Salas (Westport, CT: Ablex Publishing), 3–29.

Salas, E., Grossman, R., Hughes, A. M., and Coultas, C. W. (2015a). Measuring team cohesion: observations from the science. *Hum. Factors* 57, 365–374. doi: 10.1177/0018720815578267

Salas, E., Shuffler, M. L., Thayer, A. L., Bedwell, W. L., and Lazzara, E. H. (2015b). Understanding and improving teamwork in organizations: a scientifically based practical guide. *Hum. Resour. Manag.* 54, 599–622. doi: 10.1002/hrm.21628

Salas, E., Reyes, D. L., and McDaniel, S. H. (2018). The science of teamwork: progress, reflections, and the road ahead. *Am. Psychol.* 73, 593–600. doi: 10.1037/amp0000334

Sander, P. C., van Doorn, R. R. A., van der Pal, J., and Zijlstra, F. R. H. (2015). Team adaptation to an unforeseen system failure: limits of the potential aids of shared knowledge and standardized communication. *Eur. J. Work Organ. Psychol.* 24, 796–811. doi: 10.1080/1359432x.2015.1006199

Santos, C. M., Uitdewilligen, S., and Passos, A. M. (2015). Why is your team more creative than mine? The influence of shared mental models on intra-group conflict, team creativity and effectiveness. *Creat. Innov. Manag.* 24, 645–658. doi: 10.1111/caim.12129

Sarstedt, M., Ringle, C. M., Smith, D., Reams, R., and Hair, J. F. Jr. (2014). Partial least squares structural equation modeling (PLS-SEM): a useful tool for family business researchers. *J. Fam. Bus. Strategy* 5, 105–115. doi: 10.1016/j.jfbs.2014.01.002

Schumacker, R. E., and Lomax, R. G. (2010). *A Beginner's Guide to Structural Equation Modeling*, 3rd Edn. New York, NY: Routledge.

Shaner, M. B., Beeler, L., and Noble, C. H. (2016). Do we have to get along to innovate? The influence of multilevel social cohesion on new product and new service development. *J. Prod. Innov. Manag.* 33, 148–165. doi: 10.1111/jpim.12327

Shuffler, M. L., Kramer, W. S., Carter, D. R., Thayer, A. L., and Rosen, M. A. (2018). Leveraging a team-centric approach to diagnosing multiteam system functioning: the role of intrateam state profiles. *Hum. Resour. Manag. Rev.* 28, 361–377. doi: 10.1016/j.hrmr.2017.08.003

Simons, T. L., and Peterson, R. S. (2000). Task conflict and relationship conflict in top management teams: the pivotal role of intragroup trust. *J. Appl. Psychol.* 85, 102–124.

Sorkhi, M., and Hashemi, S. (2015). Effective team formation in collaboration networks using vertex and proficiency similarity measures. *AI Commun.* 28, 637–654. doi: 10.3233/aic-140628

Sosik, J. J., Kahai, S. S., and Piovoso, M. J. (2009). Silver bullet or voodoo statistics? A primer for using the partial least squares data analytic technique in group and organization research. *Group Organ. Manag.* 34, 5–36. doi: 10.1177/1059601108329198

Srivastava, A., Bartol, K. M., and Locke, E. A. (2006). Empowering leadership in management teams: effects on knowledge sharing, efficacy, and performance. *Acad. Manag. J.* 49, 1239–1251. doi: 10.5465/amj.2006.23478718

Stewart, G. L. (2010). The past twenty years: teams research is alive and well. *J. Manag.* 36, 801–805. doi: 10.1177/0149206310371512

Stewart, G. L., Fulmer, I. S., Banick, M. R., and Hollenbeck, J. (2005). An exploration of member roles as a multilevel linking mechanism for individual traits and team outcomes. *Pers. Psychol.* 58, 343–365. doi: 10.1111/j.1744-6570.2005.00480.x

Swanson, R. A., and Holton, E. F. (2005). *Research in Organizations: Foundations and Methods in Inquiry*. Oakland, CA: Berrett-Koehler Publishers.

Taggar, S. (2002). Individual creativity and group ability to utilize individual creative resources: a multilevel model. *Acad. Manag. J.* 45, 315–330. doi: 10.5465/3069349

Tajfel, H., and Turner, J. C. (1985). "The social identity theory of intergroup behavior," in *Psychology of Intergroup Relations*, eds S. Worchel and W. G. Austin (Chicago, IL: Nelson-Hall), 7–24.

Taras, V., Kirkman, B. L., and Steel, P. (2010). Examining the impact of culture's consequences: a three-decade, multilevel, meta-analytic review of Hofstede's cultural value dimensions. *J. Appl. Psychol.* 95, 405–439. doi: 10.1037/a0018938

Thompson, E. P. (1967). Time, work-discipline, and industrial capitalism. *Past Present* 38, 56–97. doi: 10.1093/past/38.1.56

Tuckman, B. W. (1965). Developmental sequence in small groups. *Psychol. Bull.* 63, 384–399. doi: 10.1037/h0022100

Tuckman, B. W., and Jensen, M. A. C. (1977). Stages of small-group development revisited. *Group Organ. Stud.* 2, 419–427. doi: 10.1177/105960117700200404

Turner, J. C. (1987). *Rediscovering the Social Group: A Self-Categorization Theory*. Oxford: Basil Blackwell.

Uitdewilligen, S., Rico, R., and Waller, M. J. (2018). Fluid and stable: dynamics of team action patterns and adaptive outcomes. *J. Organ. Behav.* 39, 1113–1128. doi: 10.1002/job.2267

Uitdewilligen, S., and Waller, M. J. (2018). Information sharing and decision-making in multidisciplinary crisis management teams. *J. Organ. Behav.* 39, 731–748. doi: 10.1136/bmjqs-2014-003096

Van Bunderen, L., Greer, L. L., and van Knippenberg, D. (2018). When interteam conflict spirals into intrateam power struggles: the pivotal role of team power structures. *Acad. Manag. J.* 61, 1100–1130. doi: 10.5465/amj.2016.0182

Van Knippenberg, D., De Dreu, C. K., and Homan, A. C. (2004). Work group diversity and group performance: an integrative model and research agenda. *J. Appl. Psychol.* 89, 1008–1022. doi: 10.1037/0021-9010.89.6.1008

Van Osch, W., and Steinfield, C. W. (2018). Strategic visibility in enterprise social media: implications for network formation and boundary spanning. *J. Manag. Inf. Syst.* 35, 647–682. doi: 10.1080/07421222.2018.1451961

Waber, B. N., Olguin, D. O., Kim, T., and Pentland, A. (2008). Understanding organizational behavior with wearable sensing technology. *SSRN Electron. J.* 1–36. doi: 10.2139/ssrn.1263992 (accessed March 31, 2019).

Waldman, D. A., Wang, D., Stikic, M., Berka, C., and Korszen, S. (2015). Neuroscience and team processes. *Organ. Neurosci.* 7, 277–294. doi: 10.1108/s1479-357120150000007012

Wegner, D. M. (1987). "Transactive memory: a contemporary analysis of the group mind," in *Theories of Group Behavior*, eds B. Mullen and G. R. Goethals (New York, NY: Springer), 185–208. doi: 10.1007/978-1-4612-4634-3_9

Weiss, H. M., and Cropanzano, R. (1996). Affective events theory. *Res. Organ. Behav.* 18, 1–74.

Wheelan, S. A. (2003). An initial exploration of the internal dynamics of leadership teams. *Consult. Psychol. J. Pract. Res.* 55, 179–188. doi: 10.1037/1061-4087.55.3.179

Wold, H. (1982). "Soft modeling: the basic design and some extensions," in *Systems Under Indirect Observation: Casualty, Structure, Prediction*, eds K. G. Joreskong and H. Wold (Amsterdam: North Holland), 1–54.

Wong, K. K. K. (2013). Partial least squares structural equation modeling (PLS-SEM) techniques using SmartPLS. *Mark. Bull.* 24, 1–32.

Xiang, C., Yang, Z., and Zhang, L. (2016). Improving IS development teams' performance during requirement analysis in project—The perspectives from shared mental model and emotional intelligence. *Int. J. Project Manag.* 34, 1266–1279. doi: 10.1016/j.ijproman.2016.06.009

Young-Hyman, T. (2017). Cooperating without co-laboring: how formal organizational power moderates cross-functional interaction in project teams. *Adm. Sci. Q.* 62, 179–214. doi: 10.1177/0001839216655090

Zhou, Z. (2018). *Planning and Team Shared Mental Models as Predictors of Team Collaborative Processes*. Ann Arbor, MI: ProQuest.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Delice, Rousseau and Feitosa. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

REVIEW
published: 19 June 2019
doi: 10.3389/fpsyg.2019.01417

Understanding Team Learning Dynamics Over Time

Christopher W. Wiese[1] and C. Shawn Burke[2]*

[1] Georgia Institute of Technology, Atlanta, GA, United States, [2] Institute for Simulation and Training, University of Central Florida, Orlando, FL, United States

Organizations depend on the learning capabilities of teams in order to be competitive in today's information-laden business landscape. Hence, it is not surprising that there have been tremendous efforts made to understand team learning within the past two decades. These efforts, however, have produced a cluttered literature-base that overlooks a fundamental aspect of team learning: How do teams learn over time? In this paper, we first synthesize the literature to develop a shared vocabulary to understand team learning dynamics. We then leverage research investigating how teams operate within the context of time (e.g., team development, performance cycles, emergent state development) and combine it with the extant team learning literature in developing an unfolding model of team learning. This comprehensive model addresses a noticeable gap in the extant literature by illustrating how teams learn over time. Finally, we put forth three grand challenges for the future of team learning research.

Keywords: team learning, temporal dynamics, team learning behaviors, time, review

OPEN ACCESS

Edited by:
Marissa Shuffler,
Clemson University, United States

Reviewed by:
Vanessa Urch Druskat,
University of New Hampshire,
United States
Joseph Andrew Allen,
The University of Utah, United States

****Correspondence:***
Christopher W. Wiese
ChrisWWiese@gmail.com

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *17 December 2018*
Accepted: *03 June 2019*
Published: *19 June 2019*

Citation:
Wiese CW and Burke CS (2019) Understanding Team Learning Dynamics Over Time. Front. Psychol. 10:1417. doi: 10.3389/fpsyg.2019.01417

TEAM LEARNING DYNAMICS OVER TIME

"Learning and innovation go hand in hand. The arrogance of success is to think that what you did yesterday will be sufficient for tomorrow" – C. William Pollard in *The Soul of the Firm*

"Team learning is vital because teams, not individuals, are the fundamental learning unit in modern organizations. This is where 'the rubber meets the road'; unless teams can learn, the organization cannot learn." – Peter M. Senge in *The Fifth Discipline*.

Learning is key to remaining successful in today's business landscape. The pressure to change and evolve at a moment's notice is higher than ever – and this pressure often falls on the shoulders of teams. Teams are a collection of individuals who are interdependently working to achieve a shared goal (Salas et al., 1992) and organizations have come to rely on teams that can learn in order to be successful (Edmondson et al., 2007). When teams do not learn, it is likely that the organization will suffer. For example, teams that fail to learn will take longer to bring a new product to market (e.g., Sarin and McDermott, 2003). Hence, it has become crucial in both practice and academia to better understand team learning in order to enhance effectiveness throughout the organization.

The abundance of team learning research in recent years has revealed two main concerns with the state of the science, the resolution of which serve as the aims of the current manuscript. The first aim of these efforts is to explicate a shared understanding of team learning terminology. Through

a review of the literature, we organize team learning constructs into two broad categories: team learning outcomes and team learning processes. We define two different types of team learning outcomes. Specifically, we use the term *team learning* to refer to a shift in a team's collective knowledge state and the term *team learning curves* to represent changes in performance due to team learning over time. Additionally, we assert that *team learning behaviors* (i.e., behaviors that aid in the development of collective knowledge) can be further delineated into three different types of behaviors: *intrateam, interteam,* and *fundamental learning behaviors*. The conglomeration of different terminologies prevent meaningful discussion of the state of the science and a synthesis of unequivocal phraseology is necessary if we wish to move team learning science forward.

The second aim is to facilitate the understanding of how team learning occurs over time by presenting an unfolding model of team learning (**Figure 1**). By its very nature, team learning is a phenomenon that takes place over time and there is a critical need to understand teams in the context of time (e.g., Cronin et al., 2011). For team learning to occur, information needs to be shared amongst team members, discussed and scaffolded to existing knowledge, and stored in some way to be retrieved later. This process does not happen in a single moment, but in a series of interactions that unfold over time. While some of these aspects have been addressed in previous team learning models (e.g., Decuyper et al., 2010), our unfolding model of team learning provides a comprehensive framework of when, how, and what teams learn over time. By viewing team learning through our unfolding model (**Figure 1**), researchers and practitioners can reveal new insights on how learning develops over time and highlight factors that facilitate team learning and increase performance.

These two aims are accomplished as follows. First, we provide a detailed look into team learning terminology. The term *team learning* has been used to refer to various aspects of the team learning process – from behaviors that facilitate learning to shifts in collective knowledge to performance improvements over time. Hence, it is critical that, before presenting our unfolding model of team learning, a common understanding of language is achieved. Next, we describe how teams operate in the context of time. Here, we pull from the team development and team temporal dynamics literatures to discuss the evolution of teams in time and what that tells us about when, how, and what teams learn. Our efforts culminate in the presentation of an unfolding model of team learning, which leverages the existing literature to describe how teams learn over time. Finally, we set forth three grand challenges that need to be addressed in order to push the field forward. These challenges represent crucial gaps in the collective scientific knowledge state and, if addressed, will help teams learn and perform more effectively in practice.

TEAM LEARNING TERMINOLOGY

In order to understand how team learning occurs over time, it is first necessary to approach the topic with a shared vocabulary. While learning has been a key topic of research with respect to individual (e.g., Argyris, 1982) and organizational levels (e.g., Huber, 1991), a historical assessment of the literature suggests that team learning has only come into its own in the last two decades. Edmondson's (1999) seminal article on team learning and psychological safety can be considered the catalyst of today's team learning research landscape. In it, Edmondson defines team learning as a behavioral process – representing the cyclical process of seeking out (e.g., seeking feedback), gathering (e.g., asking questions), and discussing and integrating information (e.g., discussing errors). As shown in **Figure 2**, research in the organizational sciences focusing on team learning took off after the publication of Edmondson's article (although reducing in recent years). An unintended consequence of this research thrust was the differential use of the term *team learning*. Like Edmondson, many use *team learning* to refer to behavioral processes (e.g., Gibson and Vermeulen, 2003; Wong, 2004), while others conceptualize it as changes in performance (e.g., Darr et al., 1995; Pisano et al., 2001), or shifts in collective knowledge (e.g., Ellis et al., 2003). Hence, before understanding how team learning unfolds over time, it is imperative that we approach this literature with a shared vocabulary.

Through a review of the literature, we collected different uses of the term "team learning" and summarize these findings in **Table 1**. Generally, there are two different thoughts on how to conceptualize team learning – as an outcome or as a process. Like previous authors, we adopt this distinction as an overarching categorization mechanism to better understand team learning. Elaborated upon in the next section, team learning as an outcome reflects the end result of learning processes, which fall into two distinct conceptualizations. Specifically, team learning outcomes could refer to either (1) changes in collective knowledge (i.e., *team learning*) or (2) shifts in performance (i.e., *learning curves*). Similarly, we found that team learning processes (i.e., *team learning behaviors*) can be further delineated into (1) *intrateam,* (2) *interteam,* and (3) *fundamental learning behaviors*. In the following section, we elucidate on this breakdown. It is our hope that our synthesis of team learning terminology will provide some much-needed conceptual clarity to the literature as well as facilitate understanding of our unfolding team learning model.

Team Learning as an Outcome

In order for us to understand how teams learn over time, it is crucial to recognize that learning – across all levels of consideration – is a temporally infused phenomenon. It infers a shift in knowledge state – a knowledge trajectory from one point in time to another. It is only logical, then, that conceptualizations of team learning outcomes hold these similar temporal properties. That is, team learning outcomes need to reflect a change in collective knowledge over time. Our review of the literature suggests that this is typically approached in two ways. The first is what we call *team learning*, which is a shift in collective knowledge. It represents the purest form of learning, harkening back to philosophical discussions on individual knowledge gain (e.g., Cornford, 1935). Collective knowledge refers to information held by the team about the team and its surrounding system. As it is a characteristic of the team, collective knowledge does not reflect knowledge held by

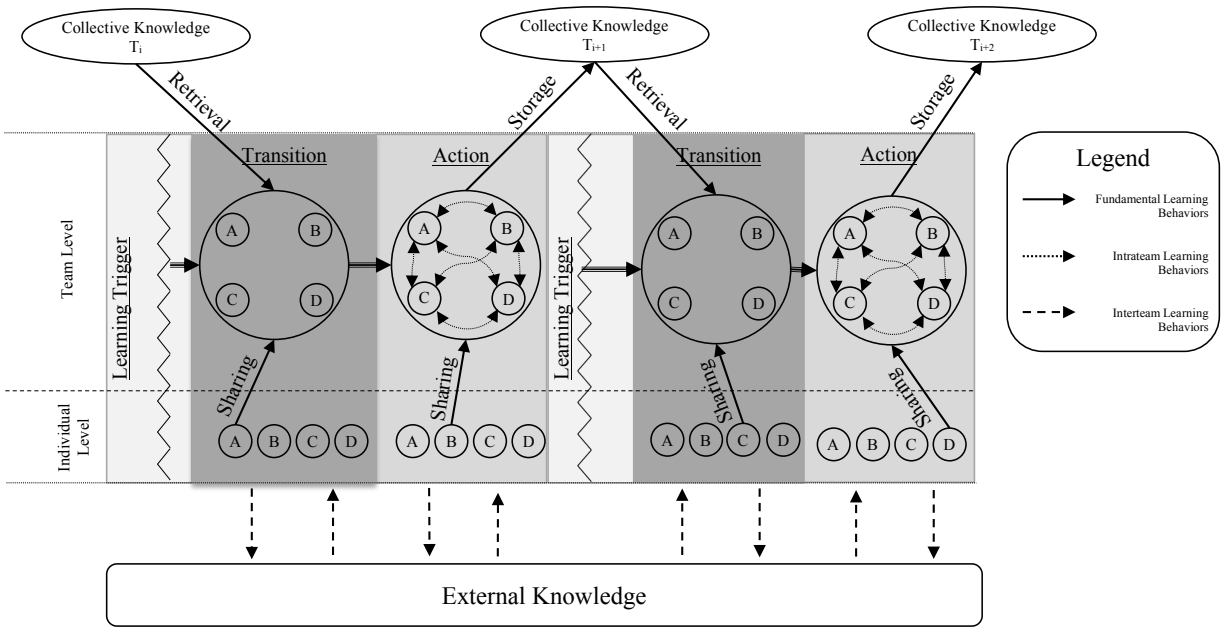

FIGURE 1 | Unfolding model of team learning.

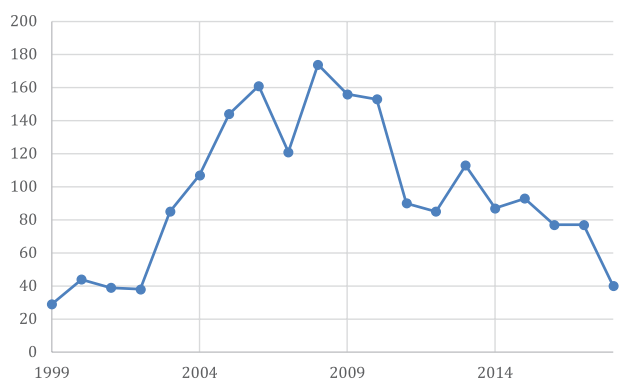

FIGURE 2 | Number of articles using the keywords "team learning" or "group learning since 1999 in using Academic Search Complete, Applied Science and Business, Applied Science and Technology, Business Abstracts, Business Source Complete, PsycArticles, PsycINFO, and Vocational and Career Collection databases.

any particular team member, but knowledge held by the team as its own united entity. For example, collective knowledge should remain intact when a member leaves the team. As Wilson et al. (2007) wrote "If an individual leaves the group and the group cannot access his or her learning, the group has failed to learn" (p. 1042–1043). Hence, in order for shifts in collective knowledge to occur, it is necessary for team members to interact and integrate individually held information into the team's collective knowledge state.

While our conceptualization of team learning represents the most direct form of learning in teams (Kozlowski and Bell, 2008), it is nearly impossible to assess directly. One would need to identify the exact moment knowledge moved from an individually-held property to a team-held property. It is not surprising, then, that proxies such as team shared mental models and transactive memory systems are more commonly used to infer team learning. Both team mental models and transactive memory systems reflect the current state of the team's collective knowledge, albeit in different ways. Team mental models represent the collective understanding of various aspects of the team's operational system with respect to both content (what the teams know) and structure (relationship between different knowledge elements). Team learning can be inferred from team mental models in two ways, either mental model similarity at a single point in time or tracking mental model convergence over time (e.g., McComb, 2007; Santos and Passos, 2013).

Another proxy of team learning are evaluations of transactive memory systems. Transactive memory systems are representative of a shared information encoding, storing, and retrieval process among team members (Wegner et al., 1985; Wegner, 1986) and reflect who knows what on a team (Ren and Argote, 2011). Teams develop an understanding of their knowledge network through the cross-pollination of knowledge. In other words, team learning is a necessary prerequisite of transactive memory system development (Ellis et al., 2008) and, as such, transactive memory systems can be used as an indirect indicator of team learning.

It is also important to note that team learning has been inferred through changes in performance/effectiveness metrics, or *learning curves*. Much like team mental models and transactive memory systems, learning curves represent a consequence of team learning. The most pragmatic sign that teams are learning is increased performance due to the application of collective knowledge. Most often, this research has focused on efficiency

TABLE 1 | Team learning terminology.

	Term	Definition	Citations
Outcomes	Team learning	Shift in the team's collective knowledge state	Ellis et al., 2003; Wilson et al., 2007
	Learning curves	Shifts in team's performance over time	Adler, 1990; Darr et al., 1995; Pisano et al., 2001; Edmondson et al., 2003; Reagans et al., 2005
Processes	Fundamental learning behaviors	Basic learning processes that promote learning in teams.	Wilson et al., 2007; sharing, storage, retrieval
	Interteam learning behaviors	Behaviors that seek and integrate information from entities outside of the immediate team that promote team learning.	Wong, 2004; Bresman, 2010; boundary spanning, scanning
	Intrateam learning behaviors	Internal behavioral processes that teams engage in that build shared meaning from existing information, identify and fill in gaps in the team's collective knowledge, as well as challenge, test, and explore assumptions.	Edmondson, 1999; Drach-Zahavy and Somech, 2001; Van den Bossche et al., 2006; Savelsbergh et al., 2009; asking questions, seeking feedback, exploration, experimentation

indices. For example, decreases in task completion times (e.g., Pisano et al., 2001; Edmondson et al., 2003; Reagans et al., 2005) or decreased costs (e.g., Adler, 1990; Darr et al., 1995) are common metrics when studying learning curves. Still, whether it is speed, cost, or effectiveness, improvements in performance metrics are indicative that the team has learned. They have incorporated information into their collective knowledge and have subsequently applied that knowledge to improve the speed or performance of their collective action.

Team Learning as a Process

Team learning over time (i.e., shifts in collective knowledge) are process-driven, which is how much of the literature has conceptualized team learning. Indeed, this is exactly how Edmondson (1999) characterized team learning – as an ongoing behavioral process. Over the years, the research on team learning has evolved, looking at various types of team learning behaviors. **Table 2** provides an overview of what was found with respect to the different actions that have fallen under the label of team learning behaviors. Here, the term *team learning behaviors* is used to encapsulate all of the actions that aid in the development of collective knowledge. These actions, however, are not qualitatively similar. To better represent the nuances of team learning behaviors, we break them down into three different types: intrateam, interteam, and fundamental learning behaviors. In the following, the rationale behind this breakdown is briefly described by comparing and contrasting the three types of team learning behaviors.

First, *intrateam learning behaviors* are illustrative of the internal processes teams engage in that build shared meaning from existing information, identify and fill in gaps in the team's collective knowledge, as well as challenge, test, and explore assumptions. This is representative of how most of the literature has operationalized team learning processes (Bresman, 2010). Examples of intrateam learning behaviors are: asking questions, experimenting, discussing errors and outcomes, constructive criticism, and exploration (e.g., Edmondson, 1999; Drach-Zahavy and Somech, 2001; Savelsbergh et al., 2009). Intrateam learning behaviors do not necessarily reflect the actions of sharing information with the team, but, instead, how the team obtains new information from their fellow team members and how that information is integrated into their collective knowledge. In other words, they are the knowledge obtaining and scaffolding processes that occur within the immediate team. However, information and insight may not only be provided by those from within the team, but outside the team as well.

Interteam learning behaviors occur when teams seek and integrate information from individuals outside the immediate team. While some of these behaviors (e.g., asking questions, seeking feedback) may be indistinguishable from intrateam learning behaviors, the consequence of these actions is absolutely different. Individuals outside the team are likely to bring new and different perspectives to the team's dynamic compared to internal team members (Wong, 2004). On the one hand, these sorts of behaviors can be helpful. Fresh eyes can promote innovation and help teams better understand complex problems. New perspectives can be gleaned from individuals who are unfamiliar with the team's current situation or individuals who can provide expert feedback (e.g., Ancona and Caldwell, 1992; Perry-Smith and Shalley, 2003; Hülsheger et al., 2009). On the other hand, integrating novel and unique information may produce drastic shifts to the team's collective knowledge. While these drastic shifts may eventually be helpful, teams may initially experience decrements in coordination and increases in conflict (e.g., Jehn, 1995). Further, interteam learning behaviors not only differ with respect to who is providing information, but they also encapsulate learning processes not covered by intrateam learning behaviors. For example, in order to know what external knowledge is out there and subsequently act upon it, teams must engage in boundary spanning behaviors, which does not have a clear parallel in intrateam learning behaviors. Because of these differences with respect to both action and consequence, we distinguish between intrateam and interteam learning behaviors.

Lastly, *fundamental learning behaviors* represent the basic learning processes that promote learning in teams (Wilson et al., 2007). Unlike intrateam and interteam learning behaviors, fundamental learning behaviors are actions that individual

TABLE 2 | Overview of team learning behaviors with likelihood of occurring during the course of a team learning episode.

		Learning episode			
Learning behavior	**Definitions**	**Trigger**	**Transition**	**Action**	**Completion**
Fundamental learning behaviors					
Sharing	Actions team take to distribute information to team members	X	X	X	
Reception	Actively or passively listening to or receiving information	X	X	X	
Retrieval	Behaviors that clean collective knowledge from knowledge repositories (Wilson et al., 2007)		X		
Storage	Behaviors that support the maintenance and retention of collective knowledge over time (Wilson et al., 2007)				X
Interteam learning behaviors					
Scanning	Surveying the external environment for information relevant to the team's task (Wong, 2004; Bresman, 2010)		X	X	
Boundary spanning	Obtaining information from individuals outside of the team (Ancona and Caldwell, 1992)		X	X	
Intrateam learning behaviors					
Asking questions	Seeking new or clarifying information (Edmondson, 1999)		X	X	
Seeking feedback	Seeking feedback from members internal to the team (Schippers et al., 2003)	X	X	X	
Exploration	Seeking out new knowledge and information (March, 1991)			X	
Experimenting	Collectively testing ideas and assumptions that deviate from pre-existing standards (van Woerkom, 2003)			X	
Discussing errors	Sharing and discussing errors the team has made (Van Dyck, 2000)		X		
Co-construction	Collaborative conversations that refine, build, or otherwise modify collective knowledge by producing new meaning (Savelsbergh et al., 2009)			X	
Constructive conflict	Discussion designed to resolve divergence in interpretations and opinions.			X	
Reflexivity	Reviewing and reflecting on previous team functioning (Schippers et al., 2013)	X	X		

team members take to share, store, and retrieve information. Our conceptualization of fundamental learning behaviors is an adaptation of the work by Wilson and colleagues. While we conceptualize both storage (i.e., behaviors that maintain collective knowledge over time) and retrieval (i.e., behaviors that glean knowledge from repositories) similarly, we diverge from Wilson et al., in our conceptualization of sharing. Wilson et al., conceptualizes sharing as behavioral processes that encompass most actions regarding the dissemination and integration of information within a team. We simply hold that sharing represents the actions teams take to make their fellow members aware of individually held information. Fundamental behaviors are distinct from intrateam and interteam learning behaviors as they exclusively represent how knowledge is transported across time. While, sharing represents how knowledge is transported from the individual to the team, storage behaviors are illustrative of how collective knowledge is preserved across time. Similarly, retrieval processes are those which represent how collective knowledge is transferred from repositories to the team's awareness.

In the preceding section, the literature was synthesized to develop a shared understanding of team learning terminology. In addition to creating a shared language for those researching team learning, team learning terminology plays an important role in discussing the integrative, dynamic model of team learning presented herein (see **Figure 1**). With an established terminology, how teams operate in the context of time is presented next. Specifically, in the following section, team development and temporal dynamic theories are discussed in light of how these perspectives can inform the what, when, and how of team learning.

TEAMS (AND TEAM LEARNING) IN TIME

Teams are, in a word, dynamic. They develop; they change; they evolve. Researchers have been discussing teams in the context of time for at least three decades (McGrath, 1986; Cronin et al., 2011) and there has been much theoretical progress, which can be leveraged to better understand team learning dynamics. Specifically, work advancing our understanding of how teams develop (e.g., Team Development Theories, Tuckman and Jensen, 1977; Gersick, 1991), when teams engage in certain behaviors (e.g., Marks et al., 2001), and the nature of emergence (e.g., Kozlowski, 2015) can directly inform the dynamic nature of team learning. In the following section, we describe how team development theories shed light on *what* teams are learning, how temporal team

process phases describe *how* teams are learning, and how understanding the nature of emergence can highlight *when* teams are learning.

Team Development Theories and *What* Teams Learn

Some of the earliest work on understanding how teams operate over time comes from team development theories. These theories seek to understand the processes teams go through from their initial conception to their eventual disbandment. Most development theories can be classified as being grounded in either a linear growth model or a punctuated equilibrium model (Garfield and Dennis, 2012). Linear growth models describe team development as a series of ordered distinct phases, where teams accomplish particular goals within each stage. For instance, Tuckman's (1965) model describes four stages where teams get to know each other (forming), begin to form a common understanding of the task landscape (storming), develop norms for task accomplishment (norming), and finally engage in task work (performing). In contrast, punctuated equilibrium models focus less on the order in which activities occurs and more on the timing of intense action. Typified by Gersick's (1991) punctuated equilibrium model, team development is conceptualized as a period of activity at the team's onset, followed by a period of inertia until the team reaches the midpoint of their performance cycle. At this point, teams reflect on their performance and reconsider their current strategies, culminating in a frenzy of team activity. This is followed by another period of inertia, with the team remaining relatively stable until the team disbands.

To varying degrees, team development theories speak to *what* teams are learning during specific stages in their development. Presently, we use Kozlowski et al. (1999) process model of team compilation as an illustrative case. This model suggests that team members learn different content at each of the four proposed phases. In the first phase, teams develop foundational knowledge that will facilitate knowledge growth in future stages. They form interpersonal communication networks, develop a shared understanding of the team's task and requisite requirements (e.g., goals, task expectations), and a general sense of the team's climate. In the second phase, teams begin to learn about team performance dynamics and member task-competencies. Specifically, team members begin to engage in task work, which conveys to other team members how performance will be completed and illuminates the capabilities of their teammates. As teams transition to the third phase, team members learn how their respective roles are interconnected. In other words, they learn about the coordination requirements of the task; who they will have to coordinate with, what they will need to coordinate about, and when/how this coordination will take place. Teams really come into their own during the fourth phase. Here, teams develop an understanding of multiple task-networks describing *who* and *how* to interact with about *what* under varying external contingencies. It is important to note that, while Kozlowski et al. (1999) proposed that initial stages of development are individually-focused and become more collective-focused over time, we propose the content (e.g., interpersonal knowledge, task competency) of what is being discussed becomes a part of the team's collective knowledge repository. For instance, if Stan asks Lee a question that helps develop an understanding of communication styles, it is likely that the conversation is also observed by Gail and Simone – becoming part of the team's collective knowledge.

While we do support the idea that teams typically learn basic knowledge before more advanced knowledge, the Kozlowski et al., model was an illustrative case and does not represent the definitive order of what teams learn. Instead, readers should take away that teams learn different content over time, which is often influenced by where they are in their developmental process. Next, we discuss what the temporal dynamics research on teams can tell us about *how* teams learn.

Temporal Team Process Phases and *How* Teams Learn

While team development theories attempt to explain key considerations across the team's lifecycle, time can also be used to help explain how teams accomplish their goals on a much smaller temporal scale. In their seminal paper, Marks et al. (2001) set out to describe the behaviors teams engage in during different periods of time (called performance episodes) as they seek to attain their goals. The framework that Marks et al. (2001), set forth has become the standard way to understand team processes over time and can be leveraged to address *how* teams learn over time.

Two fundamental contributions of the Marks et al. (2001) paper are utilized presently to help understand *how* teams learn in time. First, the authors apply a temporal layer to the concept of team performance episodes. Popularized in the 1990s, team performance episodes are discernable blocks of time where teams engage in goal directed activity (Mathieu and Button, 1992). These performance episodes are not independently occurring, nor are they similar in structure. In other words, a team can be engaged in multiple performance episodes related to different tasks simultaneously and the time taken to complete each can vary (e.g., McGrath, 1991). Marks et al. (2001) suggested that a temporally-based classification system can be derived from types of activities teams are engaging in that facilitate goal accomplishment. Specifically, they suggest two phases of team processes: action and transition phases. A sub-episode, a period of time within a particular performance episode, is classified as an action phase if the team is directly working toward accomplishing their goal (i.e., engaging in taskwork). In contrast, transition phases are when the team takes a respite from taskwork – taking time to reflect on their past performance and plan for the future.

Second, Marks et al. (2001) supplement this distinction by positing that there are certain types of behaviors that teams typically engage in within and across these phases. That is, these temporal phases can be used to describe *how* teams go about accomplishing their goal. Specifically, there are processes that generally occur during transition phase (transition processes), action phase (action processes), and across these phases (interpersonal processes). In short, teams are more

likely to engage in behaviors that support the reflection and evaluation of goal progress during the transition phase (e.g., mission analysis, goal specification), behaviors that directly support goal accomplishment during the action phase (e.g., coordination, monitoring progress toward goals), and behaviors that facilitate team and task-work across these phases (e.g., conflict management, affect management). In essence, the Marks et al. (2001), framework provides a temporal structure in explaining how teams accomplish their goals.

This framework is leveraged to better understand *how* teams learn across time. First, the idea of performance episode phases is directly applicable to how team learning occurs. Specifically, *team learning episodes* can be thought of discernable periods of time where teams become aware of and integrate information into their collective knowledge state. Much like Marks et al.'s (2001) model, these episodes can be characterized by transition and action phases, where transition phases are those where information makes its way to the team's collective awareness and the action phase represents the time where teams discuss and debate that information to the point in which it becomes part of their collective knowledge state. Additionally, as discussed earlier, there are many different types of learning behaviors – some of which are more likely to occur within a specific phase and others which are likely to occur across all phases. **Table 2** provides an overview of where we believe these learning behaviors may be most likely to occur. Our rationale for this is elaborated upon later.

Multilevel Emergence and *When* Teams Learn

In this section, the process of emergence is described and how emergence relates to when teams learn is discussed. Generally, emergence is used to describe the bottom-up process, wherein lower level characteristics manifest to higher order phenomenon through interactions (Holland, 1998; Morgeson and Hofmann, 1999; Kozlowski and Klein, 2000). As such, it is a multilevel phenomenon that is process oriented and takes place over time (Kozlowski et al., 2013). Within teams, it is the interactions between team members that drives the development of team-level emergent states such as psychological safety, trust, and cohesion. The speed at which emergence occurs depends on several factors. For instance, there are conceptual differences between different types of emergent states that may influence how quickly they emerge (Kozlowski et al., 2013). Another factor that drives emergence is exposure to particular events (or triggers). For instance, teams need to engage in some risk-taking behaviors to judge their fellow teammates reactions and develop psychological safety (Edmondson, 2004). Further, Kozlowski et al. (2013) discuss how triggers could lead to swings in cohesion over time. Hence, the speed and pattern of emergence varies based on the conceptual underpinnings of the construct in question as well as the exposure to triggers – both of which are factors to consider when thinking about the manner in which team learning emerges.

Team learning is an emergent state. It stems from team processes (process-driven) that integrate individual information into the team's collective knowledge state (multi-level), which occurs over a period of time (over time). The speed in which team learning emerges is highly contingent on what is being learned. Going back to the Kozlowski et al. (1999) framework, teams will quickly learn about interpersonal interaction patterns, whereas learning about team member task competencies may take more time. Interestingly, the content of what is being learned will also influence the pattern of emergent states across time. For example, learning about interpersonal interaction preferences should create a monotonically increasing pattern when using a shared knowledge index of team learning (**Figure 3A**). As long as membership does not change, knowledge about the social interaction patterns of the team should remain stable over time. Conversely, a similarity index used to capture the team's agreement on how a new, controversial piece of information influences the task landscape my result in a more dynamic pattern (**Figure 3B**). While agreement was previously a characteristic of the team's past collective knowledge state, differences in opinion could drive team members apart and it will take time to come to a shared understanding again. These examples also suggest that events may be the catalyst of team learning; we call these events *learning triggers*. We define learning triggers as events in which the team inspects or questions their collective knowledge state in some way. It could be due to new information coming to light, a change in task demands, or an external entity bringing new information to the team.

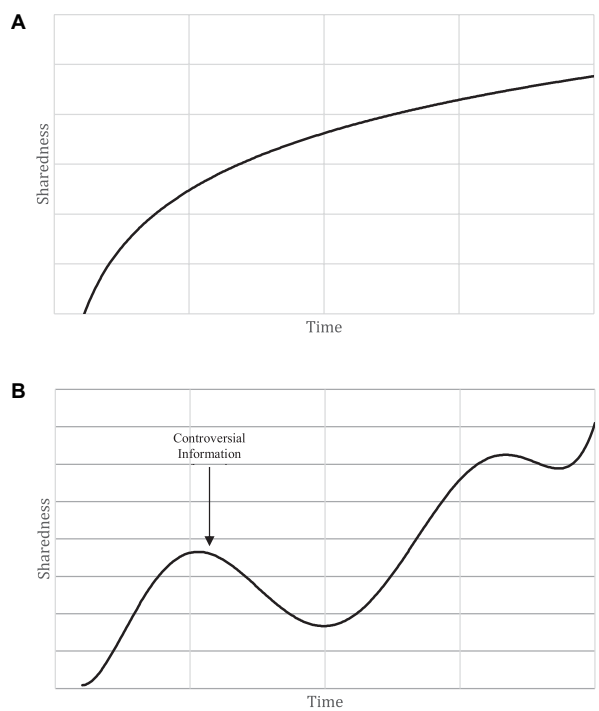

FIGURE 3 | (A) Illustration of monotonically increasing sharedness of interpersonal interaction pattern over time. **(B)** Illustration of how controversial information impacts sharedness of collective task knowledge over time.

UNFOLDING MODEL OF TEAM LEARNING

In this section, we explain our unfolding model of team learning (**Figure 1**) in detail. This model was developed by leveraging the extant literature on team learning and integrating it with our current understanding of teams in time. In the following, we discuss *when* teams learn by elaborating upon the catalyst of team learning, team learning triggers. Following this, we describe *how* teams learn by first describing what happens within the two phases of team learning: transition and action. Next, we elaborate on *how* teams deal with and integrate information by placing team learning behaviors in the context of time. Finally, we extend our model outside of a single learning episode and discuss what learning looks like over longer periods of time.

Learning Triggers

As mentioned earlier, team learning triggers are events which cause the team to inspect their current collective knowledge state. These events have the potential to generate change in the team's collective knowledge state (i.e., generate team learning). As such, it is important to discuss where these triggers come from and how they set teams on a path of learning. Team learning triggers come from a variety of sources, the likelihood of which partially depends on where the teams are in their development. During initial phases of the team's development, team learning triggers are likely to come from individual sources. For example, imagine a new product development team that has never worked together. Individual team members will need to share their communication preference with their teammates in order to develop collective knowledge with respect to the team's interpersonal network. Team leaders can also provide a source of learning during the initial phases of development. Using the same example, a product team's leader will provide goals and expectations for team such as providing clear deadlines and relationship expectations between team members.

As teams develop, learning triggers may begin to come from team level sources. For example, some team developmental models suggest that teams reflect on their performance progress and establish new goals for future performance after a period of time together (e.g., Gersick, 1991), which can be used to stimulate learning. Further, the learning process may be triggered by process-oriented events such as making mistakes or facing difficult challenges, which typically occur after initial stages of development. For example, product development teams may face challenges that cannot be addressed by their team's current collective knowledge state (e.g., Edmondson and Nembhard, 2009). In these cases, teams may seek the opinion of external sources of knowledge (e.g., Marrone et al., 2007), which can stimulate the process of learning.

Lastly, some team learning triggers are unpredictable in nature and could occur at any time during the team's life-cycle. Unexpected changes are a common characteristic of many teams (e.g., SWAT teams, Bechky and Okhuysen, 2011; military teams, Burke et al., 2006) and teams need to adapt and learn in order to respond to these changes (e.g., London and Sessa, 2007; Oertel and Antoni, 2014). No matter where the trigger is coming from, the presence of a trigger does not necessarily mean that the teams will learn. Teams exposed to new information can easily dismiss it or may not be aware that a trigger has occurred. In order for teams to learn, team members must become collectively aware of new information and then integrate it into their collective knowledge. This process is described in detail in the next two subsections.

Transition/Action Phases

Team learning triggers can generate *team learning episodes*, which are discernable periods of time where teams becomes aware of and integrate information into their collective knowledge state. As alluded to earlier, there are two temporal phases that occur within these episodes. During the transition phase, the information embedded in the team learning trigger must reach a state of collective awareness within the team. Having the team be aware of this new information is a crucial prerequisite for team learning to occur. As Wilson et al. (2007) put forth, if knowledge is lost when a team member leaves the group, the team has not learned. Hence, it is imperative that all team members are aware of the new information at the onset of the learning process. During this phase, the team's current collective knowledge state also needs to be brought into the team's collective awareness. As mentioned earlier, team learning triggers are events that call into question the team's collective knowledge state. Once collective awareness is achieved, teams move onto the action phase, where they begin the process of integrating new knowledge into their collective knowledge state. As elaborated upon in the next section, teams scaffold the new knowledge onto their collective knowledge state through discussion, experimentation, conflict, and construction. These processes build new meaning and facilitate shifts in the team's collective knowledge.

A quick illustrative case can highlight how this process unfolds. After creating a prototype of a new foldable smartphone, the marketing-lead on a new product development team receives consumer feedback that the malleable screen material is breaking down after repeated uses. In order for team learning to occur, the marketing-lead must not only provide this new information to the team at-large, but also remind the team how it relates to the previous conversations on what materials to use for their new smartphone (transition phase). This new information is then integrated into the team's collective knowledge state (e.g., we cannot use this material on our new smartphones) and previously discussed alternative materials will need to be deliberated until a new decision is reached (action phase).

Thus far, the temporal structure of our unfolding model of team learning has been discussed. First, a team learning trigger occurs that contains new information that the team will consider. Next, this information makes its way to the team's collective awareness (transition phase), which then leads to scaffolding information with respect to the team's collective knowledge state (action phase). Team learning occurs once this information is integrated into the team's collective knowledge state. However, team learning is an emergent state which is inherently process-driven and we would be remiss if the processes that facilitate team learning over time were not discussed.

Specifically, we next discuss *how* team learning occurs and, in doing so, highlight the temporal patterns associated with different learning behaviors.

Learning Behaviors Over Time

Earlier, we classified team learning behaviors into three categories (intrateam, interteam, fundamental) which facilitate team learning in different ways. While this classification helps clarify different types of learning behaviors, it does not necessarily speak to when these learning behaviors are likely to occur. Hence, in this section, we walk through a team learning episode to not only highlight how these behaviors facilitate team learning, but also when they are likely to do so. Specifically, we discuss when team learning behaviors are likely to occur as part of a learning trigger, during the transition and action phase, and the eventual emergence of team learning. We summarize the likelihood of these learning behaviors occurring in **Table 2**.

The Learning Trigger

First, team learning behaviors can serve as the catalyst of a team learning episode. As highlighted earlier, simply sharing (fundamental learning behavior) information about communication preferences can trigger a learning episode that can lead to team learning. A learning episode may also be triggered by teams reflecting on past performance or discussing errors that have occurred. Research has shown that the act of reflection can stimulate learning, especially when teams are not performing well (e.g., Schippers et al., 2013). Reflection often brings to light errors that teams have made in the past, but have not had the opportunity to discuss. It is important to note that these reflective behaviors may only *trigger* a learning episode. That is, shining a light on errors or performance may not necessarily lead to adaptation and adjustments (e.g., Kluger and DeNisi, 1996). In order to learn, teams need to engage in behaviors typified in the transition and action phases.

Transition Phase

As teams move onto the transition phase, teams need to recall their collective knowledge state as well as ensure collective awareness, which require different learning behaviors. First, teams engage in retrieval behaviors to bring collective knowledge into the team's collective awareness. Retrieval is a fundamental learning behavior where team members search for, gather, and recall previously learned knowledge (Wilson et al., 2007). Second, teams must not only retrieve their collective knowledge state, but also guarantee that the team is aware of this new information. This is done through fundamental learning behaviors (sharing, receiving) as well as interteam (e.g., scanning) and intrateam (e.g., asking questions) learning behaviors. Awareness of the new information is spread throughout the team by simultaneous engagement in sharing and receiving behaviors. Sharing promotes collective awareness by directly telling fellow team members of new developments. Conversely, reception is passive in nature, involving the listening to and the receiving of new information. If there are questions concerning the accuracy or legitimacy of this new information, team members may seek more information through internal (e.g., asking questions) or external (e.g., scanning, boundary spanning) sources.

Action Phase

As the team enters the action phase, they begin to engage in behaviors that facilitate the integration of new knowledge into their collective knowledge state. One way teams can do this is by engaging in constructive conflict behaviors. Constructive conflict behaviors are those that bring about team members' opinions on new information and discussion of these likely differing opinions. It helps resolve disagreements and gets them on the same page before going forward. Relatedly, teams can engage in experimenting behaviors to test out hypotheses on the way to resolving conflicting opinions (e.g., Gibson and Vermeulen, 2003). Co-construction is another prime example of a learning behavior that occurs during the action phase. Co-construction occurs when team members collaboratively work together to bring new meaning to pre-existing ideas (Van den Bossche et al., 2006). In effect, team learning behaviors occurring within the action phase directly support the integration of new and existing knowledge.

Concluding a Learning Episode

Finally, once the team has integrated this new information, there is one last team learning behavior which is necessary before it can be said that the team has learned. Specifically, the team must engage in storage behaviors. These actions are where teams place collective knowledge into some form of a repository to be retrieved later (Wilson et al., 2007). Here, repositories are broadly defined. Team members can store knowledge in physical repositories (i.e., paper copies, digital databases) or, more often, knowledge is stored cognitively (i.e., in memory). These actions help sustain and retain the conclusion of the learning process. Indeed, if new information is lost, it is difficult to say that the team experienced any learning.

It is important to note that some team learning behaviors can support learning across different phases. For instance, sharing information is a crucial learning behavior in the transition phase as it helps teams become aware of new information as well as the action phase, where team members are expressing their opinions in constructing new knowledge. Also important is the idea that our framework does not propose that learning behaviors exclusively occur during a particular phase. Much like the Marks et al. (2001), framework, we suggest that team learning behaviors are *likely* to occur during these phases. In the next section, the presented model (see **Figure 1**) is expanded beyond learning episodes to discuss team learning over longer periods of time.

Learning Over Time

Up to this point, team learning has been discussed as it occurs from a micro/learning episode perspective. That is, the discussion has focused on how a piece of information is integrated into and changes the team's collective knowledge state. However, team learning takes place over the entire course of the team's life cycle, which has implications for how learning fluctuates over longer

periods of time. Namely, we address learning fluctuations with respect to learning episodes and learning patterns over time. First, the factors that influence the speed, length, and completion of learning episodes are delineated. Second, the manner in which different learning patterns may emerge over time is highlighted.

Team Learning Episodes

Not every team learning episode is the same. Some learning episodes will only last for a short while, whereas others may never be completed. The length of team learning episodes depends on a number of factors. First, learning episodes will last longer when the information is more complex. When teams face the challenge of integrating complex information into their collective knowledge state, they have a higher propensity to engage in information-processing failures (Schippers et al., 2014). Schippers et al. (2014) suggest three categories of information-processing failures where teams fail to (1) reveal/discuss information, (2) explain or scrutinize information, and (3) successfully integrate new information into their prior beliefs/current behaviors. Teams do make efforts to avoid these failures, however, doing so will prolong the team learning episode.

Second, team learning episodes may also be prolonged when teams are asked to integrate information that is conflicting or starkly divergent from the current state of their collective knowledge. Teams are comfortable maintaining the status quo and ideas that come into conflict with the status quo will be met with resistance (e.g., Janis, 1972; Whyte, 1989; Schulz-Hardt et al., 2002). Further, divergent information is more likely to engender differences in opinion, which will need to be resolved before the team can learn. Incorporating information that is not congruent with the team's collective knowledge state may take more time, but there are also payoffs down the road. For instance, teams that are able to integrate this conflicting information may be more likely to perform better on creative or innovative tasks (e.g., Dahlin et al., 2005; Edmondson and Nembhard, 2009), which is ultimately worth the longer time it takes for them to learn.

Third, factors external to a particular team learning episode could prevent teams from completing that learning episode. As mentioned earlier, multiple learning episodes can occur simultaneously, overlapping each other and, potentially, conflicting with one another. Some team learning episodes may fall to the wayside as they are no longer prioritized in the grand scheme of the team's agenda. For example, federally-funded research teams who are learning about different methods of securing funding in light of a looming governmental shutdown may cease learning about funding alternatives once a budget gets passed. Another external factor that could prevent completion of a team learning episode is change in membership. If a team member suddenly exits, it could slow down or halt the progress of learning.

Team Learning Patterns

By using similarity/dissimilarity indices of team learning (e.g., shared mental models), one can begin to observe patterns of learning over time. The forms the patterns take over time are influenced by a number of factors. First, much like team learning episodes, the complexity of the information being learned becomes a factor when considering the pattern of team learning over time. As mentioned above, the complexity of information could prolong a single learning episode. This idea can be extended to the similarity of team's collective knowledge over time. Simple information could be integrated into the team's collective knowledge state relatively quickly; producing a monotonically increasing pattern of similarity over time. Complex information, however, may (1) take longer to integrate into a shared mindset and (2) be more prone to disagreements along the way. These two scenarios will produce different learning patterns over time, with one illustrating a monotonically increasing pattern of similarity over time (albeit at a slower rate) and the other more variable pattern of similarity.

Second, the content of what is being learned may vary in its susceptibility to change. As mentioned earlier, teams can learn different content at different times during their development and throughout their performance cycle. Some of this content will remain stable across the course of their performance cycle whereas other content will be more likely to change. Similarity indices have been used to capture a variety of different types of knowledge (Cannon-Bowers et al., 1993) and can be used to capture the different patterns of similarity over time. For instance, similarity in knowledge about team characteristics may monotonically increase and remain consistent across the team's lifespan (baring no membership change). However, this stability may not be mirrored when the content of collective knowledge concerns more tasked based information. For example, team member similarity with respect to budgetary allotments may change drastically over time as new information comes to light.

Inferred in many of these examples is the idea that learning triggers can influence the shape of learning patterns over time. Although not exclusively focused on learning, this idea can be extracted from Gersick's (1991) punctuated equilibrium model. Within this model, teams experience a learning trigger in the form of time pressure that comes with the recognition that they are halfway through their performance cycle. This recognition spurs on team activity and, in a sense, learning. Unlike Gersick's model, we proposed that teams experience multiple learning triggers throughout their performance cycle, which could lead to various patterns in learning over time. As indicated above, learning triggers may not immediately result in a shared understanding. Using a similarity index to model learning, learning triggers could result in either more similar mental models or dissimilar mental models. As we discuss later, this has measurement implications for those looking to track learning patterns over time.

Summary of Model

In the preceding section, we detail *what*, *when*, and *how* teams learn over time. Specifically, a temporal framework of how teams integrate new information into the collective knowledge states as well as the behaviors that facilitate this process was presented. We also described the manner in which teams learn over longer periods of time. Herein, the factors that may influence the length of learning episodes as well as the influences that shape learning

patterns over time were discussed. In the next section, avenues for future team learning research are delineated. Specifically, three challenges are laid out for researchers interested in understanding team learning in the future.

CHALLENGES FOR RESEARCH

Team learning is a crucial aspect of what makes organizations successful, but there is still much that is not understood. In the previous sections, research on team learning and teams in time was integrated to produce an unfolding model of team learning. In this process, areas that may best serve as the next frontier of research on team learning were highlighted, but not necessarily explicitly stated. In this section, we explicitly state these areas in the form of three challenges for research that we believe are the logical next steps for researchers to address. These challenges are not necessarily the lowest hanging fruit – in fact – quite the opposite. They represent the most fundamental gaps in knowledge and practice that we believe future researchers will need to accomplish to advance the field.

Team Learning Measurement

As mentioned earlier, measuring the point in which new knowledge becomes part of the team's collective knowledge state is practically impossible. In the future, methods may exist whereby one can infer this conceptualization of team learning through subtle social cues (e.g., body language when a statement concerning the new state of collective knowledge is articulated), but these ideas are of no help to current research. Instead, research should focus on creating better methods by which to measure team learning proxies and modeling the team learning process over time.

More Frequent Measurement of Team Learning Proxies

This manuscript has presented team learning as an emergent state that is process driven, multi-level, and unfolds over a period of time. Unfortunately, measurement proxies to capture team learning (e.g., team mental models, transactive memory system) are not typically measured in a way to capture this emergence. Early research capturing team learning proxies measured these constructs once or twice through the team's performance period (e.g., Roe, 2008; Zhou and Wang, 2010). This does not allow researchers to infer how team learning over a period of time unfolds. Hence, to better understand the emergence of sharedness or the development of transactive memory, researchers need to measure these team learning proxies multiple times throughout performance cycles. This, however, represents the practical roots of the challenge.

Measures of mental models and transactive memory systems are relatively intensive and disruptive. For example, card sorting programs are often used to capture both the content and structure in team member mental models (e.g., DeChurch and Mesmer-Magnus, 2010). This requires team members to cease what they are currently doing, open up the card sorting program, and sort the cards by making associations between cards before they can engage in taskwork again. Further, it is difficult to capture these cognitive emergent states in an unobtrusive way. Despite several calls for these types of measures (e.g., Rosen et al., 2011; Kozlowski, 2015) there has not been much development of unobtrusive, inexpensive measures of cognitive emergent states. Hence, we call upon researchers to measure team learning proxies more often throughout a team's performance cycle, which could mean the development of unobtrusive measures that capture the team's collective cognitive state.

Smarter Measurement of Team Learning

As[1] team learning is a process-driven emergent phenomenon, it will be important to consider *where* learning episodes take place when trying to assess team learning and team learning behaviors. In this manuscript, we have taken a stance similar to that of other organizational scientists: that organizational phenomenon needs to be modeled with time in mind (Cronin et al., 2011; Lehmann-Willenbrock and Allen, 2018). In this effort, we have presented our unfolding model of team learning without addressing the influence of *where* these interactions take place. More specifically, the processes that drive team learning take place at various points within the team's lifespan, however, there may be certain times in which behaviors that facilitate learning are more likely to occur.

Teams researchers understand that *where* team interactions occur plays an important role of the development of emergent states and can lend insight on how teams learn. This is especially important in the age of virtuality. Team dynamics do not occur purely in a face-to-face environment (e.g., Connaughton and Shuffler, 2007; Shuffler et al., 2010) and the degree to which team processes encourage team learning likely depend on the virtuality involved in team interactions. Hence, it is crucial for teams researcher to not only consider how team learning unfolds over time, but also recognize the where learning takes place could include the speed and quality of emergence. This calls for a smarter measurement approach to understanding the phenomenon – capitalizing on contexts where team learning is most likely to take place.

More Complete Measurement of Team Learning Model Over Time

In the model of team learning presented herein, several drivers of team learning were delineated. Specifically, teams experience a learning trigger, which is then followed by a series of behavioral processes that facilitate team learning. To be best of our knowledge, very few studies have examined how either triggers or behaviors influence team learning (or proxies of team learning) over time. A notable example is the work by Oertel and Antoni (2015), who investigated how transactive memory systems developed over time, finding that the effectiveness of different types of learning behaviors (e.g., knowledge-based, communication-based) in the development

[1]We would like to thank one of our reviewers for this suggestion.

of transactive memory systems depended on *when* these behaviors were enacted.

Despite being a focal aspect of how emergent states develop, there is a relative dearth of research investigating how events (i.e., learning triggers) influence the sequence of learning behaviors teams engage in, let alone the development of team learning. For us, this represents the largest and most crucial gap in knowledge on team learning. In order to facilitate change in the team's collective knowledge state, it is crucial to understand the catalyst of that change. However, there are several fundamental questions concerning team learning triggers that are currently unanswered. Are different teams equally aware of the same learning trigger? How do differences in learning triggers (e.g., content, intensity) influence how teams respond to these triggers (e.g., behaviors they engage in, speed in which they learn)? What can be done to enhance the clarity of learning triggers to facilitate subsequent learning episodes? The answers to these questions are unclear. Hence, we posit that studies need to be designed such that a more complete picture of the learning process is captured through measuring learning triggers, team learning behaviors, and team learning proxies longitudinally.

Team Learning Content

Related to the previous challenge, there is a need to understand how the content of what is being learned influences the multiple aspects of team learning. Earlier in the manuscript, it was argued that the content of what the team is learning will influence how quickly the teams develop a shared understanding of that knowledge. The content of what is being learned may not only influence the speed at which information is learned, but also the rate in which collective knowledge is lost. A popular colloquialism applies here: *Use it or lose it*. The limited about of research that seeks to capture how teams learn over time investigates how teams gain/develop shared mental representation of the construct space – not how knowledge is lost over time. To address this issue, we challenge researchers to investigate this with respect to both the content of knowledge and the storage of behaviors.

Looking into *what* the team has learned may be predictive of how quickly that information is lost. Specifically, researchers interested in modeling knowledge loss over time need to think about how the content of collective knowledge is related to its usage and, subsequently, design measurement occasions around how quickly they believe this knowledge is lost. For instance, knowledge concerning interpersonal communication networks may never depart the team's collective knowledge state as it is constantly used and reinforced. Conversely, collective knowledge with respect to a specific communication medium (e.g., how to use Slack) may dissipate over time with a lack of use. Further, the rate in which collective knowledge is lost may be influenced by particular storage behaviors that facilitate the maintenance of collective knowledge. For example, teams relying solely on cognitive repositories (i.e., memory) to retain collective knowledge may lose this knowledge quicker than teams that who rely on physical knowledge repositories (e.g., file systems, meeting notes, etc.).

Disruptive Learning Triggers

Not all team learning triggers will have the same impact on team learning. As mentioned earlier, some team learning triggers are relatively simple in nature, such as the ones that stem from knowledge shifts with respect to interpersonal communication networks. However, other team learning triggers can be more disruptive and, consequently, have a large impact on team learning and subsequent performance. Team member exit and entrance are two of the most common and disruptive learning triggers teams can experience, yet seldom investigated (Liu et al., 2011). With respect to team member turnover, teams will have to undergo an intensive relearning period (van der Vegt et al., 2010). At the point of member exit, it is likely that the team has developed a shared understanding of routines and interaction patterns (Katz, 1982), which need to be re-established once one of the crucial nodes in their network is no longer present. Teams will also need to engage in a similar relearning period in the event of newcomers. Routines and interaction patterns will need to be adjusted and re-established to incorporate the new member. Currently, little research exists documenting how disruptive learning triggers influence team learning behaviors or team learning, which is why we believe it represents a pressing challenge for future research.

CONCLUSION

Teams are the cornerstone of most organizations today and, hence, it is crucial that researchers and practitioners alike take the time and effort to understand teams better. One of the most crucial functions teams perform for these organizations is learning. As Senge and Peter (1991) pointed out nearly three decades ago, teams are the central learning unit of the organization and, consequently, organizational success will very much be determined by how well teams learn. Starting with Edmondson's (1999) article, the literature on team learning began to grow and expand – budding off in different directions until the team learning literature landscape was cluttered and confusing.

This manuscript is an attempt to integrate the disparate research streams that contribute to our understanding of the dynamic nature of team learning. Herein, the literatures on team development, temporal process phases, and multilevel emergence are leveraged to present a path forward for understanding what, how, and when teams learn. In doing so, we provide a cohesive terminology and describe the ways in which team learning has been conceptualized in the literature. We extended the literature base by clearly delineating the intra- and inter-team learning processes, as well as fundamental learning processes. Next, we describe the role of team learning triggers and their differential impact across the temporal phases within team performance episodes. This information was then incorporated into an integrated model that can serve as basis for understanding the nuances of team learning in time. Finally, following from the presented model are three grand challenges that we believe are next steps for research on team learning. It is our hope that the

description of the dynamic nature of team learning, the factors that impact it, and the model presented herein will serve to guide future discussions and push the field toward more consideration of the temporal aspects of team learning.

AUTHOR CONTRIBUTIONS

CW and CB contributed to the writing and theoretical development of the manuscript.

REFERENCES

Adler, P. S. (1990). Shared learning. *Manage. Sci.* 36, 938–957. doi: 10.1287/mnsc.36.8.938

Ancona, D. G., and Caldwell, D. F. (1992). Demography and design: predictors of new product team performance. *Organ. Sci.* 3, 321–341. doi: 10.1287/orsc.3.3.321

Argyris, C. (1982). *Reasoning, Learning, and Action: Individual and Organizational*. San Francisco, CA: ssey-Bass.

Bechky, B. A., and Okhuysen, G. A. (2011). Expecting the unexpected? How SWAT officers and film crews handle surprises. *Acad. Manage. J.* 54, 239–261. doi: 10.5465/amj.2011.60263060

Bresman, H. (2010). External learning activities and team performance: a multimethod field study. *Organ. Sci.* 21, 81–96. doi: 10.1287/orsc.1080.0413

Burke, C. S., Stagl, K. C., Salas, E., Pierce, L., and Kendall, D. (2006). Understanding team adaptation: a conceptual analysis and model. *J. Appl. Psychol.* 91, 1189–1207. doi: 10.1037/0021-9010.91.6.1189

Cannon-Bowers, J. A., Salas, E., and Converse, S. (1993). "Shared mental models in expert team decision making," in *Individual and Group Decision Making: Current Issues*, ed. N. J. Castellan Jr. (Hillsdale, NJ: Lawrence Erlbaum Associates, Inc), 221–246.

Connaughton, S. L., and Shuffler, M. (2007). Multinational and multicultural distributed teams: a review and future agenda. *Small Group Res.* 38, 387–412. doi: 10.1177/1046496407301970

Cornford, F. M. (1935). *Plato's Theory of Knowledge*. Abingdon: Routledge.

Cronin, M. A., Weingart, L. R., and Todorova, G. (2011). Dynamics in groups: are we there yet? *Acad. Manage. Ann.* 5, 571–612. doi: 10.1080/19416520.2011.590297

Dahlin, K. B., Weingart, L. R., and Hinds, P. J. (2005). Team diversity and information use. *Acad. Manage. J.* 48, 1107–1123. doi: 10.5465/AMJ.2005.19573112

Darr, E. D., Argote, L., and Epple, D. (1995). The acquisition, transfer, and depreciation of knowledge in service organizations: productivity in franchises. *Manage. Sci.* 41, 1750–1762. doi: 10.1287/mnsc.41.11.1750

DeChurch, L. A., and Mesmer-Magnus, J. R. (2010). Measuring shared team mental models: a meta-analysis. *Group Dyn.* 14, 1–14. doi: 10.1037/a0017455

Decuyper, S., Dochy, F., and Van den Bossche, P. (2010). Grasping the dynamic complexity of team learning: an integrative model for effective team learning in organisations. *Educ. Res. Rev.* 5, 111–133. doi: 10.1016/j.edurev.2010.02.002

Drach-Zahavy, A., and Somech, A. (2001). Understanding team innovation: the role of team processes and structures. *Group Dyn.* 5, 111–123. doi: 10.1037/1089-2699.5.2.111

Edmondson, A. (1999). Psychological safety and learning behavior in work teams. *Adm. Sci. Q.* 44, 350–383. doi: 10.2307/2666999

Edmondson, A. C. (2004). "Psychological safety, trust, and learning in organizations: a group-level lens," in *The Russell Sage Foundation Series on Trust. Trust and Distrust in Organizations: Dilemmas and Approaches*, eds R. M. Kramer and K. S. Cook (New York, NY: Russell Sage Foundation), 239–272.

Edmondson, A. C., Dillon, J. R., and Roloff, K. S. (2007). Three perspectives on team learning: outcome improvement, task mastery, and group process. *Acad. Manage. Ann.* 1, 269–314. doi: 10.1080/078559811

Edmondson, A. C., and Nembhard, I. M. (2009). Product development and learning in project teams: the challenges are the benefits. *J. Prod. Innov. Manage.* 26, 123–138. doi: 10.1111/j.1540-5885.2009.00341.x

Edmondson, A. C., Winslow, A. B., Bohmer, R. M., and Pisano, G. P. (2003). Learning how and learning what: effects of tacit and codified knowledge on performance improvement following technology adoption. *Decis. Sci.* 34, 197–224. doi: 10.1111/1540-5915.02316

Ellis, A. P. J., Hollenbeck, J. R., Ilgen, D. R., Porter, C. O. L. H., West, B. J., and Moon, H. (2003). Team learning: collectively connecting the dots. *J. Appl. Psychol.* 88, 821–835. doi: 10.1037/0021-9010.88.5.821

Ellis, A. P. J., Porter, C. O. L. H., and Wolverton, S. A. (2008). "Learning to work together: an examination of transactive memory system development in teams," in *Work Group Learning: Understanding, Improving and Assessing How Groups Learn in Organizations*, eds V. I. Sessa and M. London (New York, NY: Taylor & Francis Group), 91–115.

Garfield, M. J., and Dennis, A. R. (2012). Toward an integrated model of group development: disruption of routines by technology-induced change. *J. Manage. Inform. Syst.* 29, 43–86. doi: 10.2753/MIS0742-1222290302

Gersick, C. J. (1991). Revolutionary change theories: a multilevel exploration of the punctuated equilibrium paradigm. *Acad. Manage. Rev.* 16, 10–36. doi: 10.2307/258605

Gibson, C., and Vermeulen, F. (2003). A healthy divide: subgroups as a stimulus for team learning behavior. *Adm. Sci. Q.* 48, 202–239. doi: 10.2307/3556657

Holland, J. H. (1998). *Emergence From Chaos to Order*. Oxford: Oxford University Press.

Huber, G. P. (1991). Organizational learning: the contributing processes and the literatures. *Organ. Sci.* 2, 88–115. doi: 10.1287/orsc.2.1.88

Hülsheger, U. R., Anderson, N., and Salgado, J. F. (2009). Team-level predictors of innovation at work: a comprehensive meta-analysis spanning three decades of research. *J. Appl. Psychol.* 94, 1128–1145. doi: 10.1037/a0015978

Janis, I. L. (1972). *Victims of Groupthink: A Psychological Study of Foreign-Policy Decisions and Fiascoes*. Oxford: Houghton Mifflin.

Jehn, K. A. (1995). A multimethod examination of the benefits and detriments of intragroup conflict. *Adm. Sci. Q.* 40, 256–282. doi: 10.2307/2393638

Katz, R. (1982). The effects of group longevity on project communication and performance. *Adm. Sci. Q.* 27, 81–104. doi: 10.2307/2392547

Kluger, A. N., and DeNisi, A. (1996). The effects of feedback interventions on performance: a historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychol. Bull.* 119, 254–284. doi: 10.1037/0033-2909.119.2.254

Kozlowski, S. W. (2015). Advancing research on team process dynamics: theoretical, methodological, and measurement considerations. *Organ. Psychol. Rev.* 5, 270–299. doi: 10.1177/204138661453358

Kozlowski, S. W. J., and Bell, B. S. (2008). "Team learning, development, and adaptation," in *Work Group Learning: Understanding, Improving and Assessing How Groups Learn in Organizations*, eds V. I. Sessa and M. London (New York, NY: Taylor & Francis Group), 15–44.

Kozlowski, S. W. J., Chao, G. T., Grand, J. A., Braun, M. T., and Kuljanin, G. (2013). Advancing multilevel research design: capturing the dynamics of emergence. *Organ. Res. Methods* 16, 581–615. doi: 10.1177/1094428113493119

Kozlowski, S. W. J., Gully, S. M., Nason, E. R., and Smith, E. M. (1999). "Developing adaptive teams: a theory of compilation and performance across levels and time," in *The Changing Nature of Work Performance: Implications for Staffing, Personnel Actions, and Development*, eds D. R. Ilgen and E. D. Pulakos (San Francisco, CA: Jossey-Bass), 240–292.

Kozlowski, S. W. J., and Klein, K. J. (2000). "A multilevel approach to theory and research in organizations: contextual, temporal, and emergent processes," in *Multilevel Theory, Research, and Methods in Organizations: Foundations, Extensions, and New Directions*, eds K. J. Klein and S. W. J. Kozlowski (San Francisco, CA: Jossey-Bass), 3–90.

Lehmann-Willenbrock, N., and Allen, J. A. (2018). Modeling temporal interaction dynamics in organizational settings. *J. Bus. Psychol.* 33, 325–344. doi: 10.1007/s10869-017-9506-9

Liu, D., Zhang, S., Wang, L., and Lee, T. W. (2011). The effects of autonomy and empowerment on employee turnover: test of a multilevel model in teams. *J. Appl. Psychol.* 96, 1305–1316. doi: 10.1037/a0024518

London, M., and Sessa, V. I. (2007). The development of group interaction patterns: how groups become adaptive, generative, and transformative learners. *Hum. Res. Dev. Rev.* 6, 353–376. doi: 10.1177/1534484307307549

March, J. G. (1991). Exploration and exploitation in organizational learning. *Organ. Sci.* 2, 71–87. doi: 10.1287/orsc.2.1.71

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manage. Rev.* 26, 356–376. doi: 10.5465/amr.2001.4845785

Marrone, J. A., Tesluk, P. E., and Carson, J. B. (2007). A multilevel investigation of antecedents and consequences of team member boundary-spanning behavior. *Acad. Manage. J.* 50, 1423–1439. doi: 10.5465/AMJ.2007.28225967

Mathieu, J. E., and Button, S. B. (1992). An examination of the relative impact of normative information and self-efficacy on personal goals and performance over time. *J. Appl. Soc. Psychol.* 22, 1758–1775. doi: 10.1111/j.1559-1816.1992.tb00975.x

McComb, S. A. (2007). "Mental model convergence: the shift from being an individual to being a team member," in *Research in Multi-Level Issues*, Vol. 6, eds F. Dansereau and F. Yammarino (Amsterdam: Elsevier), 95–147. doi: 10.1016/s1475-9144(07)06005-5

McGrath, J. E. (1986). "Studying groups at work: ten critical needs for theory and practice," in *Designing Effective Work Groups*, ed. P. S. Goodman (San Francisco, CA: Jossey-Bass), 362–392.

McGrath, J. E. (1991). Time, interaction, and performance (TIP): a theory of groups. *Small Group Res.* 22, 147–174. doi: 10.1177/1046496491222001

Morgeson, F. P., and Hofmann, D. A. (1999). The structure and function of collective constructs: implications for multilevel research and theory development. *Acad. Manage. Rev.* 24, 249–265. doi: 10.2307/259081

Oertel, R., and Antoni, C. H. (2014). Reflective team learning: linking interfering events and team adaptation. *Team Perform. Manage.* 20, 328–342. doi: 10.1108/TPM-03-2014-0027

Oertel, R., and Antoni, C. H. (2015). Phase-specific relationships between team learning processes and transactive memory development. *Eur. J. Work Organ. Psychol.* 24, 726–741. doi: 10.1080/1359432X.2014.1000872

Perry-Smith, J. E., and Shalley, C. E. (2003). The social side of creativity: a static and dynamic social network perspective. *Acad. Manage. Rev.* 28, 89–106. doi: 10.2307/30040691

Pisano, G. P., Bohmer, R. M., and Edmondson, A. C. (2001). Organizational differences in rates of learning: evidence from the adoption of minimally invasive cardiac surgery. *Manage. Sci.* 47, 752–768. doi: 10.1287/mnsc.47.6.752.9811

Reagans, R., Argote, L., and Brooks, D. (2005). Individual experience and experience working together: predicting learning rates from knowing who knows what and knowing how to work together. *Manage. Sci.* 51, 869–881. doi: 10.1287/mnsc.1050.0366

Ren, Y., and Argote, L. (2011). Transactive memory systems 1985–2010: an integrative framework of key dimensions, antecedents, and consequences. *Acad. Manage. Ann.* 5, 189–229. doi: 10.1080/19416520.2011.590300

Roe, R. A. (2008). Time in applied psychology: the study of "what happens" rather than "what is". *Eur. Psychol.* 13, 37–52. doi: 10.1027/1016-9040.13.1.37

Rosen, M. A., Bedwell, W. L., Wildman, J. L., Fritzsche, B. A., Salas, E., and Burke, C. S. (2011). Managing adaptive performance in teams: guiding principles and behavioral markers for measurement. *Hum. Res. Manage. Rev.* 21, 107–122. doi: 10.1016/j.hrmr.2010.09.003

Salas, E., Dickinson, T. L., Converse, S. A., and Tannenbaum, S. I. (1992). "Toward an understanding of team performance and training," in *Teams: Their Training and Performance*, eds R. W. Swezey and E. Salas (Westport, CT: Ablex Publishing), 3–29.

Santos, C. M., and Passos, M. A. (2013). Team mental models, relationship conflict and effectiveness over time. *Team Perform. Manage.* 19, 363–385. doi: 10.1108/TPM-01-2013-0003

Sarin, S., and McDermott, C. (2003). The effect of team leader characteristics on learning, knowledge application, and performance of cross-functional new product development teams. *Decis. Sci.* 34, 707–739. doi: 10.1111/j.1540-5414.2003.02350.x

Savelsbergh, C. M. J. H., van der Heijden, B. I. J. M., and Poell, R. F. (2009). The development and empirical validation of a multidimensional measurement instrument for team learning behaviors. *Small Group Res.* 40, 578–607. doi: 10.1177/1046496409340055

Schippers, M. C., Den Hartog, D. N., Koopman, P. L., and Wienk, J. A. (2003). Diversity and team outcomes: the moderating effects of outcome interdependence and group longevity and the mediating effect of reflexivity. *J. Organ. Behav.* 24, 779–802. doi: 10.1002/job.220

Schippers, M. C., Edmondson, A. C., and West, M. A. (2014). Team reflexivity as an antidote to team information-processing failures. *Small Group Res.* 45, 731–769. doi: 10.1177/1046496414553473

Schippers, M. C., Homan, A. C., and Van Knippenberg, D. (2013). To reflect or not to reflect: prior team performance as a boundary condition of the effects of reflexivity on learning and final team performance. *J. Organ. Behav.* 34, 6–23. doi: 10.1002/job.1784

Schulz-Hardt, S., Jochims, M., and Frey, D. (2002). Productive conflict in group decision making: genuine and contrived dissent as strategies to counteract biased information seeking. *Organ. Behav. Hum. Decis. Process.* 88, 563–586. doi: 10.1016/S0749-5978(02)00001-8

Senge, and Peter, M. (1991). *The Fifth Discipline: the Art and Practice of the Learning Organization*. New York, NY: Doubleday/Currency.

Shuffler, M. L., Wiese, C. W., Salas, E., and Burke, C. S. (2010). Leading one another across time and space: exploring shared leadership functions in virtual teams. *Rev. Psicol. Trab. Organ.* 26, 3–17. doi: 10.5093/tr2010v26n1a1

Tuckman, B. W. (1965). Developmental sequence in small groups. *Psychol. Bull.* 63, 384–399. doi: 10.1037/h0022100

Tuckman, B. W., and Jensen, M. A. (1977). Stages of small-group development revisited. *Group Organ. Stud.* 2, 419–427. doi: 10.1177/105960117700200404

Van den Bossche, P., Gijselaers, W. H., Segers, M., and Kirschner, P. A. (2006). Social and cognitive factors driving teamwork in collaborative learning environments: team learning beliefs and behaviors. *Small Group Res.* 37, 490–521. doi: 10.1177/1046496406292938

van der Vegt, G. S., Bunderson, S., and Kuipers, B. (2010). Why turnover matters in self-managing work teams: learning, social integration, and task flexibility. *J. Manage.* 36, 1168–1191. doi: 10.1177/0149206309344117

Van Dyck, C. (2000). *Putting Errors to Good Use: Error Management Culture in Organizations*. Ph. D. thesis. University of Amsterdam: Amsterdam.

van Woerkom, M. (2003). *Critical reflection at work: bridging individual and organisational learning*. Enschede: Twente University Press.

Wegner, D. (1986). "Transactive memory: A contemporary analysis of the group mind," in *Theories of Group Behavior*, eds G. Mullen and G. Goethals (New York, NY: Springer-Verlag), 185–208. doi: 10.1007/978-1-4612-4634-3_9

Wegner, D. M., Guiliano, T., and Hertel, P. T. (1985). "Cognitive interdependence in close relationships," in *Compatible and Incompatible Relationships*, ed. W. J. Ickes (New York, NY: Springer-Verlag), 253–276. doi: 10.1007/978-1-4612-5044-9_12

Whyte, G. (1989). Groupthink reconsidered. *Acad. Manage. Rev.* 14, 40–56. doi: 10.2307/258190

Wilson, J. M., Goodman, P. S., and Cronin, M. A. (2007). Group learning. *Acad. Manage. Rev.* 32, 1041–1059. doi: 10.2307/20159355

Wong, S.-S. (2004). Distal and local group learning: performance trade-offs and tensions. *Organ. Sci.* 15, 645–656. doi: 10.1287/orsc.1040.0080

Zhou, Y., and Wang, E. (2010). Shared mental models as moderators of team process-performance relationships. *Soc. Behav. Pers.* 38, 433–444. doi: 10.2224/sbp.2010.38.4.433

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Wiese and Burke. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

ORIGINAL RESEARCH
published: 26 June 2019
doi: 10.3389/fpsyg.2019.01480

A Team Training Field Research Study: Extending a Theory of Team Development

Joan H. Johnston[1], Henry L. Phillips[2], Laura M. Milham[2], Dawn L. Riddle[2], Lisa N. Townsend[2], Arwen H. DeCostanza[3], Debra J. Patton[4], Katherine R. Cox[3] and Sean M. Fitzhugh[3]*

[1] Combat Capabilities Development Command, Soldier Center, Simulation Training and Technologies Center, Orlando, FL, United States, [2] Naval Air Warfare Center Training Systems Division, Orlando, FL, United States, [3] CCDC, Army Research Laboratory, Human Research and Engineering Directorate, Aberdeen Proving Ground, Aberdeen, MD, United States, [4] CCDC, Human Systems Integration Division, Data and Analysis Center, Aberdeen Proving Ground, Aberdeen, MD, United States

Recent advances in the science of teams have provided much insight into the important attitudes (e.g., team cohesion and efficacy), cognitions (e.g., shared team cognition), and behaviors (e.g., teamwork communications) of high performing teams and how these competencies emerge as team members interact, and appropriate measurement methods for tracking development. Numerous training interventions have been found to effectively improve these competencies, and more recently have begun addressing the problem of team dynamics. Team science researchers have increasingly called for more field studies to better understand training and team development processes in the wild and to advance the theory of team development. In addition to the difficulty of gaining access to teams that operate in isolated, confined, and extreme environments (ICE), a major practical challenge for trainers of ICE teams whose schedules are already strained is the need to prioritize the most effective strategies to optimize the time available for implementation. To address these challenges, we describe an applied research experiment that developed and evaluated an integrated team training approach to improve Tactical Combat Casualty (TC3) skills in U.S. Army squads. Findings showed that employing effective team training best practices improved learning, team cognition, emergent team processes, and performance. We recommend future research should focus on understanding the types of training strategies needed to enable teams and team leaders to develop from novices to experts. Effectively modifying training to scale it to team expertise requires more research. More laboratory and field research is needed to further develop measures of team knowledge emergence for complex task domains, and include other potential emergent factors such as team leadership and resilience. Practical implications for research include developing automated tools and technologies needed to implement training and collect team data, and employ more sensitive indicators (e.g., behavioral markers) of team attitudes, cognitions and behaviors to model the dynamics of how they naturally change over time. These tools are critical to understanding the dynamics of team development and to implement interventions that more effectively support teams as they develop over time.

Keywords: team knowledge emergence, teamwork, team training, team development, field research

OPEN ACCESS

Edited by:
Marissa Shuffler,
Clemson University, United States

Reviewed by:
Ashley M. Hughes,
University of Illinois at Chicago, United States
Riccardo Sartori,
University of Verona, Italy

****Correspondence:***
Joan H. Johnston
Joan.h.johnston.civ@mail.mil

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *31 October 2018*
Accepted: *11 June 2019*
Published: *26 June 2019*

Citation:
Johnston JH, Phillips HL, Milham LM, Riddle DL, Townsend LN, DeCostanza AH, Patton DJ, Cox KR and Fitzhugh SM (2019) A Team Training Field Research Study: Extending a Theory of Team Development. Front. Psychol. 10:1480. doi: 10.3389/fpsyg.2019.01480

INTRODUCTION

Recent advances in the science of teams have provided much insight into the important attitudes (e.g., team cohesion and efficacy), cognitions (e.g., shared team cognition), and behaviors (e.g., teamwork communications) of high performing teams and how these competencies emerge as team members interact and communicate and appropriate measurement methods for tracking development (Marlow et al., 2018; McDaniel and Salas, 2018). Numerous training interventions have been found to effectively improve these competencies (Smith-Jentsch et al., 2008; Salas et al., 2012), and more recently have begun addressing the problem of team dynamics (Grand et al., 2016; Allen et al., 2018; Lacerenza et al., 2018). Team science researchers have increasingly called for more field studies to better understand training and team development processes in the wild and to advance the theory of team development (e.g., Kozlowski et al., 2009; Salas et al., 2017; Mathieu et al., 2018). Driskell et al. (2018) discussed the importance of conducting theory-based applied experimental research to solve real-world practical problems that expand theoretical models. They noted "what we don't know regarding teams in extreme environments far exceeds what we do know. One reason for this is that conducting applied research on teams in extreme environments is difficult" (p. 444). In addition to the difficulty of gaining access to teams that operate in isolated, confined, and extreme environments (ICE), a major practical challenge for trainers of ICE teams whose schedules are already strained is the need to prioritize the most effective strategies to optimize the time available for implementation. In this paper we describe an applied research experiment that addressed these challenges by developing and evaluating team training for improving Tactical Combat Casualty (TC3) skills in U.S. Army squads.

Conducting casualty care in combat is the epitome of teams operating in ICE environments (Goodwin et al., 2018; Power, 2018). Becoming distracted when casualties occur on the battlefield can have catastrophic consequences, as decision making, information processing, attention, and situational awareness are impaired (Stokes and Kite, 1994). When a casualty occurs, the Army medic or Navy Corpsman may not be able to immediately respond, so instead another squad member closer to the injured may react more quickly as a first responder. But, this could result in at least two squad members being unable to respond to the tactical engagement which can put the squad's safety at greater risk, and potentially limit its ability to achieve the tactical mission. Mission failure, as well as civilian and squad member casualties are factors that have been linked to future mental health stress management challenges in service members (Hoge et al., 2004; Grieger et al., 2006).

The command-directed casualty response system for TC3 was developed by Kotwal et al. (2011, 2013) to address the need for squads and their medics/Corpsman to effectively adapt to sudden changes in tactical priorities when squad members have to tend to casualties under fire. To reduce combat casualties, they developed procedures that specified squad interactions to be performed during the four phases of TC3: care under fire, tactical field care, casualty collection point care, and casualty evacuation. Important team interactions for casualty management include employment of effective procedures for addressing medical priorities (e.g., bleeding and suffocation), and the effective management of squad roles, precision communications, and decision making. The TC3 training program includes a Commander driven after action review (AAR) process that analyzes tactical and medical outcomes to gather and implement lessons learned for continuous systemic quality improvement. Kotwal et al. (2011) demonstrated that training resulted in a measurable reduction in Died of Wounds.

However, no TC3 training has been available for conventional forces that builds the cognitive and teamwork skills necessary to manage performance under highly stressful TC3 mission tasks. Conventional military squad training has mainly focused on battle drills for physical and mechanical aspects of combat. Live, outdoor training environments lack realistic combat casualty events, utilizing mostly training lanes and popup targets (Brimstin et al., 2015). Therefore, the Office of the Secretary of Defense sponsored the Squad Overmatch (SOvM) for TC3 training program to demonstrate that including the medic/corpsman in team training could improve the potential for saving lives on the battlefield.

A training needs analysis was conducted leveraging previous research on tactical decision making under stress (e.g., Cannon-Bowers and Salas, 1998), and critical incident interviews with Subject Matter Experts (SMEs). Based on the critical incidents of typical TC3 events, SMEs identified the task role interactions and instances of cooperation needed to effectively perform TC3 and then identified four major skill area requirements (Brimstin et al., 2015). Advanced situation awareness skills involve using cognitive and behavioral skills for pattern and threat recognition and decision making. This includes identifying and interpreting non-verbal cues in the tactical environment to determine deception; physical distances in groups to determine who is in charge; voice patterns and sweating to determine whether a person is a threat or under stress; terrain and cultural features to determine where and how people are moving and acting; and applying decision heuristics to assess any anomalies that could trigger a need to take action. Stress management skills involve using cognitive and behavioral skills to maintain tactical effectiveness under combat stress that includes application of acceptance, "what's important now," deliberate breathing, self-talk and buddy-talk, grounding, and personal AAR. Teamwork skills were adapted from the U.S. Navy's Team Dimensional Training program (Townsend et al., 2016) and involve team members using information exchange, communication delivery, supporting behavior, and initiative/leadership.

Next, the SOvM TC3 training was developed that incorporated existing validated curriculum for TC3 (Kotwal et al., 2011), stress exposure training (Driskell et al., 2006), and empirically validated simulation-based training design characteristics that develop team cognition, cohesion, efficacy, team knowledge emergence (TKE), and team performance (Gabelica et al., 2016; Fernandez et al., 2017). The stress exposure training method was used as the design framework (Townsend et al., 2016) for integrating instruction and training, and to ensure team members could develop skills under stress. Classroom-based

instruction provided information about the skill areas and typical stressors experienced during TC3. The TC3 task stressors were gradually increased beginning with skills practice during two simulation-based training scenarios, and then skills application during three event-based scenarios in live training at an outdoor, urban training complex comprised of buildings configured as a small village. The simulation-based training approach incorporated events in the scenarios that focused on developing effective behaviors for strategic planning, information gathering, and sharing; enabled team leaders to lead pre-briefs and AARs using a structure format focused on team competency development, engage team members in goalsetting and increase motivation (cohesion and efficacy), provide feedback and encourage team members to reflect on performance, discuss progress on goals, dealing with challenges, and identify task prioritization; and monitor team performance during exercises (Kozlowski et al., 2009; Fernandez et al., 2017). An initial evaluation of the methodology was conducted in 2015 with three U.S. Army and two U.S. Marine Corps squads at an Army post based in the Southeastern U.S. (Milham et al., 2017).

The revised ITA employed in the present study was conducted over three and one half days to ensure teams had the time needed for skill development. Compared to teams receiving 1-day of standard tactical training in an outdoor facility, ITA trained teams were expected to demonstrate: (a) more emergent team process and TC3 performance behaviors during event-based scenarios and more team self-correction behaviors during the AAR (Smith-Jentsch et al., 2008; Ceschi et al., 2014; Gabelica et al., 2016; Grand et al., 2016; Fernandez et al., 2017) (Hypothesis 1); (b) higher levels of perceived team cohesion, team efficacy, team processes, team performance, and AAR climate (Smith-Jentsch et al., 2008; DeChurch and Mesmer-Magnus, 2010; Gabelica et al., 2016; Fernandez et al., 2017) (Hypothesis 2); and higher levels of shared situation awareness (DeChurch and Mesmer-Magnus, 2010; Gabelica et al., 2016; Fernandez et al., 2017) (Hypothesis 3).

Study Design

Random assignment of squads to condition was not possible, therefore a partial-treatment control group, with multiple post-tests, quasi-experimental design was employed (Shaddish et al., 2001). Demographic information, self-reported pre-training motivation, self-reported changes in skill levels, and tested changes in knowledge were collected to determine whether any differences between experimental and control condition participants would affect the internal validity of the study (Shaddish et al., 2001), and whether training had an effect on learning (Alvarez et al., 2004).

MATERIALS AND METHODS

Participants

Participants were 72 male members of eight U.S. Army dismounted infantry squads. Each squad was augmented with a U.S. Army medic. Two of the squads in the control condition and one squad in the experimental condition had nine members, all of the other squads had 10 members. Data were collected during the squads' pre-deployment training at an Army post in the southeastern U.S. and in accordance with the ARL Institutional Review Board approved protocol ARL 16-030 titled "Tactical Combat Casualty Care Training for Readiness and Resilience." The eight squads that participated in the study were drawn from two different U.S. Army Companies, were qualified to perform their squad tasks, and were able to train with medics and learn TC3.

Experimental Task

An overarching chronological narrative taking place over a fictional 3-week time period was used to develop two 30-min scenarios for the simulation-based training, and three 45-min scenarios for live training. Subject matter experts used the event-based approach to training method to link critical tasks, task stressors and learning objectives to task cue-strategy relationships in the scenarios that would deliberately elicit TC3, advanced situation awareness, stress management, and teamwork behaviors (Fowlkes et al., 1994). The SMEs designed the narrative that gradually increased problem complexity and TC3 stressors across the five scenarios. Stressors included combat casualties to civilians and participants, improvised explosive device explosions, and sniper fire. Squad tasks included: conducting a key leader engagement; encountering hostile actors that are observing unit movement; a complex ambush consisting of a car bomb detonation followed by a far ambush; an enemy actor that attempts a failed suicide bombing; and a sniper attack on civilians and participants. Casualty status was presented on a smart phone touch screen display worn by participants, role players and Medical Simulation Training Centers trauma mannequins. It indicated mechanism of injury, injury type and location including a realistic video of the specific wound (e.g., gunshot wound), signs and symptoms, responded to treatment provided and the individual's tactical capabilities were displayed as a result of the specific injury (move, shoot, communicate). The display provided dynamic updates of casualty status over time. If wounds were correctly assessed and treated through self, buddy, combat life saver or medic care in a timely manner, the squad member or civilian stabilized and, if not, the display depicted a "Died of Wounds" condition.

Integrated Training Approach

Classroom instruction focused on defining and developing team member's declarative knowledge of the important cognitions and behaviors for each skill area. Existing knowledge and skills were refreshed (i.e., combat lifesaver skills) and new knowledge areas were introduced to emphasize the importance of teamwork and performance in each of the five skill areas. Instructors engaged participants with lecture, discussion, videos, and in-class simulations, and they emphasized the importance of teamwork and team performance. The TC3 and advanced situation awareness skills were taught on the first morning. Hands-on practice was conducted to familiarize squads with their Improved First Aid Kit II. Each Soldier used simulations of the combat application tourniquet, chest decompression needle, and the nasopharyngeal airway on a

trauma mannequin with realistic blood. Video snippets were used to illustrate advanced situation awareness skills, and the importance of using teamwork behaviors to ensure advanced situation awareness information was communicated throughout the squad and higher command echelons to make timely and accurate decisions. Stress management, teamwork, and integrated AAR (IAAR) instruction were taught on the second morning. Appropriate behaviors and thought processes were modeled and communicated out loud by SMEs to improve trainee understanding of how both thoughts and actions influence stress reduction. Videos and live demonstrations of stress management skills showed how performance problems could develop from losing task focus because of combat stressors, and were followed by demonstrations of how performance could be enhanced by using coping skills. Informational cross-training and positional modeling were used to engage squad members on how teamwork can potentially facilitate or hinder each other in performing TC3 tasks; and demonstrated how tasks performed by teammates working different roles for casualty care could save lives. Demonstrations and practice scenarios were used to develop an understanding of what constitutes the IAAR, and how to conduct effective IAARs.

Pre-briefing and Integrated AAR

The Army standard AAR is a structured review, guided by Army doctrine, that is conducted after a training exercise. It is led by a trainer (usually the Company commander or Platoon Leader) who reviews scenario events in chronological order and discusses with the team differences between actual and expected tactical performance. Team members, or participants, provide responses to questions about what happened, why it happened, and agree on how to sustain strengths and improve performance. Although the reference doctrine has incorporated guidelines from team training research, and leader training emphasizes the use of effective dialog between team members, often, the AAR is done very quickly, and focuses on only what could have been done better, paying little attention to what was done well and why (Smith-Jentsch et al., 2008).

The prebrief and IAAR method developed for this study adapted the Army standard format and also incorporated the proven methods described above for improving team motivation, cognition and performance (Townsend et al., 2018). The U.S. Navy's Team Dimensional Training method was adapted to ensure formative feedback was given, and to encourage self-monitoring, self-reflection, knowledge exchange, and team self-correction. The trainer was required to encourage all squad members to participate and engage with the team vice letting the squad leader do most of the talking. The IAAR began with gaining team member agreement on overall performance goals. The trainer encouraged soldiers to reconstruct scenario events using geographical maps and the VBS3 replay mode of squad member avatar movements throughout exercise. Discussions compared expected performance to actual performance and required individual accountability for task performance. Following tactical skills discussions, only the IAAR incorporated topic SMEs discussing their observations of TC3, ASA, TW, and resilience, with special emphasis on explicit discussion of the teamwork behaviors required for effective ASA, resilience and TC3. The topic SMEs used information they had recorded during the scenario using skill area observation and assessment job aids and encouraged squad members to reflect on and identify tactical triggers of good and poor team behaviors, discuss their consequences, and determine behavioral solutions. Then, the Platoon leader led the squad members in setting and documenting goals for improvement to reinforce the lessons learned and integrate them into the next mission's planning.

Simulation-Based Training

The U.S. Army's Virtual Battlespace 3 (VBS3) system was the simulation-based training environment that was used and it was configured for team training via networked, desktop PCs. It is an interactive "first-person" shooter virtual environment in which squad members verbally communicate over two channels with each other through embedded virtual radios. The same live training environment squads trained on during days 3 and 4 was modeled in the VBS3 to support skills development and transfer to the live environment. Each squad member was assigned a virtual avatar that they controlled throughout a scenario. A VBS3 controller/administrator performed scenario management throughout the scenarios and several role players managed voice and control of avatar characters in the scenarios. Following each scenario, the standard AAR involved just the trainer/Platoon Leader facilitating a 40 min discussion on tactical performance and then setting tactical performance goals for the next mission planning pre-brief. The IAAR tactical discussion was discussed for 20 min facilitated by the trainer/Platoon Leader, and the remaining IAAR was facilitated by each of the knowledge area SMEs highlighting learning objectives and engaging team members in discussions as described in the introduction. Then the trainer and SMEs led the squad members in setting and documenting goals for improvement in all topic areas that were then integrated into the next mission's planning and scenario pre-brief.

Squad virtual interactions were automatically recorded by VBS3 for use during AARs and IAARs. Only video and audio recordings were made of the squads during the AARs and IAARs.

Live Training

For the live training scenarios, squad member rifles were fitted with non-intrusive simulated bullets (laser-based). The urban training environment was instrumented with simulation technologies that were triggered based on pre-determined scenario events. Non-pyrotechnical devices were used that simulated explosions for improvised explosive devices, gunshots, suicide bombs, and booby traps. Fake blood devices were employed in exploding suicide vests, improvised explosive device blast effects, and gunshot wounds with active bleeding. Role players, trauma mannequins, and squad members had simulated injuries requiring the First Aid Kit II, combat application tourniquet, chest decompression needle, the nasopharyngeal airway, occlusive dressings, and TC3 cards for reporting casualty status. Squad members interacted with various avatar simulations that required observing behaviors and cues exhibited during interactions to develop a baseline of

advanced situational awareness, enable identification of tactical threats, and accomplish mission objectives. During the M1 training scenario, brief coaching pauses were conducted by an observer/controller to provide formative performance feedback to the squad members in real time. The AARs and IAARs were conducted using the same approach as described above, using recorded auditory and video snippets of the squad members moving and communicating through the urban complex performing mission tasks.

Procedure

Four experimental condition squads (two from each Company) participated in three and one half days of the ITA and four control condition squads participated in 1 day of live training on scenarios M2 and M3. The first 2 days of the ITA involved classroom instruction in the morning and simulation based team training and IAARs in the afternoon. The live training scenarios (M1, M2, and M3) were conducted on days 3 and 4 with IAARs after each one. Due to schedule limitations, one experimental condition squad did not complete the last live scenario (M3). Control condition squads only participated in scenarios M2 and M3 during 1 day, and were led in the standard U.S. Army AAR by the 2nd Lieutenant trainer after each one. All squads participated in unrelated pre-deployment training when they were not participating in the study.

Measures

Self-Report Surveys

Pre-training motivation

Prior to the start of all training, all participants rated their pre-training motivation on a scale of 0–100 on their perceived importance (1 item) of and willingness (1 item) to successfully complete the training (Fatkin and Hudgens, 1994).

Self-reported skills

Prior to the start and then after the end of all training, all participants completed a 30-item self-report survey asking them to rate their current level of skill (i.e., beginner, advanced beginner, proficient, and expert) on each of the five skill areas. This survey was developed specifically for the experiment.

Team attitudes

Following each scenario AAR all participants completed four team attitude questionnaires with a 6-point Likert-type response format (1 = strongly disagree, 2 = agree, 3 = neither agree or disagree, 4 = agree, and 5 = strongly agree) that asked participants to rate the degree they agreed with items written as statements. A high score indicated high levels of perceived team cohesion, efficacy, processes, and performance. All the scales were developed with input from U.S. military subject matter experts in order to establish relevant face and content validity.

The 12-item team cohesion scale asked participants how their team felt about how close a unit they were during the mission just completed (e.g., at this point in time my squad feels that we are a close-knit team). This scale was adapted from a scale developed by Orvis et al. (2005), who had based their development on Craig and Kelly (1999). A coefficient alpha of 0.95 was reported by Orvis et al. (2005), and a coefficient alpha of 0.92 was reported by Orvis et al. (2006).

The eight-item team efficacy scale asked participants how confident the squad was in its ability to successfully perform and complete future missions together (e.g., at this point in time my squad is confident that we will be able to understand the tasks at hand). This scale was adapted from a collective efficacy scale developed by Karrasch (2003) who reported an inter-item reliability of 0.93.

The 14-item team action processes scale was developed to ask participants how well they thought their team coordinated and communicated during the mission just completed (e.g., during the mission my squad exchanged information with each other so that we could work together toward mission accomplishment). Scale items were based on four team action processes identified by Marks et al. (2001), however, no previous reliability estimates have been officially published.

The five-item team performance scale asked how well participants thought their team successfully performed various goals and actions during the mission just completed (e.g., during the action phase of this mission my squad completed important execution tasks in a high quality and timely fashion). No previous reliability estimates have been officially published.

AAR climate

Following each scenario AAR all participants completed an 8-item AAR Climate survey that had been developed for this study. It presented each item as a 7-point rating scale with word pairs anchored at each end of the scale. They circled a number on the scale that best represented the climate established in the AAR in which they had just participated (e.g., distrustful vs. trusting).

Team cognition

Following each AAR all participants rated their shared situation awareness on a four point Likert-type scale that had four items asking about their squad's ability to detect and understand cues that were presented during the scenario just completed. Matthews et al. (2002) demonstrated discriminant and convergent validity for the scale in experiments with live and virtual environments, but did not report reliability estimates.

Topic Knowledge Tests

Prior to and after classroom instruction, experimental condition participants completed a 58-item multiple choice test of their knowledge of each of the five skill areas. Due to scheduling constraints, control condition participants completed only a post-test after their last AAR. The test was developed specifically for this experiment.

Team Behavior Checklists

The SMEs used the Targeted Acceptable Responses to Generated Events or Tasks (TARGETs) method to develop structured observation checklists of behavioral markers for advanced situation awareness, teamwork, and TC3 to be collected during scenarios M2 and M3, and for IAAR behaviors following each scenario (Fowlkes et al., 1994). Fowlkes et al. (1994) reported an 89% inter-observer agreement and an internal

reliability estimate (split half correlation with a Spearman–Brown correction) of 0.93.

Team processes

The TKE measure was created based on a combination of advanced situation awareness and teamwork markers following collection of the markers during the scenarios.

Advanced situation awareness. During each scenario, a SME would note on the TARGET checklist whether or not pre-determined markers were observed. Examples of advanced situation awareness behaviors were: "the squad member verbally describes characteristics of non-verbal human cues during the key leader engagement" and "the squad member verbally describes how a person's behavior is consistent with expectations from intelligence received." Immediately following a scenario, the SME consulted with the SME instructors to complete the checklist. Also following the experiment the SME corrected the ratings using audio and video recordings collected during the exercises.

Teamwork. Two SMEs used Android tablets to record whether or not teamwork TARGET behaviors were exhibited by squad members during scenario execution. Examples of teamwork behaviors were: "information is verbally communicated among squad members about their observations of the town" (Information Exchange/Passing Information) and "other squad member(s) physically provide back-up to the squad member conducting an interview with a key person." Following the experiment, the same SMEs reviewed their ratings together using the audio and video recordings to establish 100% consensus on the teamwork behaviors.

Team knowledge emergence. The TKE measure was developed based on the Grand et al. (2016) definitions of retrieval, sharing, and acknowledgment. They proposed that eight core concepts and mechanisms are needed for knowledge to effectively emerge. Data Selection occurs when a team member identifies information to be learned from the task environment. Encoding is defined as a team member transforming the observed data from the environment into internalized data. Decoding is referred to as a team member transforming knowledge received from other team members into internalized knowledge. A team member performs Integration when they transform internalized data with organized relationships into internalized knowledge. Member selection involves a team member choosing to speak to other team members and Retrieval occurs when a team member identifies internalized knowledge from memory to be shared. Sharing involves a team member communicating internalized knowledge to other team members, and Acknowledgment involves generating externalized knowledge by confirming knowledge shared by another team member is internalized.

In the present study retrieval was operationalized as advanced situation awareness behavioral markers because they fit the definition of representing internalized bits of knowledge from memory that had to be shared with other team members. Sharing was operationalized as the teamwork behavioral markers for stating priorities, providing guidance, and providing situation updates because they involved communicating an organized, and coherent collection of internalized knowledge to other team members. Acknowledgment was operationalized as the teamwork behavioral markers for backup, error correction, passing information before being asked, using available internal and external sources of information, and making complete, brief, and clear reports of information because they represent an individual generating externalized knowledge by confirming knowledge shared by another team member was internalized. For example, scenario M2, event 1 had three Retrieval, two Sharing, and two Acknowledgment behaviors. Scenario event scores were created by summing the TKE behaviors and then converting the scores to a percentage of the total possible event score.

Tactical combat casualty care

One SME noted on the checklist during scenario execution whether or not the behaviors were exhibited by squad members. Examples of TC3 behaviors were: "squad member provides the proper injury report (MANDOWN) to squad leader," and "squad member(s) return fire and lay suppressive fire as needed." Immediately following a scenario, the SME consulted with TC3 instructors to confirm accuracy of the events that occurred and then completed the checklist. Then following the experiment the SME re-checked and corrected the ratings using audio and video recordings collected during the exercises. TARGET checklists were summed to produce a total score for scenarios M2 and M3 and then scores were converted to a percentage of the total possible score.

Team self-correction

Two SMEs used Android tablets to record whether or not AAR behaviors were exhibited by squad members. Examples of AAR behaviors were: "key scenario events were reviewed" and "the AAR was structured around the four teamwork dimensions." Following the experiment, the same SMEs reviewed their ratings together using the audio and video recordings to establish 100% consensus. The AAR checklists were summed to produce a total score for each AAR and then scores were converted to a percentage of the total possible score.

RESULTS

Design Checks

Most of the participants in the control (91%) and experimental (97%) conditions had served between one and 16 months in their current position, with both groups about equivalent in average time served in their current position (Control: M = 7.7 months, range = 35 months; Experimental: M = 6.3 months, range = 23 months). Percentage of participants reporting training related to the SOvM curriculum, familiarity with their squad members and VBS3 training were examined. None of the participants reported having had advanced situational awareness training, about a third of the participants in each condition reported having had stress management and human performance training, and just one reported having had teamwork training. About two-thirds of the participants in both conditions reported having had Combat Lifesaver (CLS) training. Compared to the control condition, more participants in the

experimental condition reported having had training in First Aid and Self-Care. The majority of participants in each condition responded "if necessary, they could correctly perform" eight CLS actions. Experimental condition participants reported having more first aid and self-care training; with about 10% more of them reporting they could correctly clear an airway, use a chest decompression needle, treat a head injury, complete a casualty card, and prepare a 9-line report. The majority of participants reported some familiarity with others in their squad, with a larger percentage in the control condition (83%) reporting squad member familiarity than in the Experimental condition (72%).

No differences were found for pre-training motivation ($p > 0.05$) with both groups reporting about the same high levels of willingness to participate (Experimental: $M = 91.39$, $SD = 12.31$, $n = 35$; control: $M = 90.14$, $SD = 16.68$, $n = 36$) and moderate levels of training importance (Experimental: $M = 67.22$, $SD = 23.55$, $n = 35$; control: $M = 72.08$, $SD = 28.14$, $n = 36$).

Table 1 presents the results of a repeated measures ANOVA which indicated a main effect of condition, with experimental participants reporting significantly higher skill levels for all learning topics than the control condition participants. In addition, an interaction effect was found, with experimental condition participants reporting significantly greater gains in their knowledge of teamwork [$F(1,68) = 19.65$, $p < 0.001$, $\eta = 0.238$] and integrated AAR [$F(1,68) = 18.46$, $p < 0.001$, $\eta = 0.214$]. *Post hoc* analyses showed all participants reported they had developed significantly greater knowledge for all topic areas [TC3: $F(1,70) = 27.70$, $p < 0.001$, $\eta = 0.284$; advanced situation awareness: $F(1,70) = 16.89$, $p < 0.001$, $\eta = 0.194$; stress management: $F(1,70) = 14.74$, $p < 0.001$, $\eta = 0.174$; teamwork: $F(1,68) = 51.74$, $p < 0.001$, $\eta = 0.432$; and integrated AAR: $F(1,68) = 37.30$, $p < 0.001$, $\eta = 0.354$].

Table 2 presents changes in experimental condition pre- and post-training knowledge test scores, and a comparison of experimental and control condition post-training knowledge test scores. A dependent samples t-test indicated that compared to their pre-test scores, experimental condition participants had small knowledge gains in all the topics except TC3. An independent samples t-test indicated that compared to the control condition, experimental condition participants had significantly greater post-training knowledge of advanced situation awareness and stress management.

Behaviors

Support for Hypothesis 1 was found for TKE, TC3, and team self-correction.

Team Knowledge Emergence

A 2 (Condition) × 6 (Scenario Events) repeated measures ANOVA for the TKE measure indicated no interaction effect was found ($p > 0.05$), however, partial support for Hypothesis 1 was found with a main effect for condition [$F(1,6) = 15.363$, $p < 0.01$] indicating experimental condition squads demonstrated more emergent team behaviors than the control condition during

TABLE 1 | Overall main effect of condition on self-reported skills following training.

	Control				Experimental						
	Pre-training		Post-training		Pre-training		Post-training				
	M (*n*)	*SD*	*M* (*n*)	*SD*	*M* (*n*)	*SD*	*M* (*n*)	*SD*	*F*	*df*	η
TC3	29.31 (36)	8.78	34.03 (35)	8.53	33.61 (36)	9.16	39.53 (35)	8.23	7.59*	1,70	0.098
ASA	13.94 (36)	4.65	15.69 (35)	4.16	15.97 (36)	3.63	18.17 (35)	3.55	7.58*	1,70	0.098
SM	22.39 (36)	5.69	24.28 (35)	4.94	24.78 (36)	5.27	27.69 (35)	5.21	7.28*	1,70	0.094
TW	7.22 (36)	3.51	8.47 (35)	3.68	8.85 (34)	4.57	14.12 (33)	3.38	21.19**	1,68	0.238
AAR	8.75 (36)	3.89	10.25 (35)	3.38	10.71 (34)	3.94	14.62 (33)	3.09	18.46**	1,68	0.214

*TC3, Tactical Combat Casualty Care; ASA, Advanced Situation Awareness; SM, Stress Management; TW, Teamwork; AAR, After Action Review. *p < 0.01, **p < 0.001.*

TABLE 2 | Changes in experimental condition pre- and post-training knowledge test scores, and comparison of experimental and control condition post-training knowledge test scores.

	Experimental (*n* = 36)					Control (*n* = 36)			
	Pre-training		Post-training			Post-training			
	M	*SD*	*M*	*SD*	*t*(35)	*M*	*SD*	*t*	*df*
TC3	10.78	1.46	11.25	2.94	ns	10.36	1.52	ns	70
ASA	4.58	2.08	7.33	2.41	−5.75**	5.92	1.83	−2.84***	65.18[1]
SM	10.53	2.79	12.14	3.04	−3.57**	10.72	1.86	−2.38*	70
TW	7.83	2.48	8.53	2.50	−2.15*	7.67	1.88	ns	70
AAR	2.58	1.13	3.00	0.89	−2.21*	2.97	0.10	ns	70

*TC3, Tactical Combat Casualty Care; ASA, Advanced Situation Awareness; SM, Stress Management; TW, Teamwork; and AAR, After Action Review. [1]Levene's test for equality of variance was significant (F = 4.15, p < 0.05). *p < 0.05, **p < 0.01, ***p < 0.001.*

scenario M2. **Figure 1** shows the estimated marginal means and standard error bars for TKE at each event. Experimental condition squads maintained a higher level of team processes across the events compared to the control condition processes which diminished at scenario midpoint.

A 2 (Condition) × 11 (Scenario Events) repeated measures ANOVA for scenario M3 indicated an interaction effect [$F(10,50) = 2.127$, $p < 0.05$], with experimental condition squads demonstrating more emergent behaviors as the events progressed. **Figure 2** shows the estimated marginal means and standard error bars for TKE for each event. Similar to **Figure 1**, experimental condition squads maintained higher levels of team processes whereas control condition processes were lower and increased and decreased several times.

TC3 Performance

A 2 (Condition) × 2 (Scenario) repeated measures ANOVA indicated a main effect for condition [$F(1,5) = 11.037$, $p < 0.05$, $\eta = 0.688$] with experimental squads ($n = 3$) demonstrating more TC3 behaviors (M2: $M = 0.550$, $SD = 0.145$; M3: $M = 0.780$, $SD = 0.225$) than control condition squads ($n = 4$) (M2: $M = 0.403$, $SD = 0.071$; M3: $M = 0.375$, $SD = 0.139$). Experimental condition squads performed 15% more TC3 behaviors than the control condition during M2, and 41% more than the control condition during M3.

Team Self Correction

A 2 (Condition) × 2 (Scenario) repeated measures ANOVA showed a main effect for condition [$F(1,5) = 40.961$, $p < 0.01$, $\eta = 0.891$] with experimental condition squads ($n = 3$) demonstrating a larger percentage of integrated AAR behaviors (M2: $M = 0.80$, $SD = 0.132$; M3: $M = 0.883$, $SD = 0.104$) than control condition squads ($n = 4$) (M2: $M = 0.375$, $SD = 0.087$; M3: $M = 0.450$, $SD = 0.071$). Experimental condition squads performed 36% more AAR behaviors than the control condition following M2, and 43% more than the control condition following M3. A within subjects effect for scenario [$F(1,5) = 6.289$, $p = 0.05$, $\eta = 0.557$] indicated both groups demonstrated a greater percentage of integrated AAR behaviors following scenario M3 compared to scenario M2.

Attitudes and Cognitions

Table 3 presents pooled within group correlations among team attitudes and shared situation awareness following live training scenarios M2 (Time 1) and M3 (Time 2). This correlation is calculated using only within-group sums of squares in order to avoid possible variation in scores due to the objective manipulation (ITA vs. no ITA) (Pedhazur, 1982).

No support was found for Hypothesis 2. No differences were found between conditions for team cohesion, efficacy, action processes, or performance (p's > 0.05). However, **Table 4** shows a significant main effect of scenario for all measures, with all participants reporting high levels of team cohesion, efficacy, processes and performance that increased slightly from scenario M2 to M3. **Table 3** shows high levels of internal consistency reliability estimates, and some evidence for validity is indicated by a strong relationship between the same measures

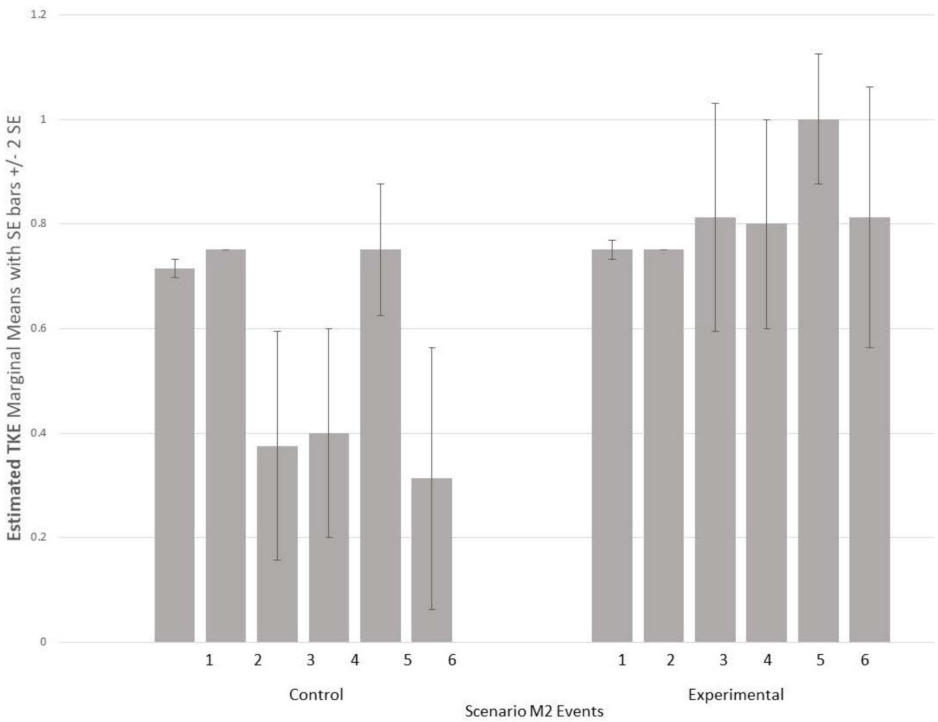

FIGURE 1 | Estimated TKE marginal means and standard error for M2 scenario events.

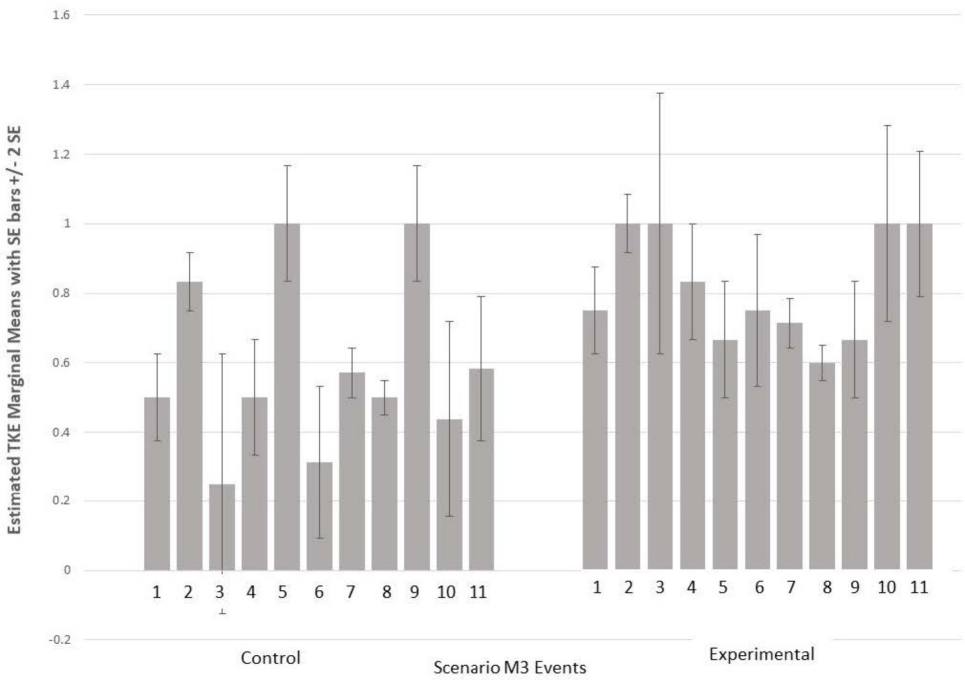

FIGURE 2 | Estimated TKE marginal means and standard error for M3 scenario events.

TABLE 3 | Pooled within group correlations among team attitudes and shared situation awareness following live training scenarios M2 (Time 1) and M3 (Time 2), $n = 59$.

	T	Measure	1	2	3	4	5	6	7	8	9	10	11	12
1	1	After-Action Review Climate	0.87											
2	1	Shared Situation Awareness	0.38*	0.76										
3	1	Team Cohesion	0.46*	0.29*	0.94									
4	1	Team Efficacy	0.55*	0.54*	0.83*	0.95								
5	1	Team Action Processes	0.45*	0.56*	0.67*	0.75*	0.95							
6	1	Team Performance	0.57*	0.48*	0.60*	0.76*	0.65*	0.88						
7	2	Team Cohesion	0.42*	0.37*	0.90*	0.79*	0.58*	0.47*	0.96					
8	2	Team Efficacy	0.46*	0.47*	0.78*	0.80*	0.56*	0.56*	0.79*	0.96				
9	2	Team Action Processes	0.44*	0.50*	0.74*	0.80*	0.61*	0.64*	0.76*	0.86*	0.95			
10	2	Team Performance	0.40*	0.52*	0.74*	0.75*	0.53*	0.63*	0.75*	0.82*	0.87*	0.91		
11	2	Shared Situation Awareness	0.18	0.46*	0.27*	0.37*	0.26*	0.38*	0.32*	0.37*	0.46*	0.58*	0.66	
12	2	After-Action Review Climate	0.73*	0.30*	0.28*	0.34*	0.20	0.23	0.34*	0.29*	0.30*	0.33*	0.29*	0.89

*T, Time. Cronbach's alpha coefficients (α) for measures are listed in the diagonal cells. *$p < 0.05$.*

TABLE 4 | Overall main effect of scenario on changes in team attitudes.

	M2 ($n = 60$)		M3 ($n = 60$)			
	M	*SD*	*M*	*SD*	*F*(1,58)	η
Cohesion	4.31	0.51	4.41	0.55	8.14**	0.123
Efficacy	4.25	0.51	4.35	0.51	5.04*	0.080
Action processes	4.04	0.55	4.27	0.47	14.01***	0.195
Performance	4.03	0.61	4.27	0.57	12.70**	0.180

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

at Times 1 and 2, and somewhat smaller relationships among the different measures.

A 2 (Condition) × 2 (Scenario) repeated measures ANOVA for AAR climate indicated no differences ($p > 0.20$), with control condition participants ($n = 36$) (M2: $M = 46.92$, $SD = 5.28$; M3: $M = 46.89$, $SD = 5.99$) and experimental condition participants ($n = 28$) (M2: $M = 47.96$, $SD = 6.39$; M3: $M = 48.82$, $SD = 5.85$) reporting moderate to very positive reactions to the AARs. **Table 3** shows high internal consistency reliability estimates at Times 1 and 2. Some evidence for validity is indicated by the strong relationship between the same measures taken at Time 1 and Time 2, and moderate relationships with the team attitude measures.

Support was found for Hypothesis 3. A 2 (Condition) × 2 (Scenario) repeated measures ANOVA indicated a between subjects effect [$F(1,61) = 7.59$, $p < 0.01$, $\eta = 0.111$]. Overall, experimental condition participants ($M = 3.46$, $SE = 0.06$) reported significantly higher levels of shared situation awareness than control condition participants ($M = 3.23$, $SE = 0.06$). A main effect of scenario was also found [$F(1,58) = 27.28$, $p < 0.001$, $\eta = 0.309$] indicating all participants reported significantly higher levels of shared awareness after the second scenario [M2 ($n = 63$): $M = 3.21$, $SD = 0.42$; M3 ($n = 63$): $M = 3.46$, $SD = 0.39$]. **Table 3** shows moderate levels of internal consistency reliability at Times 1 and 2, and some evidence for validity is indicated by a moderate relationship between the same measures at both times, and with the attitude measures.

DISCUSSION

This study replicated past research findings that employing effective team training best practices can improve attitudes, cognitions, and performance. This is reflected in the experimental condition having higher levels of shared situation awareness, and performing more team self-correction, process, and outcome behaviors. Furthermore, these findings provide support for a theory of TKE. The ITA enabled the experimental condition squads to perform more TKE behaviors that appeared to be more consistent across scenario events, and increase their TKE performance over time, which likely contributed to better TC3 performance than the control condition squads. Despite the control condition participants reporting greater familiarity with their squad members, and the same high levels of AAR climate as the experimental condition, they performed fewer TKE behaviors and appeared more inconsistent in performing them which likely resulted in poor team performance outcomes that did not change over time. These findings are similar to what Grand et al. (2016) found. Experimental condition teams achieved total team knowledge coverage earlier than the control condition team. The control condition information exchanges flattened out at about the halfway point in the training trials, whereas information exchanges in the experimental condition continued to increase.

The small changes in team cohesion, efficacy, action processes, and performance outcomes in both groups verifies findings by Gabelica et al. (2016), lending support to the theory that these team characteristics are also emergent. However, there is no definitive explanation for the similar changes in both groups. These were mostly intact and experienced squads that were highly motivated to participate, and had very positive perceptions about each other and their performance. By the end of training they all believed they had developed better skills. Increases in positive team attitudes and self-reported learning in the control condition squads is a good sign that even the live training alone was seen as an opportunity to learn more about their team members and the subject matter. The high levels of climate indicate that both the IAAR and standard AAR were seen as supportive of team development. The moderate correlations found among AAR climate and team attitudes support the notion that AAR method in both conditions contributed to improved team attitudes. Possibly using behavioral markers to collect efficacy and cohesion indicators could provide better insight into these team characteristics than just attitude measures (Sottilare et al., 2017).

Study Limitations

Generalizing findings based on the small number of squads in each condition is cause for concern about the validity of the findings. It is possible that the same results might not be found in a different sample. However, similarities in past experience and training and pre-training motivation were good indicators that both groups were mostly equivalent on factors that would affect internal validity. Efforts to sample the right level of expertise in the participating squads ensured they were ready to engage in training for the third phase (learning teamwork skills) of the Kozlowski et al. (2009) team development model. It is also possible we may not have had the same result with less experienced teams which should be the subject of further study.

The effort to collect data from just eight intact teams over five consecutive weeks was a significant challenge for these researchers and there were many instances when we did not have complete control over study procedures (e.g., stopping live training for rain, equipment breaking, squads and role players diverging from scenario scripts). As discussed above, we strived to address the various methodological limitations of the study by ensuring the groups were equivalent on demographic characteristics, that any training they had beyond the study was not related to what they received in the study, and that the study training they had was going to be seen as valuable in their development, even if it was for only one day.

Theoretical Implications and Future Research

Theories of team dynamics, team development, and theory of TKE all point to the need for future team training research to focus on understanding the types of training strategies needed to enable teams and team leaders to develop from novices to experts (Fiore and Georganta, 2017; Kozlowski and Chao, 2018). The training developed in this study would likely have been too complicated for new squads with few task work skills, and possibly not challenging enough for squads with

more experience than our participants. Effectively adapting training based on team expertise requires more research. For example, Kozlowski et al. (2009) provide a detailed model of team development that could inform an approach to such training. They highlighted the importance of the team leader in their four-stage model of team development (i.e., team formation, task and role development, team development, and adaptive improvement). Detailed guidance is provided for developing the attitudes, cognitions, and behaviors needed for effective team performance at each stage, describing how team knowledge, skills, abilities and attitudes should change over time, and prescribing how the team leader's role should adapt to these phases, moving from mentor to instructor, then coach, then to facilitator to enable team growth toward adaptability. The implication for this is a commitment to studying team training interventions over longer periods of time (Burke et al., 2017).

Extending the TKE from a highly controlled lab study to a field study of a very different and more chaotic team task enabled us to demonstrate its generalizability and value in understanding team processes. However, the TKE measure we used was limited as it represented just three of the eight core concepts described by Grand et al. (2016). More laboratory and field research is needed to further develop TKE measures for complex task domains. Furthermore, these findings indicate the need to study important constructs such as resilience and team leadership as emergent factors, and the impact of emergence on team processes and performance over time (Bowers et al., 2017).

Practical Implications

In this study we demonstrated how to integrate classroom, simulation, live training, and an integrated AAR to improve the knowledge, attitudes, processes, and performance of real, intact teams that deal with ICE environments. We also demonstrated that team training best practices can be extended to incorporate additional learning topics such as advanced situation awareness, resilience, and TC3 to emphasize the importance of how team coordination supports improving these skill areas. The U.S. Army is continuing to develop an ITA that could be implemented within its core initial military training regimen. A series of train-the-trainer studies were conducted in 2017 and 2018 with a modified ITA that was implemented mostly by a Company's own personnel. It is also exploring an enhanced resilience training component that incorporates the importance of team responses to extreme stress reactions within the squad (Patton et al., 2018).

A successful ITA, however, requires advances in data collection and team training technologies (Johnston et al., 2018). Collecting team process and outcome performance data with human labor is highly impractical during team training exercises; the time and cost for human labor is unsupportable. A large capability gap exists for automated tools and technologies needed to collect this data. Kozlowski and Chao (2018) and others (Sottilare et al., 2017; DeCostanza et al., 2018) discuss the need to supplement static, subjective surveys with assessment and analysis technologies (e.g., socio-metric badges) that employ more sensitive indicators (e.g., behavioral markers) of team attitudes, cognitions and behaviors, and model the dynamics of how they naturally change over time. Johnston et al. (2018) developed an instructional framework based on the Kozlowski et al. (2009) team development model that provides recommendations for how instructional and intelligent tutoring technologies could provide more effective training, as well as reduce instructor load for developing these skills. These tools and technologies are critical to understanding the dynamics of team development and to implement interventions that more effectively support teams as they develop over time.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the U.S. Army Research Laboratory Institutional Review Board with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The 16-030 protocol was approved by the U.S. Army Research Laboratory Institutional Review Board.

AUTHOR CONTRIBUTIONS

All authors contributed to the conception and design of the study, wrote the first draft of the manuscript, revised the manuscript, and provided approval for publication of the content. JJ, LM, DR, LT, DP, KC, and SF organized the database, and performed the statistical analysis.

FUNDING

The research reported in this article was funded by the United States Office of the Secretary of Defense for Health Affairs.

REFERENCES

Allen, J. A., Reiter-Palmon, R., Crowe, J., and Scott, C. (2018). Debriefs: teams learning from doing in context. *Am. Psychol.* 73, 504–516. doi: 10.1037/amp0000246

Alvarez, K., Salas, E., and Garofano, C. M. (2004). An integrated model of training evaluation and effectiveness. *Hum. Resour. Dev. Rev.* 3, 385–416. doi: 10.1177/1534484304270820

Bowers, C., Kreutzer, C., Cannon-Bowers, J., and Lamb, J. (2017). Team resilience as a second-order emergent state: a theoretical model and research directions. *Front. Psychol.* 8:1360. doi: 10.3389/fpsyg.2017.01360/full

Brimstin, J., Higgs, A., Wolf, R., Kemper, B., Parrish, R., Johnston, J. H., et al. (2015). "Stress exposure training for the dismounted squad: The human dimension," in *Proceedings of the Interservice/Industry Training, Simulation, and Education Conference [CD-ROM]*, (Arlington, VA: National Training and Simulation Association).

Burke, C. S., Georganta, E., and Hernandez, C. (2017). "The importance of time in team leadership research," in *Research on Managing Groups and Teams: Team Dynamics Over Time*, Vol. 18, eds E. Salas, W. B. Vessey, and L. B. Landon (Bingley: Emerald Publishing Limited), 95–122. doi: 10.1108/s1534-085620160000018005

Cannon-Bowers, J. A., and Salas, E. (1998). *Making Decisions Under Stress: Implications for Individual and Team Training*. Washington, DC: American Psychological Association.

Ceschi, A., Dorofeeva, K., and Sartori, R. (2014). Studying teamwork and team climate by using a business simulation: how communication and innovation can improve group learning and decision-making performance. *Eur. J. Train. Dev.* 38, 211–230. doi: 10.1108/ejtd-01-2013-0004

Craig, T. Y., and Kelly, J. R. (1999). Group cohesiveness and creative performance. *Group Dyn.* 3, 243–256. doi: 10.1037//1089-2699.3.4.243

DeChurch, L. A., and Mesmer-Magnus, J. R. (2010). The cognitive underpinnings of effective teamwork: a meta-analysis. *J. Appl. Psychol.* 95, 32–53. doi: 10.1037/a0017328

DeCostanza, A. H., Gamble, K. R., Estrada, A. X., and Orvis, K. L. (2018). "Team measurement: unobtrusive strategies for intelligent tutoring systems," in *Building Intelligent Tutoring Systems for Teams: What Matters*, Vol. 19, eds J. H. Johnston, R. A. Sottilare, A. M. Sinatra, and C. Shawn Burke (Bingley: Emerald Publishing Limited), 101–130. doi: 10.1108/s1534-085620180000019009

Driskell, J. E., Salas, E., and Johnston, J. H. (2006). "Decision making and performance under stress," in *Military life: The Psychology of Serving in Peace and Combat*, Vol. 1, eds T. W. Britt, C. A. Castro, and A. B. Adler (Westport, CT: Praeger Security International), 128–154.

Driskell, T., Salas, E., and Driskell, J. E. (2018). Teams in extreme environments: alterations in team development and teamwork. *Hum. Resour. Manag. Rev.* 28, 434–449. doi: 10.1016/j.hrmr.2017.01.002

Fatkin, L. T., and Hudgens, G. A. (1994). *Stress Perceptions of Soldiers Participating in Training at the Chemical Defense Training Facility: The Mediating Effects of Motivation, Experience, and Confidence Level*. Technical Report No. ARL-TR-365. Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

Fernandez, R., Shah, S., Rosenman, E. D., Kozlowski, S. W., Parker, S. H., and Grand, J. A. (2017). Developing team cognition: a role for simulation. *Simul. Healthc.* 12, 96–103. doi: 10.1097/SIH.0000000000000200

Fiore, S. M., and Georganta, E. (2017). "Collaborative problem-solving and team development:Extending the macrocognition in teams model through considerations of the team life cycle," in *Research on Managing Groups and Teams: Team Dynamics Over Time*, Vol. 18, eds E. Salas, W. B. Vessey, and L. B. Landon (Bingley: Emerald Publishing Limited), 189–208. doi: 10.1108/s1534-085620160000018008

Fowlkes, J. E., Lane, N. E., Salas, E., Franz, T., and Oser, R. (1994). Improving the measurement of team performance: the TARGET methodology. *Mil. Psychol.* 6, 47–61. doi: 10.1207/s15327876mp0601_3

Gabelica, C., Van den Bossche, P., Fiore, S. M., Segers, M., and Gijselaers, W. H. (2016). Establishing team knowledge coordination from a learning perspective. *Hum. Performan.* 29, 33–53. doi: 10.1080/08959285.2015.1120304

Goodwin, G. F., Blacksmith, N., and Coats, M. R. (2018). The science of teams in the military: contributions from over 60 years of research. *Am. Psychol.* 73, 322–333. doi: 10.1037/amp0000259

Grand, J. A., Braun, M. T., Kuljanin, G., Kozlowski, S. W. J., and Chao, G. T. (2016). The dynamics of team cognition: a process-oriented theory of knowledge emergence in teams. *J. Appl. Psychol.* 101, 1353–1385. doi: 10.1037/apl0000136

Grieger, T. A., Cozza, S. J., Ursano, R. J., Hoge, C., Martinez, P. E., Engel, C. C., et al. (2006). Posttraumatic stress disorder and depression in battle-injured soldiers. *Am. J. Psychiatry* 163, 1777–1783. doi: 10.1176/ajp.2006.163.10.1777

Hoge, C. W., Castro, C. A., Messer, S. C., McGurk, D., Cotting, D. I., and Koffman, R. L. (2004). Combat duty in Iraq and Afghanistan, mental health problems, and barriers to care. *N. Engl. J. Med.* 351, 13–22. doi: 10.1056/nejmoa040603

Johnston, J. H., Burke, C. S., Milham, L. A., Ross, W. M., and Salas, E. (2018). "Challenges and propositions for developing effective team training with adaptive tutors," in *Building Intelligent Tutoring Systems for Teams: What Matters*, Vol. 19, eds J. H. Johnston, R. A. Sottilare, A. M. Sinatra, and C. Shawn Burke (Bingley: Emerald Publishing Limited), 75–97. doi: 10.1108/s1534-085620180000019008

Karrasch, A. I. (2003). *Lessons Learned on Collective Efficacy in Multinational Teams*. Technical Report No. ARI-TR-1137. Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences.

Kotwal, R., Montgomery, H., Kotwal, B., Champion, H., Butler, F., Mabry, R., et al. (2011). Eliminating preventable death on the battlefield. *Arch. Surg.* 146, 1350–1358. doi: 10.1001/archsurg.2011.213

Kotwal, R. S., Butler, F. K., Edgar, E. P., Shackelford, S. A., Bennett, D. R., and Bailey, J. A. (2013). *Saving Lives on the Battlefield: A Joint Trauma System Review of Pre-Hospital Trauma Care in Combined Joint Operating Area – Afghanistan (CJOA-A)*. MacDill Air Force Base, FL: U.S. Central Command.

Kozlowski, S. W., Watola, D. J., Jensen, J. M., Kim, B. H., and Botero, I. C. (2009). "Developing adaptive teams: a theory of dynamic team leadership," in *Team Effectiveness in Complex Organizations: Cross-Disciplinary Perspectives and Approaches*, eds E. Salas, G. W. Goodwin, and C. S. Burke (New York, NY: Routledge), 113–155.

Kozlowski, S. W. J., and Chao, G. T. (2018). Unpacking team process dynamics and emergent phenomena: challenges, conceptual advances, and innovative methods. *Am. Psychol.* 73, 576–592. doi: 10.1037/amp0000245

Lacerenza, C. N., Marlow, S. L., Tannenbaum, S. I., and Salas, E. (2018). Team development interventions: evidence-based approaches for improving teamwork. *Am. Psychol.* 73, 517–531. doi: 10.1037/amp0000295

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manag. Rev.* 26, 356–376. doi: 10.5465/amr.2001.4845785

Marlow, S. L., Lacerenza, C. N., Paoletti, J., Burke, C. S., and Salas, E. (2018). Does team communication represent a one-size-fits-all approach? A meta-analysis of team communication and performance. *Organ. Behav. Hum. Decis. Process.* 144, 145–170. doi: 10.1016/j.obhdp.2017.08.001

Mathieu, J. E., Wolfson, M. A., and Park, S. (2018). The evolution of work team research since Hawthorne. *Am. Psychol.* 73, 308–321. doi: 10.1037/amp0000255

Matthews, M. D., Beal, S. A., and Pleban, R. J. (2002). *Situation Awareness in a Virtual Environment: Description of a Subjective Assessment Scale (Research Report No. 1786)*. Alexandria, VA: Army Research Institute.

McDaniel, S. H., and Salas, E. (2018). The science of teamwork: introduction to the special issue. *Am. Psychol.* 73, 305–307. doi: 10.1037/amp0000337

Milham, L. M., Phillips, H. L., Ross, W. A., Townsend, L. N., Riddle, D. L., Smith, K. M., et al. (2017). Squad-level training for tactical combat casualty care: instructional approach and technology assessment. *J. Def. Model. Simul.* 14, 345–360. doi: 10.1177/1548512916649075

Orvis, K. A., Horn, D. B., and Belanich, J. (2006). *Videogame-based Training Success: The Impact of Trainee Characteristics-Year 2*. Technical Report No. ARI-TR-1188. Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences.

Orvis, K. A., Orvis, K. L., Belanich, J., and Mullin, L. N. (2005). *The Influence of Trainee Gaming Experience and Computer Self-Efficacy on Learner Outcomes of Videogame-Based Learning Environments*. Technical Report No. ARI-TR-1164. Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences.

Patton, D., Johnston, J., Gamble, K., Milham, L., Townsend, L., Riddle, D., et al. (2018). "Training for Readiness and Resilience," in *Proceedings of the International Conference on Applied Human Factors and Ergonomics*, (Cham: Springer International Publishing), 292–302.

Pedhazur, E. J. (1982). *Multiple Regression in Behavioral Research*. New York, NY: Holt, Rinehart and Winston.

Power, N. (2018). Extreme teams: toward a greater understanding of multiagency teamwork during major emergencies and disasters. *Am. Psychol.* 73, 478–490. doi: 10.1037/amp0000248

Salas, E., Tannenbaum, S. I., Kraiger, K., and Smith-Jentsch, K. A. (2012). The science of training and development in organizations: what matters in practice. *Psychol. Sci. Public Interest* 13, 74–101. doi: 10.1177/1529100612436661

Salas, E., Vessey, W. B., and Landon, L. B. (2017). *Research on Managing Groups and Teams: Team Dynamics Over Time*, Vol. 18. Bingley: Emerald Publishing Limited.

Shaddish, W. R., Cook, T. D., and Campbell, D. T. (2001). *Experimental and Quasi-Experimental Designs for Causal Inference*. Boston: Houghton-Mifflin.

Smith-Jentsch, K. A., Cannon-Bowers, J. A., Tannenbaum, S. I., and Salas, E. (2008). Guided team self-correction impacts on team mental models, processes, and effectiveness. *Small Group Res.* 39, 303–327. doi: 10.1177/1046496408317794

Sottilare, R. A., Burke, C. S., Salas, E., Sinatra, A. M., Johnston, J. H., and Gilbert, S. B. (2017). Designing adaptive instruction for teams: a meta-analysis. *Int. J. Artif. Intell. Educ.* 28, 1–40.

Stokes, A. F., and Kite, K. (1994). *Flight Stress: Stress, Fatigue, and Performance in Aviation*. Brookfield, VT: Avebury Aviation.

Townsend, L., Johnston, J., Ross, W. A., Milham, L., Riddle, D., and Phillips, H. (2018). "An integrated after action review (AAR) approach: Conducting AARs for scenario-based training across multiple and distinct skill areas," in *Engineering Psychology and Cognitive Ergonomics*, Vol. 10906, ed. D. Harris (Cham: Springer International Publishing), 230–240. doi: 10.1007/978-3-319-91122-9_20

Townsend, L., Milham, L., Riddle, D., Phillips, C. H., Johnston, J., and Ross, W. (2016). "Training tactical combat casualty care with an integrated training approach," in *Foundations of Augmented Cognition: Neuroergonomics and Operational Neuroscience*, Vol. 9744, eds D. Schmorrow and C. Fidopiastis (Cham: Springer International Publishing), 253–262. doi: 10.1007/978-3-319-39952-2_25

Conflict of Interest Statement: The views, opinions, and findings contained in this article are the authors and should not be construed as official or as reflecting the views of the Department of Defense. This paper is intended to be approved for public release and unlimited distribution.

Copyright © 2019 Johnston, Phillips, Milham, Riddle, Townsend, DeCostanza, Patton, Cox and Fitzhugh. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

REVIEW
published: 28 June 2019
doi: 10.3389/fpsyg.2019.01478

Laborious but Elaborate: The Benefits of Really Studying Team Dynamics

Michaela Kolbe[1] and Margarete Boos[2]*

[1] Simulation Center, University Hospital Zurich, Zurich, Switzerland, [2] Institute for Psychology, University of Göttingen, Göttingen, Germany

In this manuscript we discuss the consequences of methodological choices when studying team processes "in the wild." We chose teams in healthcare as the application because teamwork cannot only save lives but the processes constituting effective teamwork in healthcare are prototypical for teamwork as they range from decision-making (e.g., in multidisciplinary decision-making boards in cancer care) to leadership and coordination (e.g., in fast-paced, acute-care settings in trauma, surgery and anesthesia) to reflection and learning (e.g., in post-event clinical debriefings). We draw upon recently emphasized critique that much empirical team research has focused on describing team states rather than investigating how team processes dynamically unfurl over time and how these dynamics predict team outcomes. This focus on statics instead of dynamics limits the gain of applicable knowledge on team functioning in organizations. We first describe three examples from healthcare that reflect the importance, scope, and challenges of teamwork: multidisciplinary decision-making boards, fast-paced, acute care settings, and post-event clinical team debriefings. Second, we put the methodological approaches of how teamwork in these representative examples has mostly been studied centerstage (i.e., using mainly surveys, database reviews, and rating tools) and highlight how the resulting findings provide only limited insights into the actual team processes and the quality thereof, leaving little room for identifying and targeting success factors. Third, we discuss how methodical approaches that take dynamics into account (i.e., event- and time-based behavior observation and micro-level coding, social sensor-based measurement) would contribute to the science of teams by providing actionable knowledge about interaction processes of successful teamwork.

Keywords: team process, team dynamics, interaction analysis, methods, measurement

OPEN ACCESS

Edited by:
Marissa Shuffler,
Clemson University, United States

Reviewed by:
Michela Cortini,
Università degli Studi G. d'Annunzio Chieti e Pescara, Italy
William Samuel Kramer,
University of Nebraska Omaha, United States

****Correspondence:***
Michaela Kolbe
mkolbe@ethz.ch;
michaela.kolbe@usz.ch

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *29 October 2018*
Accepted: *11 June 2019*
Published: *28 June 2019*

Citation:
Kolbe M and Boos M (2019) Laborious but Elaborate: The Benefits of Really Studying Team Dynamics. Front. Psychol. 10:1478. doi: 10.3389/fpsyg.2019.01478

INTRODUCTION

Modern organizations rely on teams (Edmondson, 2012; Salas et al., 2013b; Mathieu et al., 2014). For decades, team researchers have been studying how teams create and maintain high performance, how they learn, and how they satisfy their members' needs. A remarkable finding of this research is that high team performance is not so much predicted by how able single team members are but by the way they cooperate with one another: the team process (West, 2004;

Woolley et al., 2010, 2015). Team process is defined as "members' interdependent acts that convert inputs to outcomes through cognitive, verbal, and behavioral activities directed toward organizing taskwork to achieve collective goals" (Marks et al., 2001, p. 357). This definition implies that team processes are actually dynamic, emerging over time, and changing their pattern. It stands in contrast to the way teams have mostly been studied: much empirical team research has been static rather than dynamic, assessing team states rather than exploring how team processes dynamically develop over time and how these dynamics are related to team outcomes such as performance, satisfaction, and learning (Roe, 2008; Cronin et al., 2011; Humphrey and Aime, 2014; Mathieu et al., 2014; Kozlowski, 2015). As such, much team research has relied on self-reported and cross-sectional data with small samples and short analysis periods rather than on more meaningful, time-based behavioral data. While the number of theories and concepts factoring in time and temporal dynamics in team research is rising (McGrath and Tschan, 2004; Ballard et al., 2008; Lehmann-Willenbrock, 2017), the number of published empirical studies actually integrating dynamics is small considering for how long and how urgently this research has been requested (Stachowski et al., 2009; Tschan et al., 2009, 2015; Grote et al., 2010; Lehmann-Willenbrock et al., 2011, 2013; Zijlstra et al., 2012; Boos et al., 2014; Kolbe et al., 2014; Lei et al., 2016). This may be due to both the "unease of the psychologist in face of interaction" (Graumann, 1979) as well as to methodological challenges. However, recent team research has revealed that team members' interaction patterns rather than the frequencies of their individual actions are what discriminates higher- from lower-performing teams (Kim et al., 2012; Zijlstra et al., 2012; Kolbe et al., 2014; Lei et al., 2016). These distinguishing dynamics cannot be uncovered with static research but require process-related methods like sequential analysis, time series analysis or process modeling. It is critical to understand how team processes emerge and change and what they need and do to achieve best outcomes. This is specifically important in light of the evidence showing that poor teamwork in high-risk/high complexity fields such as healthcare can have disastrous consequences, i.e., loss of a patient's life (Cooper et al., 1984; Flin and Mitchell, 2009; Reynard et al., 2009; Fernandez Castelao et al., 2011; Salas and Frush, 2013; Salas et al., 2013b).

In this manuscript, we use teams in healthcare as the application context for illustrating the consequences of methodological choices in studying teams. We deliberately chose healthcare as application context for three reasons. First, teamwork can save lives (Rosen et al., 2018a). There is vast evidence demonstrating that poor teamwork has been involved in medical error (Gawande et al., 2003; Greenberg et al., 2007). Improving teamwork is a major initiative in patient safety and healthcare (Pronovost, 2013; Salas and Frush, 2013; Vincent and Amalberti, 2016). Second, the processes constituting effective teamwork in healthcare are prototypical for teamwork in general: they range from decision-making (e.g., in multidisciplinary decision-making boards in cancer care) to leadership and coordination (e.g., in fast-paced, acute-care settings in trauma, surgery and anesthesia) to reflection and learning (e.g., in post-event, clinical debriefings). Many of the research gaps and much of the knowledge gained from studying teams in healthcare is applicable to teams in other industries (Salas et al., 2013b). Third, given the broad occurrence and critical importance of teams not only in healthcare, knowledge must be gained on what contributes to effective teamwork. Team science has not only a lot to offer with respect to theory and methodology, it has also an obligation to contribute to improving teamwork by providing theoretical and methodological knowledge and supporting teams in healthcare.

The goal of this manuscript is to illustrate the consequences of methodological choices when attempting to study and measure team processes "in the wild" such as in healthcare (Rosen et al., 2012; Salas, 2016). In particular, we aim to show that using methods relying on summative, cross-sectional data collection (e.g., rating teamwork aspects after a medical team performance episode) will result in limited insights into the actual dynamic team process. Instead, gaining critical comprehension of dynamics that characterize effective teamwork requires methods that are more laborious (e.g., real-time behavior coding during the medical team performance episode) but provide more elaborate understanding of what happened while working together. We argue that static team research is a methodical choice that diminishes rather than enhances potential contributions to the science of teams. While we greatly appreciate the value of teamwork surveys such as the Team Diagnostic Survey (Wageman et al., 2005) and the Aston Team Performance Inventory (West et al., 2006), particularly for assessing team members' subjective perspective of team process functioning for the purpose of training and reflection, we argue that studying team dynamics by means of dynamic teamwork measures is a better methodological fit (Edmondson and McManus, 2007) and more promising for teamwork interventions.

For this purpose, we first describe three examples representing typical teamwork in healthcare and briefly refer to both team conceptual foundation underlying these examples and current research needs, also in order to highlight their representativeness for teamwork in general. Second, we put the methodological approaches of how teamwork in these representative examples has mostly been studied centerstage and highlight the respective consequences. Third, we illustrate potential other methodological approaches which are, for the time being, more extensive but provide benefits for applied team science.

THREE REPRESENTATIVE EXAMPLES FOR TEAMWORK

As prototypical examples for teamwork we chose three team settings from healthcare: (1) multidisciplinary decision-making boards, (2) fast-paced, acute care settings, and (3) post-event, clinical team debriefings. The examples convey the criticality of both *teamwork* for a range of tasks in an important professional sector as well as of team *process* as a mediator between input and outcome of teamwork. All three examples represent contemporary forms of more or less *ad hoc* team constellations (Tannenbaum et al., 2012). Embedded in organizational structures, they highlight the dynamic and

emergent features of teams and the resulting requirements for appropriate methods in order to grasp these features.

Example 1: Multidisciplinary Decision-Making Boards

Multidisciplinary decision-making boards are a prototype of diverse teams in complex organizations for which the successful exchange of expertise should result in synergy. The most common example is the multidisciplinary tumor board in cancer care (Homayounfar et al., 2015) where experts of multiple disciplines discuss individual patient cases. More recently, Heart Teams have been formed consisting of experts from disciplines involved in management of complex, severe heart diseases (e.g., cardiologists, cardiac surgeons, imaging specialists, anesthesiologists and, if required, general practitioners, geriatricians, and intensive care specialists) and should find optimal treatments (Seiffert et al., 2013; Antonides et al., 2017; Falk et al., 2017). Multidisciplinary decision-making boards are implemented as countermeasure to the increasing complexity of treatment options. Their objective is to provide patients with the most effective treatment in light of the severity of the disease, patients' requests, resources, and the current state of medical research. Multidisciplinary tumor boards have already become an international standard of cancer care (Pox et al., 2013). Heart Teams are recommended by the European Society of Cardiology and the European Association of Cardio-Thoracic Surgery (Falk et al., 2017).

The criticality of team process in multidisciplinary decision-making boards is illustrated in a meeting situation in **Table 1**. It shows that a lack of evidence-based communication rules, professional facilitation, and participative leadership behavior that take into account task complexity, conflicting goals, hierarchical structure, and time pressure can jeopardize the effective functioning, synergy, and development of multidisciplinary decision-making boards, and thus their ultimate mission to enhance patient care (Kolbe et al., 2019). As a consequence, team science must provide insights into effective teamwork processes as well as respective countermeasures.

Example 2: Fast-Paced, Acute Care Settings

Fast-paced, acute care settings such as medical emergencies are prototypical for so-called action teams, i.e., teams that are confronted with highly dynamic, complex, and consequential tasks (Tschan et al., 2006, 2011a). They require teamwork at its best (Driskell et al., 2018; Maynard et al., 2018). For example, resuscitating a patient requires prompt and well-coordinated actions such as diagnosing the cardiac arrest, oxygenating the brain and reestablishing spontaneous circulation (Tschan et al., 2011b). Other fast-paced, acute care settings require more sense-making processes, for example when the diagnosis is not yet clear. Team members must adaptively engage in immediate problem awareness and diagnosis, information-processing, problem-solving, and coordination of actions (Hunziker et al., 2011; Tschan et al., 2011a,b, 2014). They must do this under time pressure and high workload—and in many instances off the cuff as *ad hoc* action teams (Kolbe et al., 2013a). Both the European Resuscitation Council (ERC) and the American Heart Association (AHA) recommend integrating teamwork trainings into advanced life support education (Bhanji et al., 2010; Soar et al., 2010). This is, in part, realized by simulation-based team training (Kolbe et al., 2013b; Salas et al., 2013a; Weaver et al., 2014).

The criticality of team process in fast-paced, acute care settings is illustrated in a sample situation in **Table 2**. This example highlights teamwork problems that are particularly challenging if teams face complex tasks, unpredictable circumstances, time pressure, high risk and/or rapid workload changes as it is the case in action teams.

Example 3: Clinical Team Debriefings

Designed to promote learning from reflected experience, debriefings are guided conversations that facilitate the understanding of the relationship among events, actions, thought and feeling processes, and team performance outcomes (Ellis and Davidi, 2005; Rudolph et al., 2007). With respect to the team setting, debriefings have some characteristics in common with the multidisciplinary decision-making boards (example 1): they rely on psychological safety for providing a conversational climate which allows for information-sharing and sense-making. They are also formed *ad hoc*, consist of interprofessional, and in many cases, multidisciplinary members across the authority gradient and exist within complex, hierarchical organizations. What distinguishes them from multidisciplinary decision-making boards is their task: whereas the boards' task is to make decisions regarding future diagnosis and treatment, the task of debriefings is to learn from previous, collective experience. Learning outcomes may vary among team members and decisions are not necessarily required. Also called after-action reviews, after-event reviews, and post-event reviews, debriefings aim to provide the structure for shifting from automatic/habitual to more conscious/deliberate action and information processing (Ellis and Davidi, 2005; DeRue et al., 2012). Debriefings allow for reflection and self-explanation, data verification and feedback, understanding the relationship between teamwork and task work, uncovering and closing knowledge gaps and disparity in shared cognition, structured information sharing, goal setting and action planning, as well as changes in attitudes, motivation, and self and collective efficacy (Ellis and Davidi, 2005; Rudolph et al., 2007, 2008; DeRue et al., 2012; Eddy et al., 2013; Tannenbaum and Cerasoli, 2013; Tannenbaum and Goldhaber-Fiebert, 2013; Tannenbaum et al., 2013; Kolbe et al., 2015; Eppich et al., 2016; Sawyer et al., 2016b; Allen et al., 2018). In healthcare, debriefings are particularly suited for *ad hoc* teams. While they have become a core ingredient of simulation-based team training (Cheng et al., 2014; Eppich et al., 2015; Sawyer et al., 2016a), their use in daily clinical practice is still limited (Tannenbaum and Goldhaber-Fiebert, 2013) given their vast potential (Mullan et al., 2014; Kessler et al., 2015; Eppich et al., 2016).

The criticality of team process in clinical team debriefings is illustrated in a sample situation in **Table 3**. This example sheds light on the question how team members and teams as a whole can make use of reflexivity on their team- and taskwork. This

TABLE 1 | Example of a problematic teamwork situation in multidisciplinary decision-making boards.

Situation	Potential teamwork process problems	Required teamwork process insights
During a tumor board meeting, the chief of surgery arrives late while the discussion of a particular patient initially referred to her department has already started with a preliminary vote for inclusion into a new clinical trial instead of surgery. Using her dominant character she states that the patient will have to get surgery. None of the other board participants repeated the previously discussed arguments favoring the clinical trial and in the protocol a vote for surgery was documented as concordant decision.	Counterproductive meeting behaviors and lack of meeting rules (Allen et al., 2015).	Identification of actions required to set up and facilitate multidisciplinary tumor board meetings.
	Risk that leaders dominate discussion (Larson et al., 1998).	Understanding of facilitation techniques which allow for balanced exploitation of information from all board members and of optimal decision rules.
	Lack of psychological safety and lack of sharing information, opinions, and concerns by all board members (Mesmer-Magnus and DeChurch, 2009; Edmondson and Lei, 2014).	Understanding how to establish and maintain psychological safety during interdisciplinary tumor board meetings.

TABLE 2 | Example of a problematic teamwork situation in fast-paced, acute care settings.

Situation	Potential teamwork process problems	Required teamwork process insights
At 2 a.m. a patient is being brought into the trauma center. She appears to have multiple traumatic injuries. The nurses prepare the patient as quickly as possible and the anesthesia sub-team begins with inducting of anesthesia. The trauma doors open, the attending trauma surgeon comes in and starts yelling and forcefully expressing her disapproval that the patient lies uncovered, bare, and fully exposed in the cold room and that she wouldn't know how many more times she has to complain about it until the nurses would eventually get it. The nurses look at each other, roll their eyes, and continue their work. So does the anesthesiologist.	High frequency of uncivil behavior and its detrimental and contagiously spreading effects for team performance outcomes (Porath and Erez, 2009; Riskin et al., 2015; Foulk et al., 2016; Bar-David, 2018; Klingberg et al., 2018).	Insights into the unfolding of incivility during fast-paced, acute care settings and into potential triggers of civility.
	Low frequency of voice behavior and related missed opportunities for improvement (Morrison and Milliken, 2000; Kobayashi et al., 2006; Detert and Burris, 2007; Tangirala and Ramanujam, 2012; Schwappach and Gehring, 2014; Raemer et al., 2016).	Understanding of social dynamics enabling voice behavior during fast-paced, acute care settings.
	Difficulty to function as highly interdependent team because of low civility (Salas, 2016).	Identification of team adaptation mechanisms for maintaining and regaining functionality despite low civility.

includes the issue of identifying process-related markers that indicate turning points in the team process, setting the course for more or less effective team output.

The three examples were chosen to illustrate generic features of team tasks and team processes. Team tasks call for heterogeneous expertise to be shared, and problem-solving and decision-making procedures that fit task requirements. The tasks require teams to effectively handle interdependent subtasks. And, teams can learn best when they reflect on their team- and taskwork. The vehicle for the accomplishment of all of these task requirements is the team process. The identification of functional team behaviors, critical points and phases in the team process, patterns of how team behavior evolves and adapts to task requirements as well as the facilitation of appropriate team process patterns can help to improve teamwork.

PREVIOUS METHODOLOGICAL APPROACHES AND THEIR CONSEQUENCES

After having outlined tasks, prototypical process patterns, and respective research needs in the three team examples, we now put the methodological approaches of how teamwork in these representative examples has mostly been studied centerstage and highlight its consequences. In order to be as specific, illustrative and substantial as possible, we will—in a subsequent step-start from the examples to conceptualize and describe methods that promise deeper and more differentiated insights into teamwork and thus provide a basis for more effective practical interventions. We show important implications of focusing on team dynamics and using suitable methods to capture dynamic processes for team performance outcomes.

Previous Methodological Approaches of Studying Teamwork in Multidisciplinary Decision-Making Boards

Studies investigating the effectiveness of multidisciplinary decision-making boards have mainly relied on surveys or database review. Database reviews include the systematic review of certain documents, for example hospitals' patient documentation system. Surveys include questionnaires on specific aspects of self-reported teamwork quality and processes, typically provided by team members in a cross-sectional way. Rating scales such as behavior-anchored rating scales include behavior examples for desired and undesired behavior and a scale for assessing the quality of these behaviors, mostly provided to non-team members (e.g., observers) in a cross-sectional way. Studies using these methods have mostly focused on input and output factors such as (a) whether a multidisciplinary decision-making board is present or not (Keating et al., 2013), (b) whether tumor boards are attended or not (Kehl et al., 2015), (c) the content that is being discussed (Snyder et al., 2017),

TABLE 3 | Example of a problematic teamwork situation in clinical debriefings.

Situation	Potential teamwork process problems	Required teamwork process insights
After the management of an unexpected cardiac arrest during surgery, most team members come together for a debriefing. While the participating attending physicians engage in a heated discussion about who was right and who caused the cardiac arrest, the residents and nurses are rather quiet. After a few minutes, the most senior attending physician shares his thoughts on why everybody did what they did and concludes the debriefing, advising the team at large that the mistake simply must not happen again.	Team members may experience fear, anxiety, and embarrassment when making and discussing potential mistakes and engage in face-saving actions such as withdrawal, reluctance to ask for help and disclose errors, and obscuring critique (Schein, 1993; Edmondson, 1999; Rudolph et al., 2013).	Identification of team adaptation mechanisms for creating and maintaining psychologically safe learning moments for clinical debriefings.
	Lack of debriefing rules (Allen et al., 2015; Kolbe et al., 2015), psychological safety and voice (Rudolph et al., 2014).	Understanding of required debriefing rules.
	Risk of shallow or short-sighted argumentation, single rather than double-loop learning, and low levels of reflection and limited effectiveness of feedback (Argyris, 2002; Homayounfar et al., 2015; Kihlgren et al., 2015; Hughes et al., 2016; Boos and Sommer, 2018).	Identification of characteristic modes of argumentation in debriefings depending on status, context, authority gradient and potential turning points and use of structural instabilities in communication.

(d) whether conducting a tumor board leads to a change in management plan or not (Tafe et al., 2015; Brauer et al., 2017; Thenappan et al., 2017), (e) the feasibility with respect to use of technology or overall duration (Marshall et al., 2014), (f) the degree to which the tumor board is valued by participants (Snyder et al., 2017), and (g) the documentation during the board meeting (Farrugia et al., 2015). These studies provide valuable information on the context and some organizational conditions of tumor boards' effectivity which should not be underestimated (Salas, 2016). However, they are limited in their potential to reveal insights into the actual process and quality of information-sharing and decision-making. This is problematic because it is particularly the quality rather than quantity of communication that is important for performance (Marlow et al., 2018). That is, whereas some effectiveness factors such as optimal team composition, infrastructure, and data base logistics are already well-investigated, there are fewer data on advantageous interaction and communication processes before and during multidisciplinary decision-making board meetings. This is challenging because, as illustrated in the meeting example above, it is particularly the dynamic process that—in interaction with task complexity, time pressure, conflicting goals, and hierarchical structure—endangers the quality of the decision outcome.

Some studies have explicitly addressed the decision-making in tumor boards. They have relied on self-reports (Lamb et al., 2011) and rating tools such as the Multidisciplinary Team Metric for Observation of Decision-Making (MDT-MODe, Lamb et al., 2013; Shah et al., 2014). Although not addressing the decision-making process as such, these studies have provided valuable knowledge on (a) the ability to reach decisions (e.g., 82.2 to 92.7%, Lamb et al., 2013), (b) the attendance rate and duration of case reviews (e.g., 3 min per case, Shah et al., 2014), (c) estimates of the (poor) quality of presented information (e.g., 29.6 to 38.3%, Lamb et al., 2013), (d) estimates of the (poor) quality of teamwork (e.g., 37.8 to 43.0%, Lamb et al., 2013), (e) the comparative quality of team members' contributions (e.g., highest from surgeons, Shah et al., 2014), and (f) the barriers to reaching decisions (e.g., inadequate information, Lamb et al., 2013). Although the authors of these studies conclude that rating and self-report tools allow for reliably assessing the quality of teamwork and decision-making (e.g., Lamb et al., 2011), we argue that the methodology of these studies does not allow for insights into the actual, dynamic process of information-sharing and decision-making and the quality of the communication process: it remains unanswered (a) how contributions are shared among board members of different levels of hierarchy, (b) who actually contributes when with which information, (c) how other board members react, (d) how individual contributions (not) influence the decision recommendation, and (e) how dissent about evaluations and recommendations emerges and dissolves. We have argued that neglecting these critical characteristics of the decision-making process is to some degree comparable to a patient undergoing surgery while his or her condition is judged using a rating scale from 1 (*bad*) to 5 (*good*) instead of collecting and interpreting data using continuous, machine-based monitoring of heartbeat, breathing, blood pressure, body temperature, and other body functions (Kolbe and Boos, 2018).

Previous Methodological Approaches of Studying Teamwork in Fast-Paced, Acute Care Settings

A number of studies have been conducted to assess how healthcare teams manage fast-paced, acute care settings. They relied on various methods ranging from surveys (Valentine et al., 2015), over rating tools (e.g., Undre et al., 2009; Couto et al., 2015) to event and time-based observation tools (e.g., Riethmüller et al., 2012; Schmutz et al., 2015; Su et al., 2017). Teamwork observation measures have been developed for capturing teamwork in complex medical situations (e.g., Fletcher et al., 2004; Yule et al., 2006; Manser et al., 2008; Kolbe et al., 2009, 2013a; Tschan et al., 2011b; Kemper et al., 2013; Robertson et al., 2014; Seelandt et al., 2014). Overall, these observation tools fall into two main categories: *behavioral marker systems* (e.g., Fletcher et al., 2004; Yule et al., 2006;

Undre et al., 2009; Kemper et al., 2013; Jones et al., 2014; Robertson et al., 2014) and *coding schemes* (e.g., Manser et al., 2008; Kolbe et al., 2009, 2013a; Tschan et al., 2011b; Seelandt et al., 2014). Both types of tools include a number of advantages and disadvantages (Kolbe and Boos, 2018). For examp le, Undre and colleagues applied a behavioral marker system at three designated times during 50 surgical procedures. They found that teamwork behavior could actually be compared between members of different operating room subteams (Undre et al., 2007). They were also able to show that surgeons' teamwork scores deteriorated toward the end of procedures (Undre et al., 2007). Whereas these results provide valuable knowledge of teamwork estimates and perceived quality, they do not provide insights into the actual operating room team interaction process. This has been possible with studies using behavior coding. For example, Tschan and colleagues continuously coded communication of 167 surgical procedures and found that especially case-irrelevant communication during the closing phase of the procedure was associated with higher rates of surgical site infections (Tschan et al., 2015). Similarly, Riethmüller and colleagues applied a category system for team coordination in anesthesia (Kolbe et al., 2009) for coding coordination activities of simulated anesthesia task episodes and, in addition, assessed awareness for situational triggers and subsequent handling of complications within post-simulation interviews based on stimulated video-recall of the critical phases around the complication. They showed that the occurrence of a complication, e.g., an anaphylaxis or a malign hyperthermia, during a simulated routine anesthesia requires a shift from implicit to explicit coordination behavior (Riethmüller et al., 2012). Also, Weiss and colleagues tested the effects of inclusive leader language on voice in multi-professional healthcare teams in simulated medical emergencies. Specifically, they coded implicit (i.e., First-Person Plural pronouns) and explicit (i.e., invitations and appreciations) inclusive leader language and found that leaders' implicit leader utterances were more strongly related to residents' (in- group) and explicit invitations related more strongly to nurses' (out-group) voice behavior (Weiss et al., 2017a).

As these studies using behavior coding as stand-alone method for capturing teamwork indicate, they—although requiring much time and many resources—do not only provide very specific insights into the relationship between team dynamics and outcomes but also offer actionable knowledge for more targeted team training intervention.

Previous Methodological Approaches of Studying Teamwork in Clinical Debriefing

The empirical investigation of debriefing and reflexivity in teams is relatively new. Although their overall team context bears similarities with multidisciplinary decision-making boards, research on debriefings has been significantly different from research on the decision-making boards. In disciplines such as psychology and organizational behavior, this research involves experiments (e.g., Gurtner et al., 2007; Ellis et al., 2009, 2010; DeRue et al., 2012; Eddy et al., 2013; Konradt et al., 2015; Otte et al., 2018) and field studies (Vashdi et al., 2013; Weiss et al., 2017b) in which the impact of reflexivity interventions on defined outcomes is tested and different debriefing approaches are compared (e.g., unstructured vs. structured). In disciplines such as healthcare and medical education, there is far more conceptual than empirical work on debriefings. The conceptual work has focused on how to conduct debriefings (Rudolph et al., 2007, 2008, 2013, 2014; Cheng et al., 2014; Eppich et al., 2015, 2016; Kessler et al., 2015; Sawyer et al., 2016a; Cheng et al., 2017; Kolbe and Rudolph, 2018; Endacott et al., 2019). The empirical work has focused on communication in debriefings, albeit rather unsystematically and rarely applying rigorous team science methodology (e.g., Husebø et al., 2013; Kihlgren et al., 2015). Consequences of previous research on teamwork in debriefings include valuable knowledge on debriefing effectiveness and on macro-level debriefing process on the one hand and very limited actionable knowledge on optimal debriefing interaction processes and facilitation for high quality reflection on the other hand.

There are measures available for assessing team reflection and debriefing: (a) REMINT—a reflection measure for individuals and teams (Otte et al., 2017), (b) Debriefing Assessment for Simulation in Healthcare (DASH, The Center for Medical Simulation, 2010; Brett-Fleegler et al., 2012), (c) Objective Structured Assessment of Debriefing (OSAD, Arora et al., 2012), and (d) DECODE for assessing debriefers' and learners' communication in debriefings (Seelandt et al., 2018). While REMINT is a self-report measure and not applicable for assessing team dynamics, DASH and OSAD are behavioral marker systems. A recent study pointed to the challenges of measuring team debriefing quality via behavioral markers: Hull and colleagues compared OSAD-based evaluations by examining expert debriefing evaluators, debriefers, and learners (i.e., team members). They found significant differences between these groups: (a) Debriefers perceived the quality of their debriefings more favorably than expert debriefing evaluators. (b) Weak agreement between learner and expert evaluators' perceptions as well as debriefers' perceptions were found (Hull et al., 2017). That is, whereas research applying behavioral marker tools can reveal knowledge on differences in perceptions of debriefer/debriefing quality, it provides only limited insights into optimal debriefing interaction processes and how to facilitate high quality reflection in debriefings. This is problematic because, similarly to multidisciplinary decision-making boards (example 1), it is the quality rather than quantity of communication that is important for performance (Marlow et al., 2018); and so far not much is known about how to achieve high quality team interaction during clinical debriefings.

In sum, the review of existing methods used in the three exemplary team research areas shows that approaches for assessing team processes as the critical mechanism mediating the effects of input factors on team performance outcomes exist. Particularly advanced is the research on teamwork in fast-paced, acute care settings with progressive development and application of methods apt for capturing the dynamics of teamwork. Still, overall there is too much focus on aggregate

measures, rating tools, and self-report data instead of fine-grained process analysis (**Table 4**). In what follows, we illustrate potential additional methodological approaches which are, for the time being, more laborious and highlight their consequences with respect to benefits for applied team science. We show the benefits of team interaction process analysis for shedding light on dynamics of teamwork during decision-making in multidisciplinary boards, fast-paced, acute care settings, and during shared reflection.

LABORIOUS METHODOLOGICAL APPROACHES AND THEIR BENEFITS

We have labeled the methods we will describe in the following as laborious because they involve, for the time being, more time and resources than most of the above-mentioned approaches. In order to be as specific, illustrative and substantial as possible, we will use the three examples multidisciplinary decision-making boards, fast-paced acute care settings and clinical debriefings to conceptualize and describe methods that promise deeper and more differentiated insights into teamwork and thus provide a basis for more effective practical interventions.

Laborious Methodological Approaches of Studying Teamwork in Multidisciplinary Decision-Making Boards

In order to complement existing research on multidisciplinary decision-making boards' effectiveness we recommend to collect data by means of event-based or time-based sampling of critical interaction behavior and to analyze data by applying coding systems which have been designed to help uncovering team decision processes which are critical but invisible for the unaided eye (**Table 1**). These methods allow for in-depth analysis of what actually happens in multidisciplinary decision-making boards. This is important for identifying success factors. For example, using the Advanced Interaction Analysis for Teams (act4teams) coding scheme (Kauffeld et al., 2018) for analyzing multidisciplinary decision-making board team member behaviors could provide useful insights into (a) the optimal sequence of voicing information versus expressing decision preferences too early in the meeting (Mojzisch and Schulz-Hardt, 2010), (b) the impact of board leaders' statements compared to lower status members' contributions on the discussion and outcome (Lehmann-Willenbrock et al., 2015), (c) the emergence and impact of counterproductive meeting behaviors such as arriving late, complaining, and engaging in irrelevant discussions (Allen et al., 2015), and (d) the role of solution-focused meeting behavior such as suggesting a new idea or endorsing a solution (Lehmann-Willenbrock et al., 2017).

Likewise, applying aspects of the Hidden Profile coding scheme (Thürmer et al., 2018), MICRO-CO (Kolbe et al., 2011), or ARGUMENT (Boos and Sommer, 2018) would allow for (a) tracing information processing during the meeting, (b) reveal insights into what and how expert information is actually (not) processed and (not) integrated into decisions, and (c) disassemble the argumentation process into its elements, e.g., identifying grounds that are used to support specific claims for action. In a similar vein, continuously coding actual participation rather than attendance in the meeting would allow for insights into the balance of speaker switches, which has been found to be a predictor of good team performance (Woolley et al., 2010; Lehmann-Willenbrock et al., 2017). These insights into the complex, multi-layered decision-making process will not only be relevant for improving multidisciplinary decision-making boards in healthcare but for multi-team and board decision-making in general.

Laborious Methodological Approaches of Studying Teamwork in Fast-Paced, Acute Care Settings

To complement existing research and to provide context-sensitive tools for fast-paced, acute care setting, we need methods that capture the very process of teamwork as detailed, sensitive, and unobtrusively as possible. We need actionable knowledge on which behavioral sequences and interaction patterns are effective and which are prone for failure (Lei et al., 2016; Su et al., 2017). As previous research has shown, most of these insights can only be gained with behavior coding and – as new approach in measuring team dynamics – social sensor technology (Rosen et al., 2015, 2018b; Kolbe and Boos, 2018). Behavior coding as stand-alone method for capturing teamwork requires much time and many resources. At the same time, it not only provides very specific insights into the relationship between team dynamics and outcomes that would otherwise remain hidden but also offers actionable knowledge for more targeted team training intervention. As an attempt to more efficiently collect behavioral team data, social sensors have been recently introduced (Dietz et al., 2014; Kozlowski, 2015; Rosen et al., 2015, 2018b; Schmid Mast et al., 2015; Chaffin et al., 2017; Kozlowski and Chao, 2018). They use sensor technology which is, for example, included in smartphones or new types of wearable devices (e.g., smartwatches and bracelets) to measure behavioral cues and process these data to extract behavioral markers of relevant social constructs (Pentland, 2008). On the individual level, potential markers include participants' body activity, speech consistency, cardiovascular features, or electrodermal activity. On the team level, markers include face-to-face interaction, centrality of certain team members allowing for a social network analysis, interpersonal distance, and behavioral mimicry. As such, social sensors have the potential to provide high-frequency, automated, low-cost, and unobtrusive measurement of behavioral team data (Kozlowski, 2015; Rosen et al., 2015; Chaffin et al., 2017).

The ability to continuously monitor team members might allow for an in-depth analysis of team dynamics, especially during the management of fast-paced, acute care tasks where other forms of data access are limited and potentially intrusive. Respective

TABLE 4 | Previous and laborious methodological approaches and their consequences.

Example		Team conceptual foundation	General research question	Previous methodological approaches and their consequences	Laborious methodological approaches and their consequences
1	Multi-disciplinary decision-making boards	Collective information sharing and decision-making in *ad hoc*, diverse teams (Stasser and Titus, 1987; Larson et al., 2002; Mesmer-Magnus and DeChurch, 2009; Schulz-Hardt and Mojzisch, 2012).	What are the resulting risks of how input characteristics that are typical of multidisciplinary decision-making boards (e.g., high salience of status and hierarchy, conflicting goals, time pressure) may be associated with ineffective decision-making dynamics and suboptimal results? What are effective countermeasures for managing these risks given the special characteristics of these boards?	*Approaches:* Database reviews Surveys/self-reports Rating scales *Consequences:* + Knowledge about input-output relations + Knowledge about context factors and selected organizational conditions + Knowledge on selected effectiveness criteria such as team composition, infrastructure, data base logistics – Very limited insights into risks of how typical characteristics of multidisciplinary decision-making boards are associated with ineffective information-sharing and decision-making dynamics, management of dissent and suboptimal results – Very limited actionable knowledge for designing effective countermeasures for managing decision-making risks due to special characteristics of these boards.	*Approach:* Event- or time-based coding of each members' verbal and non-verbal contributions and analysis of board interaction patterns with respect to characteristic input factors and decision outcomes *Consequences:* – Exhaustive behavior coding and data analysis require significantly more time and resources than using surveys/rating scales + Detailed insights into risks of how typical characteristics of multidisciplinary decision-making boards are associated with ineffective information-sharing and decision-making dynamics, management of dissent and suboptimal results + Actionable knowledge for designing effective countermeasures for managing decision-making risks due to special characteristics of these boards
2	Teamwork in fast-paced, acute care settings	Leadership, coordination, and communication in *ad hoc* teams (Gaba et al., 2001; Künzle et al., 2010; Boos et al., 2011; Tschan et al., 2014; Fernandez Castelao et al., 2015; Su et al., 2017).	How does incivility unfold during fast-paced, acute care settings and what are potential team adaptation triggers of civility? What are team adaptation mechanisms for maintaining and regaining functionality despite low civility? What are the enabling social dynamics of voice behavior during fast-paced, acute care settings? How can voice behavior emerge and be effective?	*Approaches:* Surveys/self-reports Rating scales/behavior-marker systems *Consequences*: + Knowledge of perceived teamwork estimates and perceived teamwork quality + Differences in the perceptions of teamwork among team members or subteams highlighted – Very limited actionable knowledge on actual team interaction such as unfolding of incivility and how it relates to performance outcomes *Alternative approach:* Time- and event-based behavior coding *Consequences of alternative approach* – Coding requires significantly more time than using surveys/rating scales + In-depth, actionable knowledge on the process of team interaction and adaptation	*Approach:* Time- and event-based behavior coding combined with social-sensor-based measurement (e.g., physiological data, pose) *Consequences:* – Coding still requires significantly more time than surveys/rating scales +/– Sensor-based measurement is more feasible and unobtrusive but strategies for data analysis are still being developed + Comprehensive, in-depth, actionable knowledge on the dynamic process of actual visible and invisible team interactions related to phenomena such as (in-)civility and voice during fast-paced, acute care settings

(Continued)

TABLE 4 | Continued

Example		Team conceptual foundation	General research question	Previous methodological approaches and their consequences	Laborious methodological approaches and their consequences
3	Post-event, clinical team debriefing	Individual and team learning in *ad hoc* teams (Gurtner et al., 2007; Edmondson, 2012; Tannenbaum et al., 2012; Vashdi et al., 2013; Konradt et al., 2015; Schmutz and Eppich, 2017). Reflective practice (i.e., the exploration of one's mental routines, taken-for-granted assumptions, and their behavioral consequences) and shared reflection (i.e., collectively looking back on past experience) (Schön, 1983; Argyris, 2002; Edmondson, 2012; Konradt et al., 2016; Koeslag-Kreunen et al., 2018; Otte et al., 2018).	What are team adaptation mechanisms for creating and maintaining psychologically safe learning moments for clinical team debriefings? What are the team interaction processes that constitute high quality reflection? How do structural instabilities in communication (due to status, context, authority gradient) unfold and what are potential turning points in shared reflection? What are the resulting required process rules for conducting clinical debriefings?	*Approach:* Experiments and field studies testing the impact of debriefing or its structure on team outcomes *Consequences:* + Knowledge on debriefing effectiveness and on macro-level debriefing process − Very limited knowledge on optimal debriefing interaction processes − Very limited actionable knowledge on mechanisms for establishing psychological safety in debriefings − Very limited knowledge on how to facilitate high quality reflection *Alternative approach:* Self-reports Rating scales/Behavioral marker systems *Consequences of alternative approach:* +/− Knowledge on differences in perceptions of debriefer/debriefing quality − Very limited knowledge on optimal debriefing interaction processes − Very limited actionable knowledge on mechanisms for establishing psychological safety in debriefings − Very limited knowledge on how to facilitate high quality reflection	*Approach:* Time- and event-based behavior and communication content coding combined with social-sensor-based measurement (e.g., eye-tracking, pose) *Consequences:* − Behavior and communication coding still requires significantly more time than using surveys/rating scales +/− Sensor-based measurement is more feasible and unobtrusive but strategies for data analysis are still being developed + Charting of the information flow by coding utterances, e.g., mention, repeat, value an information + Actionable knowledge on optimal debriefing interaction processes and on mechanisms for establishing psychological safety in debriefings +Actionable knowledge on how to facilitate high quality reflection which can be translated into interventions and process rules for facilitating clinical debriefings

research in healthcare has revealed promising results. For example, Petrosoniak and colleagues applied an overlay tracing tool to track selected healthcare team members' movement during 12 high-fidelity *in situ* simulation trauma sessions. They found differences in workflow, movement and space used between team members which provide a deeper understanding of teamwork during managing a medical emergency (Petrosoniak et al., 2018). In another study, Vankipuram and colleagues used radio identification tags and observations to record motion and location of clinical teams and were able to model behavior in critical care environments. That is, the detected behavior could be replayed in virtual reality and provides options for further analysis and training (Vankipuram et al., 2011). More recently, Rosen and colleagues used wearable as well as environmental sensors to capture nurses' work process data in a surgical intensive care unit and found that the respective measures were able to predict perceived mental and physical exertion and, thus, contribute to the measurement of workload (Rosen et al., 2018c).

With respect to future research, social sensors might be able to capture the very process of teamwork. Especially in fast-paced, acute care settings they can complement traditional measurement methods to provide a more comprehensive analysis of team dynamics and actionable knowledge of which behavioral sequences and interaction patterns are effective (Kannampallil et al., 2011). As social sensors are able to provide information about the development and adaptation of team members' emotional states, their relative proximity, and their activity level, they could, for example, reveal insights into (a) the development of stress levels among team members while (not) speaking up (e.g., changes in heart frequency or electrodermal activity, Setz et al., 2010) and potential countermeasures, (b) the potential of mimicry by team members for revealing civility while speaking up (Chartrand and Bargh, 1999; Meyer et al., 2016), (c) the proximity and centrality of team members as enablers or barriers for speaking up (Jackson and Hogg, 2010), (d) the development of adaptive coordination, especially switching from implicitness to explicitness, as a trainable skill set (Riethmüller et al., 2012).

Again, this kind of results would provide actionable knowledge on the dynamics of leadership and voice which can be used in team trainings. Facing medical emergencies, teams must act immediately, fast and in a highly efficient manner as emergencies often times imply a life-or-death-struggle. Methods are required that can grasp the criticality of situational triggers in the flow of a routine process, the sensitivity and situational awareness thereof and the accurate fitting of well-coordinated behavior for an efficient task management.

Laborious Methodological Approaches of Studying Teamwork in Clinical Debriefings

To complement existing research on team debriefing processes and effectiveness we recommend to collect data by means of event-based or time-based sampling of interaction behavior and to analyze data by applying coding systems which have been designed to help uncovering conversational team learning processes (**Table 3**). For example, using DECODE—the coding scheme for assessing debriefers' and learners' communication in debriefings (Seelandt et al., 2018) or the act4teams Coding Scheme (Kauffeld et al., 2018) for analyzing debriefing communication behavior could provide useful insights into the debriefings' ideal macro (e.g., reaction phase, analysis phase, summary phases, Rudolph et al., 2007) as well as micro structure (e.g., what kind of facilitator's communication behaviors trigger group members' reflection statements, Husebø et al., 2013), in particular with respect to feedback and inquiry (Rudolph et al., 2007; Hughes et al., 2016; Kolbe et al., 2016). It could inform the potential association of team members' status, professional discipline, actual profession, and their contributions to the debriefing discussion (Lehmann-Willenbrock et al., 2015), the emergence and impact of counterproductive debriefing behaviors such as arriving late, complaining, lecturing, and engaging in irrelevant discussions (Allen et al., 2015, 2018; Kolbe et al., 2015), the optimal balance of understanding and exploring vs. engaging in finding solutions (Kolbe et al., 2015), characteristic modes of argumentation in debriefings depending on status, context, authority gradient, and potential turning points and use of structural instabilities in communication, and the role of leadership in debriefing discussions (Koeslag-Kreunen et al., 2018). Similarly to proposed multidisciplinary decision-making boards research, capturing actual participation rather than attendance in the debriefing would allow for insights into the balance of speaker switches, which has been found to be a predictor of good team performance (Woolley et al., 2010; Lehmann-Willenbrock et al., 2017).

With respect to future research, behavior coding of team debriefings might be complemented with other data collection technology. For example, using eye tracking technology (Hess et al., 2018) might reveal insights the role of eye-contact for establishing and maintaining psychological safety in debriefings.

CONCLUSION

We have contrasted methodological approaches for studying team dynamics and their consequences. Given the increasing use of teams in modern organizations, there is a need to develop and apply scientifically-rooted concepts and methods to grasp team process dynamics as a means to gain a deeper understanding of successful teamwork.

Coding interaction and communication processes in teams based on generic or tailor-made category systems provides benefits for the science of teams. First, a process- and behavior-oriented approach enables us to operationalize theoretical constructs and everyday phenomena such as decision-making, coordination, and reflexivity in a clear-cut manner. Second, focusing on the processual enactment of team phenomena allows for a much richer picture of how they emerge, develop, and interact, how effective patterns evolve, and for identifying breaking points for potential intervention

(Wageman et al., 2009). Third, studying team dynamics via behavior observation allows for taking the so-called functional perspective of group research seriously: opening the *black box* of team process as a mediator between input and output factors (Roe, 2011, 2014). For now, team behavior coding is still laborious. New developments in machine learning are likely to significantly reduce the involved workload in the future (Bonito and Keyton, 2018).

Implications of this research will be meaningful for team training and the design of prevention and intervention concepts to improve teamwork. Structural changes of input factors such as team composition, resources, reward systems, and norms can improve teamwork to some degree. But in the end, for determining what makes these changes effective or not, a look into how they are enacted during the team process is necessary. In this manuscript, we have tried to elaborate research questions in the realm of healthcare teams which cannot be answered sufficiently without taking the process of team communication and interaction into consideration. We are convinced that—as in other disciplines—innovation and progress in team research heavily depend on methodological and technological innovation. This is what Gigerenzer (1991) called the "tools-to-theories heuristic." It is not so much the theories and data that drive scientists to new ideas and the solution of existing problems, but instruments, techniques, and methodical skills (Gigerenzer, 1994). With an increasing innovation grade in team research, we have methods and technology available that allow for much deeper and finer-grained team research and for exploring groundbreaking, new questions.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

ACKNOWLEDGMENTS

We thank Elisabeth Brauner for supporting us with her valuable insights, guidance, and enthusiasm for group interaction analysis. We also thank Bastian Grande and Kia Homayounfar for sharing their medical expertise.

REFERENCES

Allen, J. A., Reiter-Palmon, R., Crowe, J., and Scott, C. (2018). Debriefs: teams learning from doing in context. *Am. Psychol.* 73, 504–516. doi: 10.1037/amp0000246

Allen, J. A., Yoerger, M. A., Lehmann-Willenbrock, N., and Jones, J. (2015). Would you please stop that!?: the relationship between counterproductive meeting behaviors, employee voice, and trust. *J. Manag. Dev.* 34, 1272–1287. doi: 10.1108/JMD-02-2015-0032

Antonides, C. F. J., Mack, M. J., and Kappetein, A. P. (2017). Approaches to the role of the Heart Team in therapeutic decision making for heart valve disease. *Struct. Heart* 1, 249–255. doi: 10.1080/24748706.2017.1380377

Argyris, C. (2002). Double-loop learning, teaching, and research. *Acad. Manag. Learn. Educ.* 1, 206–218. doi: 10.5465/AMLE.2002.8509400

Arora, S., Ahmed, M., Paige, J., Nestel, D., Runnacles, J., Hull, L., et al. (2012). Objective structured assessment of debriefing (OSAD): bringing science to the art of debriefing in surgery. *Ann. Surg.* 256, 982–988. doi: 10.1097/SLA.0b013e3182610c91

Ballard, D. I., Tschan, F., and Waller, M. J. (2008). All in the timing: considering time at multiple stages of group research. *Small Group Res.* 39, 328–351. doi: 10.1177/1046496408317036

Bar-David, S. (2018). What's in an eye roll? It is time we explore the role of workplace incivility in healthcare. *Isr. J. Health Policy Res.* 7:15. doi: 10.1186/s13584-018-0209-0

Bhanji, F., Mancini, M. E., Sinz, E., Rodgers, D. L., McNeil, M. A., Hoadley, T. A., et al. (2010). Part 16: education, implementation, and teams: 2010 American heart association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation* 122(18 Suppl. 3), S920–S933. doi: 10.1161/circulationaha.110.971135

Bonito, J. A., and Keyton, J. (2018). "Introduction to machine learning," in *The Cambridge Handbook of Group Interaction Analysis*, eds E. Brauner, M. Boos, and M. Kolbe (Cambridge: Cambridge University Press), 387–404.

Boos, M., Kolbe, M., and Strack, M. (2011). "An inclusive model of group coordination," in *Coordination in Human and Primate Groups*, eds M. Boos, M. Kolbe, P. Kappeler, and T. Ellwart (Heidelberg: Springer), 11–36.

Boos, M., Pritz, J., Lange, S., and Belz, M. (2014). Leadership in moving human groups. *PLoS Comput. Biol.* 10:e1003541. doi: 10.1371/journal.pcbi.1003541

Boos, M., and Sommer, C. (2018). "ARGUMENT," in *The Cambridge Handbook of Group Interaction Analysis*, eds E. Brauner, M. Boos, and M. Kolbe (Cambridge: Cambridge University Press), 460–466.

Brauer, D. G., Strand, M. S., Sanford, D. E., Kushnir, V. M., Lim, K.-H., Mullady, D. K., et al. (2017). Utility of a multidisciplinary tumor board in the management of pancreatic and upper gastrointestinal diseases: an observational study. *HPB* 19, 133–139. doi: 10.1016/j.hpb.2016.11.002

Brett-Fleegler, M., Rudolph, J. W., Eppich, W. J., Monuteaux, M., Fleegler, E., Cheng, A., et al. (2012). Debriefing assessment for simulation in healthcare: development and psychometric properties. *Simul. Healthc.* 7, 288–294. doi: 10.1097/SIH.0b013e3182620228

Chaffin, D., Heidl, R., Hollenbeck, J. R., Howe, M., Yu, A., Voorhees, C., et al. (2017). The promise and perils of wearable sensors in organizational research. *Organ. Res. Methods* 20, 3–31. doi: 10.1177/1094428115617004

Chartrand, T. L., and Bargh, J. A. (1999). The chameleon effect: the perception-behavior link and social interaction. *J. Pers. Soc. Psychol.* 76, 893–910. doi: 10.1037//0022-3514.76.6.893

Cheng, A., Eppich, W., Grant, V., Sherbino, J., Zendejas, B., and Cook, D. A. (2014). Debriefing for technology-enhanced simulation: a systematic review and meta-analysis. *Med. Educ.* 48, 657–666. doi: 10.1111/medu.12432

Cheng, A., Grant, V., Huffman, J., Burgess, G., Szyld, D., Robinson, T., et al. (2017). Coaching the debriefer: peer coaching to improve debriefing quality in simulation programs. *Simul. Healthc.* 12, 319–325. doi: 10.1097/sih.0000000000000232

Cooper, J. B., Newbower, R. S., and Kitz, R. J. (1984). An analysis of major errors and equipment failures in anesthesia management: considerations for prevention and detection. *Anesthesiology* 60, 34–42. doi: 10.1097/00000542-198401000-00008

Couto, T. B., Kerrey, B. T., Taylor, R. G., FitzGerald, M., and Geis, G. L. (2015). Teamwork skills in actual, in situ, and in-center pediatric emergencies: performance levels across settings and perceptions of comparative educational impact. *Simul. Healthc.* 10, 76–84. doi: 10.1097/sih.0000000000000081

Cronin, M. A., Weingart, L. R., and Todorova, G. (2011). Dynamics in groups: are we there yet? *Acad. Manag. Ann.* 5, 571–612. doi: 10.1080/19416520.2011.590297

DeRue, D. S., Nahrgang, J. D., Hollenbeck, J. R., and Workman, K. (2012). A quasi-experimental study of after-event reviews and leadership development. *J. Appl. Psychol.* 97, 997–1015. doi: 10.1037/a0028244

Detert, J. R., and Burris, E. R. (2007). Leadership behavior and employee voice: is the door really open? *Acad. Manag. J.* 50, 869–884. doi: 10.5465/amj.2007.26279183

Dietz, A. S., Pronovost, P. J., Benson, K. N., Mendez-Tellez, P. A., Dwyer, C., Wyskiel, R., et al. (2014). A systematic review of behavioural marker systems

in healthcare: what do we know about their attributes, validity and application? *BMJ Qual. Saf.* 23, 1031–1039. doi: 10.1136/bmjqs-2013-002457

Driskell, T., Salas, E., and Driskell, J. E. (2018). Teams in extreme environments: alterations in team development and teamwork. *Hum. Resour. Manag. Rev.* 28, 434–449. doi: 10.1016/j.hrmr.2017.01.002

Eddy, E. R., Tannenbaum, S. I., and Mathieu, J. E. (2013). Helping teams to help themselves: comparing two team-led debriefing methods. *Pers. Psychol.* 66, 975–1008. doi: 10.1111/peps.12041

Edmondson, A. (1999). Psychological safety and learning behavior in work teams. *Adm. Sci. Q.* 44, 350–383. doi: 10.2307/2666999

Edmondson, A. C. (2012). *Teaming: How Organizations Learn, Innovate, and Compete in the Knowledge Economy*. San Francisco, CA: Jossey-Bass.

Edmondson, A. C., and Lei, Z. (2014). Psychological safety: the history, renaissance, and future of an interpersonal construct. *Annu. Rev. Organ. Psychol. Organ. Behav.* 1, 23–43. doi: 10.1146/annurev-orgpsych-031413-091305

Edmondson, A. C., and McManus, S. E. (2007). Methodological fit in management field research. *Acad. Manag. J.* 32, 1155–1179. doi: 10.5465/amr.2007.26586086

Ellis, S., and Davidi, I. (2005). After-Event Reviews: drawing lessons from successful and failed experience. *J. Appl. Psychol.* 90, 857–871. doi: 10.1037/0021-9010.90.5.842

Ellis, S., Ganzach, Y., Castle, E., and Sekely, G. (2010). The effect of filmed versus personal after-event reviews on task performance: the mediating and moderating role of self-efficacy. *J. Appl. Psychol.* 95, 122–131. doi: 10.1037/a0017867

Ellis, S., Mendel, R., and Aloni-Zohar, M. (2009). The effect of accuracy of performance evaluation on learning from experience: the moderating role of after-event reviews. *J. Appl. Soc. Psychol.* 39, 541–563. doi: 10.1111/j.1559-1816.2009.00450.x

Endacott, R., Gale, T., O'Connor, A., and Dix, S. (2019). Frameworks and quality measures used for debriefing in team-based simulation: a systematic review. *BMJ Simul. Technol. Enhanc. Learn.* 5, 61–72. doi: 10.1136/bmjstel-2017-000297

Eppich, W., Mullan, P. C., Brett-Fleegler, M., and Cheng, A. (2016). "Let's talk about it": translating lessons from healthcare simulation to clinical event debriefings and clinical coaching conversations. *Clin. Pediatr. Emerg. Med.* 17, 200–211. doi: 10.1016/j.cpem.2016.07.001

Eppich, W. J., Hunt, E. A., Duval-Arnould, J. M., Siddall, V. J., and Cheng, A. (2015). Structuring feedback and debriefing to achieve mastery learning goals. *Acad. Med.* 90, 1501–1508. doi: 10.1097/acm.0000000000000934

Falk, V., Baumgartner, H., Bax, J. J., De Bonis, M., Hamm, C., Holm, P. J., et al. (2017). 2017 ESC/EACTS Guidelines for the management of valvular heart disease. *Eur. J. Cardiothorac. Surg.* 52, 616–664. doi: 10.1093/ejcts/ezx324

Farrugia, D. J., Fischer, T. D., Delitto, D., Spiguel, L. R. P., and Shaw, C. M. (2015). Improved breast cancer care quality metrics after implementation of a standardized tumor board documentation template. *J. Oncol. Pract.* 11, 421–423. doi: 10.1200/jop.2015.003988

Fernandez Castelao, E., Boos, M., Ringer, C., Eich, C., and Russo, S. G. (2015). Effect of CRM team leader training on team performance and leadership behavior in simulated cardiac arrest scenarios: a prospective, randomized, controlled study. *BMC Med. Educ.* 15:116. doi: 10.1186/s12909-015-0389-z

Fernandez Castelao, E., Russo, S. G., Cremer, S., Strack, M., Kaminski, L., Eich, C., et al. (2011). Positive impact of crisis resource management training on no-flow time and team member verbalisations during simulated cardiopulmonary resuscitation: a randomized controlled trial. *Resuscitation* 82, 1338–1343. doi: 10.1016/j.resuscitation.2011.05.009

Fletcher, G., Flin, R., McGeorge, P., Glavin, R., Maran, N., and Patey, R. (2004). Rating non-technical skills: developing a behavioral marker system for use in anaesthesia. *Cogn. Technol. Work* 6, 165–171. doi: 10.1007/s10111-004-0158-y

Flin, R., and Mitchell, L. (eds). (2009). *Safer Surgery: Analysing Behaviour in the Operating Theatre*. Farnham: Ashgate.

Foulk, T., Woolum, A., and Erez, A. (2016). Catching rudeness is like catching a cold: the contagion effects of low-intensity negative behaviors. *J. Appl. Psychol.* 101, 50–67. doi: 10.1037/apl0000037

Gaba, D. M., Howard, S. K., Fish, K. J., Smith, B. E., and Sowb, Y. A. (2001). Simulation-based training in anesthesia crisis resource management (ACRM): a decade of experience. *Simul. Gaming* 32, 175–193. doi: 10.1177/104687810103200206

Gawande, A. A., Studdert, D. M., Orav, E. J., Brennan, T. A., and Zinner, M. J. (2003). Risk factors for retained instruments and sponges after surgery. *N. Engl. J. Med.* 348, 229–235. doi: 10.1056/nejmsa021721

Gigerenzer, G. (1991). From tools to theories: a heuristic of discovery in cognitive psychology. *Psychol. Rev.* 98, 254–267. doi: 10.1037/0033-295X.98.2.254

Gigerenzer, G. (1994). "Where do new ideas come from," in *Dimensions of Creativity*, ed. M. A. Boden (Cambridge, MA: MIT Press), 53–74.

Graumann, C. F. (1979). Die scheu des psychologen vor der interaktion. Ein schisma und seine geschichte [the unease of the psychologis in face of interaction. A schism and its history]. *Z. Sozialpsychol.* 10, 284–304.

Greenberg, C. C., Regenbogen, S. E., Studdert, D. M., Lipsitz, S. R., Rogers, S. O., Zinner, M. J., et al. (2007). Patterns of communication breakdowns resulting in injury to surgical patients. *J. Am. Coll. Surg.* 204, 533–540. doi: 10.1016/j.jamcollsurg.2007.01.010

Grote, G., Kolbe, M., Zala-Mezö, E., Bienefeld-Seall, N., and Künzle, B. (2010). Adaptive coordination and heedfulness make better cockpit crews. *Ergonomics* 52, 211–228. doi: 10.1080/00140130903248819

Gurtner, A., Tschan, F., Semmer, N.-K., and Naegele, C. (2007). Getting groups to develop good strategies: effects of reflexivity interventions on team process, team performance, and shared mental models. *Organ. Behav. Hum. Decis. Process.* 102, 127–142. doi: 10.1016/j.obhdp.2006.05.002

Hess, S., Lohmeyer, Q., and Meboldt, M. (2018). Mobile eye tracking in engineering design education. *Des. Technol. Educ. Int. J.* 23, 86–98.

Homayounfar, K., Mey, D., Boos, M., Gaedcke, J., and Ghadimi, M. (2015). Communication in the tumor board. *Forum* 30, 214–217. doi: 10.1007/s12312-015-1301-9

Hughes, A. M., Gregory, M. E., Joseph, D. L., Sonesh, S. C., Marlow, S. L., Lacerenza, C. N., et al. (2016). Saving lives: a meta-analysis of team training in healthcare. *J. Appl. Psychol.* 101, 1266–1304. doi: 10.1037/apl0000120

Hull, L., Russ, S., Ahmed, M., Sevdalis, N., and Birnbach, D. J. (2017). Quality of interdisciplinary postsimulation debriefing: 360° evaluation. *BMJ Simul. Technol. Enhanc. Learn.* 3, 9–16. doi: 10.1136/bmjstel-2016-000125

Humphrey, S. E., and Aime, F. (2014). Team microdynamics: toward an organizing approach to teamwork. *Acad. Manag. Ann.* 8, 443–503. doi: 10.1080/19416520.2014.904140

Hunziker, S., Johansson, A. C., Tschan, F., Semmer, N. K., Rock, L., Howell, M. D., et al. (2011). Teamwork and leadership in cardiopulmonary resuscitation. *J. Am. Coll. Cardiol.* 57, 2381–2388. doi: 10.1016/j.jacc.2011.03.017

Husebø, S. E., Dieckmann, P., Rystedt, H., Søreide, E., and Friberg, F. (2013). The relationship between facilitators' questions and the level of reflection in postsimulation debriefing. *Simul. Healthc.* 8, 135–142. doi: 10.1097/SIH.0b013e31827cbb5c

Jackson, R. L., and Hogg, M. A. (2010). "Immediacy," in *Encyclopedia of Identity*, eds R. L. Jackson and M. A. Hogg (Thousand Oaks, CA: Sage), 382–384.

Jones, K., Rosen, M., Duval-Arnould, J., and Hunt, E. (2014). Development of a cardiopulmonary resuscitation non-technical skills scoring tool (CPR-NTS). *Crit. Care Med.* 42:A1427. doi: 10.1097/01.ccm.0000457773.66160.b8

Kannampallil, T., Li, Z., Zhang, M., Cohen, T., Robinson, D. J., Franklin, A., et al. (2011). Making sense: sensor-based investigation of clinician activities in complex critical care environments. *J. Biomed. Inform.* 44, 441–454. doi: 10.1016/j.jbi.2011.02.007

Kauffeld, S., Lehmann-Willenbrock, N., and Meinecke, A. L. (2018). "The advanced interaction analysis for teams (act4teams) coding scheme," in *The Cambridge Handbook of Group Interaction Analysis*, eds E. Brauner, M. Boos, and M. Kolbe (Cambridge: Cambridge University Press), 422–431. doi: 10.1017/9781316286302.022

Keating, N. L., Landrum, M. B., Lamont, E. B., Bozeman, S. R., Shulman, L. N., and McNeil, B. J. (2013). Tumor boards and the quality of cancer care. *J. Natl. Cancer Inst.* 105, 113–121. doi: 10.1093/jnci/djs502

Kehl, K. L., Landrum, M. B., Kahn, K. L., Gray, S. W., Chen, A. B., and Keating, N. L. (2015). Tumor board participation among physicians caring for patients with lung or colorectal cancer. *J. Oncol. Pract.* 11, e267–e278. doi: 10.1200/jop.2015.003673

Kemper, P. F., van Noord, I., de Bruijne, M., Knol, D. L., Wagner, C., and van Dyck, C. (2013). Development and reliability of the explicit professional oral communication observation tool to quantify the use of non-technical skills in healthcare. *BMJ Qual. Saf.* 22, 586–595. doi: 10.1136/bmjqs-2012-001451

Kessler, D. O., Cheng, A., and Mullan, P. C. (2015). Debriefing in the emergency department after clinical events: a practical guide. *Ann. Emerg. Med.* 65, 690–698. doi: 10.1016/j.annemergmed.2014.10.019

Kihlgren, P., Spanager, L., and Dieckmann, P. (2015). Investigating novice doctors' reflections in debriefings after simulation scenarios. *Med. Teach.* 37, 437–443. doi: 10.3109/0142159X.2014.956054

Kim, T., McFee, E., Olguin Olguin, D., Waber, B., and Pentland, A. (2012). Sociometric badges: using sensor technology to capture new forms of collaboration. *J. Organ. Behav.* 33, 412–427. doi: 10.1002/job.1776

Klingberg, K., Gadelhak, K., Jegerlehner, S. N., Brown, A. D., Exadaktylos, A. K., and Srivastava, D. S. (2018). Bad manners in the Emergency Department: incivility among doctors. *PLoS One* 13:e0194933. doi: 10.1371/journal.pone.0194933

Kobayashi, H., Pian-Smith, M., Sato, M., Sawa, R., Takeshita, T., and Raemer, D. (2006). A cross-cultural survey of residents' perceived barriers in questioning/challenging authority. *Qual. Saf. Health Care* 15, 277–283. doi: 10.1136/qshc.2005.017368

Koeslag-Kreunen, M., Van den Bossche, P., Hoven, M., Van der Klink, M., and Gijselaers, W. (2018). When leadership powers team learning: a meta-analysis. *Small Group Res.* 49, 475–513. doi: 10.1177/1046496418764824

Kolbe, M., and Boos, M. (2018). "Observing group interaction," in *The Cambridge Handbook of Group Interaction Analysis*, eds E. Brauner, M. Boos, and M. Kolbe (Cambridge: Cambridge University Press), 68–85. doi: 10.1017/9781316286302.005

Kolbe, M., Burtscher, M., and Manser, T. (2013a). Co-ACT–A framework for observing coordination behavior in acute care teams. *BMJ Qual. Saf.* 22, 596–605. doi: 10.1136/bmjqs-2012-001319

Kolbe, M., Weiss, M., Grote, G., Knauth, A., Dambach, M., Spahn, D. R., et al. (2013b). TeamGAINS: a tool for structured debriefings for simulation-based team trainings. *BMJ Qual. Saf.* 22, 541–553. doi: 10.1136/bmjqs-2012-000917

Kolbe, M., Grande, B., Marty, A., Manka, R., Taramasso, M., Nietlispach, F., et al. (2019). Making heart team discussions work. *Struct. Heart* 3, 100–103. doi: 10.1080/24748706.2019.1572254

Kolbe, M., Grande, B., and Spahn, D. R. (2015). Briefing and debriefing during simulation-based training and beyond: content, structure, attitude and setting. *Best Pract. Res. Clin. Anaesthesiol.* 29, 87–96. doi: 10.1016/j.bpa.2015.01.002

Kolbe, M., Grote, G., Waller, M. J., Wacker, J., Grande, B., Burtscher, M., et al. (2014). Monitoring and talking to the room: autochthonous coordination patterns in team interaction and performance. *J. Appl. Psychol.* 99, 1254–1267. doi: 10.1037/a0037877

Kolbe, M., Künzle, B., Zala-Mezö, E., Wacker, J., and Grote, G. (2009). "Measuring coordination behaviour in anaesthesia teams during induction of general anaesthetics," in *Safer Surgery. Analysing Behaviour in the Operating Theatre*, eds R. Flin and L. Mitchell (Aldershot: Ashgate), 203–221. doi: 10.1201/9781315607436-13

Kolbe, M., Marty, A., Seelandt, J., and Grande, B. (2016). How to debrief teamwork interactions: using circular questions to explore and change team interaction patterns. *Adv. Simul.* 1:29. doi: 10.1186/s41077-016-0029-7

Kolbe, M., and Rudolph, J. W. (2018). What's the headline on your mind right now? How reflection guides simulation-based faculty development in a master class. *BMJ Simul. Technol. Enhanc. Learn.* 4, 126–132. doi: 10.1136/bmjstel-2017-000247

Kolbe, M., Strack, M., Stein, A., and Boos, M. (2011). "Effective coordination in human group decision making: MICRO-CO. A micro-analytical taxonomy for analysing explicit coordination mechanisms in decision-making groups," in *Coordination in Human and Primate Groups*, eds M. Boos, M. Kolbe, P. Kappeler, and T. Ellwart (Heidelberg: Springer), 199–219. doi: 10.1007/978-3-642-15355-6_11

Konradt, U., Otte, K.-P., Schippers, M. C., and Steenfatt, C. (2016). Reflexivity in teams: a review and new perspectives. *J. Psychol.* 150, 153–174. doi: 10.1080/00223980.2015.1050977

Konradt, U., Schippers, M. C., Garbers, Y., and Steenfatt, C. (2015). Effects of guided reflexivity and team feedback on team performance improvement: the role of team regulatory processes and cognitive emergent states. *Eur. J. Work Organ. Psychol.* 24, 777–795. doi: 10.1080/1359432X.2015.1005608

Kozlowski, S. W. (2015). Advancing research on team process dynamics Theoretical, methodological, and measurement considerations. *Organ. Psychol. Rev.* 5, 270–299. doi: 10.1177/2041386614533586

Kozlowski, S. W. J., and Chao, G. T. (2018). Unpacking team process dynamics and emergent phenomena: challenges, conceptual advances, and innovative methods. *Am. Psychol.* 73, 576–592. doi: 10.1037/amp0000245

Künzle, B., Zala-Mezö, E., Wacker, J., Kolbe, M., and Grote, G. (2010). Leadership in anaesthesia teams: the most effective leadership is shared. *Qual. Saf. Health Care* 19:e46. doi: 10.1136/qshc.2008.030262

Lamb, B. W., Green, J. S. A., Benn, J., Brown, K. F., Vincent, C. A., and Sevdalis, N. (2013). Improving decision making in multidisciplinary tumor boards: prospective longitudinal evaluation of a multicomponent intervention for 1,421 patients. *J. Am. Coll. Surg.* 217, 412–420. doi: 10.1016/j.jamcollsurg.2013.04.035

Lamb, B. W., Sevdalis, N., Mostafid, H., Vincent, C., and Green, J. S. A. (2011). Quality improvement in multidisciplinary cancer teams: an investigation of teamwork and clinical decision-making and cross-validation of assessments. *Ann. Surg. Oncol.* 18, 3535–3543. doi: 10.1245/s10434-011-1773-5

Larson, J. J. R., Sargis, E. G., Elstein, A. S., and Schwartz, A. (2002). Holding shared versus unshared information: its impact on perceived member influence in decision-making groups. *Basic Appl. Soc. Psychol.* 24, 145–155. doi: 10.1207/S15324834BASP2402_6

Larson, J. R. J., Foster-Fishman, P. G., and Franz, T. M. (1998). Leadership style and the discussion of shared and unshared information in decision-making groups. *Pers. Soc. Psychol. Bull.* 24, 482–495. doi: 10.1177/0146167298245004

Lehmann-Willenbrock, N. (2017). Team learning. *Small Group Res.* 48, 123–130. doi: 10.1177/1046496416689308

Lehmann-Willenbrock, N., Allen, J. A., and Kauffeld, S. (2013). A sequential analysis of procedural meeting communication: how teams facilitate their meetings. *J. Appl. Commun. Res.* 41, 365–388. doi: 10.1080/00909882.2013.844847

Lehmann-Willenbrock, N., Chiu, M. M., Lei, Z., and Kauffeld, S. (2017). Understanding positivity within dynamic team interactions. *Group Organ. Manag.* 42, 39–78. doi: 10.1177/1059601116628720

Lehmann-Willenbrock, N., Meinecke, A. L., Rowold, J., and Kauffeld, S. (2015). How transformational leadership works during team interactions: a behavioral process analysis. *Leadersh. Q.* 26, 1017–1033. doi: 10.1016/j.leaqua.2015.07.003

Lehmann-Willenbrock, N., Meyers, R. A., Kauffeld, S., Neininger, A., and Henschel, A. (2011). Verbal interaction sequences and group mood: exploring the role of team planning communication. *Small Group Res.* 42, 639–668. doi: 10.1177/1046496411398397

Lei, Z., Waller, M. J., Hagen, J., and Kaplan, S. (2016). Team adaptiveness in dynamic contexts: contextualizing the roles of interaction patterns and in-process planning. *Group Organ. Manag.* 41, 491–525. doi: 10.1177/1059601115615246

Manser, T., Howard, S. K., and Gaba, D. M. (2008). Adaptive coordination in cardiac anaesthesia: a study of situational changes in coordination patterns using a new observation system. *Ergonomics* 51, 1153–1178. doi: 10.1080/00140130801961919

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manag. Rev.* 26, 356–376. doi: 10.5465/AMR.2001.4845785

Marlow, S. L., Lacerenza, C. N., Paoletti, J., Burke, C. S., and Salas, E. (2018). Does team communication represent a one-size-fits-all approach?: a meta-analysis of team communication and performance. *Organ. Behav. Hum. Decis. Process.* 144, 145–170. doi: 10.1016/j.obhdp.2017.08.001

Marshall, C. L., Petersen, N. J., Naik, A. D., Velde, N. V., Artinyan, A., Albo, D., et al. (2014). Implementation of a regional virtual tumor board: a prospective study evaluating feasibility and provider acceptance. *Telemed. J. E Health* 20, 705–711. doi: 10.1089/tmj.2013.0320

Mathieu, J. E., Tannenbaum, S. I., Donsbach, J. S., and Alliger, G. M. (2014). A review and integration of team composition models moving toward a dynamic and temporal framework. *J. Manag.* 40, 130–160. doi: 10.1177/0149206313503014

Maynard, M. T., Kennedy, D. M., and Resick, C. J. (2018). Teamwork in extreme environments: lessons, challenges, and opportunities. *J. Organ. Behav.* 39, 695–700. doi: 10.1002/job.2302

McGrath, J. E., and Tschan, F. (2004). *Temporal Matters in Social Psychology: Examining the Role of Time in the Lives of Groups and Individuals*. Washington, DC: APA.

Mesmer-Magnus, J. R., and DeChurch, L. A. (2009). Information sharing and team performance: a meta-analysis. *J. Appl. Psychol.* 94, 535–546. doi: 10.1037/a0013773

Meyer, B., Burtscher, M. J., Jonas, K., Feese, S., Arnrich, B., Tröster, G., et al. (2016). What good leaders actually do: micro-level leadership behaviour, leader evaluations, and team decision quality. *Eur. J. Work Organ. Psychol.* 25, 773–789. doi: 10.1080/1359432X.2016.1189903

Mojzisch, A., and Schulz-Hardt, S. (2010). Knowing others' preferences degrades the quality of group decisions. *J. Pers. Soc. Psychol.* 98, 794–808. doi: 10.1037/a0017627

Morrison, E. W., and Milliken, F. J. (2000). Organizational silence: a barrier to change and development in a pluralistic world. *Acad. Manag. Rev.* 25, 706–725. doi: 10.5465/amr.2000.3707697

Mullan, P. C., Kessler, D. O., and Cheng, A. (2014). Educational opportunities with postevent debriefing. *JAMA* 312, 2333–2334. doi: 10.1001/jama.2014.15741

Otte, K.-P., Konradt, U., Garbers, Y., and Schippers, M. C. (2017). Development and validation of the REMINT: a reflection measure for individuals and teams. *Eur. J. Work Organ. Psychol.* 26, 299–313. doi: 10.1080/1359432X.2016.1261826

Otte, K.-P., Konradt, U., and Oldeweme, M. (2018). Effective team reflection: the role of quality and quantity. *Small Group Res.* 49, 739–766. doi: 10.1177/1046496418804898

Pentland, A. (2008). *Honest Signals. How they Shape our World*. Cambridge, MA: MIT Press.

Petrosoniak, A., Almeida, R., Pozzobon, L. D., Hicks, C., Fan, M., White, K., et al. (2018). Tracking workflow during high-stakes resuscitation: the application of a novel clinician movement tracing tool during in situ trauma simulation. *BMJ Simul. Technol. Enhanc. Learn.* 5, 78–84. doi: 10.1136/bmjstel-2017-000300

Porath, C. L., and Erez, A. (2009). Overlooked but not untouched: how rudeness reduces onlookers' performance on routine and creative tasks. *Organ. Behav. Hum. Decis. Process.* 109, 29–44. doi: 10.1016/j.obhdp.2009.01.003

Pox, C., Aretz, S., Bischoff, S. C., Graeven, U., Hass, M., Heußner, P., et al. (2013). S3-leitlinie kolorektales karzinom version 1.0 – Juni 2013 AWMF-registernummer: 021/007OL. [S3-guideline colorectal cancer version 1.0]. *Z. Gastroenterol.* 51, 753–854. doi: 10.1055/s-0033-1350264

Pronovost, P. (2013). "Teamwork matters," in *Developing and Enhancing Teamwork in Organizations: Evidence-Based Best Practices and Guidelines*, eds E. Salas, S. I. Tannenbaum, D. Cohen, and G. Latham (San Francisco, CA: Jossey-Bass), 11–12.

Raemer, D. B., Kolbe, M., Minehart, R. D., Rudolph, J. W., and Pian-Smith, M. C. M. (2016). Improving anesthesiologists' ability to speak up in the operating room: a randomized controlled experiment of a simulation-based intervention and a qualitative analysis of hurdles and enablers. *Acad. Med.* 91, 530–539. doi: 10.1097/acm.0000000000001033

Reynard, J., Reynolds, J., and Stevenson, P. (2009). *Practical Patient Safety*. Oxford: Oxford University Press.

Riethmüller, M., Fernandez Castelao, E., Eberhardt, D., Timmermann, A., and Boos, M. (2012). Adaptive coordination development in student anaesthesia teams: a longitudinal study. *Ergonomics* 55, 55–68. doi: 10.1080/00140139.2011.636455

Riskin, A., Erez, A., Foulk, T. A., Kugelman, A., Gover, A., Shoris, I., et al. (2015). The impact of rudeness on medical team performance: a randomized trial. *Pediatrics* 136, 487–495. doi: 10.1542/peds.2015-1385

Robertson, E. R., Hadi, M., Morgan, L. J., Pickering, S. P., Collins, G., New, S., et al. (2014). Oxford NOTECHS II: a modified theatre team non-technical skills scoring system. *PLoS One* 9:e90320. doi: 10.1371/journal.pone.0090320

Roe, R. A. (2008). Time in applied psychology: the study of "what happens" rather than "what is". *Eur. Psychol.* 13, 37–52. doi: 10.1027/1016-9040.13.1.37

Roe, R. A. (2011). "What is wrong with mediators and moderators?," in *Paper Presented at the 15th European Congress of Work & Organizational Psychology*, Maastricht.

Roe, R. A. (2014). Test validity from a temporal perspective: incorporating time in validation research. *Eur. J. Work Organ. Psychol.* 23, 754–768. doi: 10.1080/1359432X.2013.804177

Rosen, M. A., DiazGranados, D., Dietz, A. S., Benishek, L. E., Thompson, D., Pronovost, P. J., et al. (2018a). Teamwork in healthcare: key discoveries enabling safer, high-quality care. *Am. Psychol.* 73, 433–450. doi: 10.1037/amp0000298

Rosen, M. A., Dietz, A. S., and Kazi, S. (2018b). "Beyond coding interaction," in *The Cambridge Handbook of Group Interaction Analysis*, eds E. Brauner, M. Boos, and M. Kolbe (Cambridge: Cambridge University Press), 142–162. doi: 10.1017/9781316286302.009

Rosen, M. A., Dietz, A. S., Lee, N., Wang, I. J., Markowitz, J., Wyskiel, R. M., et al. (2018c). Sensor-based measurement of critical care nursing workload: unobtrusive measures of nursing activity complement traditional task and patient level indicators of workload to predict perceived exertion. *PLoS One* 13:e0204819. doi: 10.1371/journal.pone.0204819

Rosen, M. A., Dietz, A. S., Yang, T., Priebe, C. E., and Pronovost, P. J. (2015). An integrative framework for sensor-based measurement of teamwork in healthcare. *J. Am. Med. Inform. Assoc.* 22, 11–18. doi: 10.1136/amiajnl-2013-002606

Rosen, M. A., Wildman, J. L., Salas, E., and Rayne, S. (2012). "Measuring team dynamics in the wild," in *Research Methods for Studying Groups and Teams: A Guide to Approaches, Tools, and Technologies*, eds A. B. Hollingshead and M. S. Poole (New York, NY: Routledge), 386–417.

Rudolph, J. W., Foldy, E. G., Robinson, T., Kendall, S., Taylor, S. S., and Simon, R. (2013). Helping without harming. The instructor's feedback dilemma in debriefing–A case study. *Simul. Healthc.* 8, 304–316. doi: 10.1097/SIH.0b013e318294854e

Rudolph, J. W., Raemer, D. B., and Simon, R. (2014). Establishing a safe container for learning in simulation: the role of the presimulation briefing. *Simul. Healthc.* 9, 339–349. doi: 10.1097/SIH.0000000000000047

Rudolph, J. W., Simon, F. B., Raemer, D. B., and Eppich, W. J. (2008). Debriefing as formative assessment: closing performance gaps in medical education. *Acad. Emerg. Med.* 15, 1010–1016. doi: 10.1111/j.1553-2712.2008.00248.x

Rudolph, J. W., Simon, R., Rivard, P., Dufresne, R. L., and Raemer, D. B. (2007). Debriefing with good judgment: combining rigorous feedback with genuine inquiry. *Anesthesiol. Clin.* 25, 361–376. doi: 10.1016/j.anclin.2007.03.007

Salas, E. (2016). Team science in cancer care: questions, an observation, and a caution. *J. Oncol. Pract.* 12, 972–974. doi: 10.1200/jop.2016.018226

Salas, E., and Frush, K. (eds). (2013). *Improving Patient Safety through Teamwork and Team Training*. New York, NY: Oxford University Press.

Salas, E., Paige, J. T., and Rosen, M. A. (2013a). Creating new realities in healthcare: the status of simulation-based training as a patient safety improvement strategy. *BMJ Qual. Saf.* 22, 449–452. doi: 10.1136/bmjqs-2013-002112

Salas, E., Tannenbaum, S., Cohen, J., and Latham, G. (eds). (2013b). *Developing and Enhancing Teamwork in Organisations: Evidence-Based Best Practices and Guidelines*. San Francisco, CA: Jossey-Bas.

Sawyer, T., Eppich, W., Brett-Fleegler, M., Grant, V., and Cheng, A. (2016a). More than one way to debrief: a critical review of healthcare simulation debriefing methods. *Simul. Healthc.* 11, 209–217. doi: 10.1097/sih.0000000000000148

Sawyer, T., Loren, D., and Halamek, L. P. (2016b). Post-event debriefings during neonatal care: why are we not doing them, and how can we start. *J. Perinatol.* 36, 415–419. doi: 10.1038/jp.2016.42

Schein, E. H. (1993). How can organizations learn faster? The challenge of entering the green room. *Sloan Manag. Rev.* 34:85.

Schmid Mast, M., Gatica-Perez, D., Frauendorfer, D., Nguyen, L., and Choudhury, T. (2015). Social sensing for psychology: automated interpersonal behavior assessment. *Curr. Dir. Psychol. Sci.* 24, 154–160. doi: 10.1177/0963721414560811

Schmutz, J., Hoffman, F., Heimberg, E., and Manser, T. (2015). Effective coordination in medical emergency teams: the moderating role of task type. *Eur. J. Work Organ. Psychol.* 24, 761–776. doi: 10.1080/1359432X.2015.1018184

Schmutz, J. B., and Eppich, W. J. (2017). Promoting learning and patient care through shared reflection: a conceptual framework for team reflexivity in health care. *Acad. Med.* 92, 1555–1563. doi: 10.1097/acm.0000000000001688

Schön, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action*. New York, NY: Basic Books.

Schulz-Hardt, S., and Mojzisch, A. (2012). How to achieve synergy in group decision making: lessons to be learned from the hidden profile paradigm. *Eur. Rev. Soc. Psychol.* 23, 305–343. doi: 10.1080/10463283.2012.744440

Schwappach, D. L. B., and Gehring, K. (2014). Silence that can be dangerous: a vignette study to assess healthcare professionals' likelihood of speaking up about safety concerns. *PLoS One* 9:e104720. doi: 10.1371/journal.pone.0104720

Seelandt, J. C., Grande, B., Kriech, S., and Kolbe, M. (2018). DE-CODE: a coding scheme for assessing debriefing interactions. *BMJ Simul. Technol. Enhanc. Learn.* 4, 51–58. doi: 10.1136/bmjstel-2017-000233

Seelandt, J. C., Tschan, F., Keller, S., Beldi, G., Jenni, N., Kurmann, A., et al. (2014). Assessing distractors and teamwork during surgery: developing an event-based method for direct observation. *BMJ Qual. Saf.* 23, 918–929. doi: 10.1136/bmjqs-2014-002860

Seiffert, M., Conradi, L., Baldus, S., Schirmer, J., Blankenberg, S., Reichenspurner, H., et al. (2013). Severe intraprocedural complications after transcatheter aortic valve implantation: calling for a heart team approach. *Eur. J. Cardiothorac. Surg.* 44, 478–484. doi: 10.1093/ejcts/ezt032

Setz, C., Arnrich, B., Schumm, J., La Marca, R., Tröster, G., and Ehlert, U. (2010). Discriminating stress from cognitive load using a wearable EDA device. *IEEE Trans. Inf. Technol. Biomed.* 14, 410–417. doi: 10.1109/TITB.2009.2036164

Shah, S., Arora, S., Atkin, G., Glynne-Jones, R., Mathur, P., Darzi, A., et al. (2014). Decision-making in colorectal cancer tumor board meetings: results of a prospective observational assessment. *Surg. Endosc.* 28, 2783–2788. doi: 10.1007/s00464-014-3545-3

Snyder, J., Schultz, L., and Walbert, T. (2017). The role of tumor board conferences in neuro-oncology: a nationwide provider survey. *J. Neurooncol.* 133, 1–7. doi: 10.1007/s11060-017-2416-x

Soar, J., Mancini, M. E., Bhanji, F., Billi, J. E., Dennett, J., Finn, J., et al. (2010). Part 12: education, implementation, and teams. *Resuscitation* 81, e288–e332. doi: 10.1016/j.resuscitation.2010.08.030

Stachowski, A. A., Kaplan, S. A., and Waller, M. J. (2009). The benefits of flexible team interaction during crisis. *J. Appl. Psychol.* 94, 1536–1543. doi: 10.1037/a0016903

Stasser, G., and Titus, W. (1987). Effects of information load and percentage of shared information on the dissemination of unshared information during group discussion. *J. Pers. Soc. Psychol.* 53, 81–93. doi: 10.1037/0022-3514.53.1.81

Su, L., Kaplan, S., Burd, R., Winslow, C., Hargrove, A., and Waller, M. (2017). Trauma resuscitation: can team behaviours in the prearrival period predict resuscitation performance? *BMJ Simul. Technol. Enhanc. Learn.* 3, 106–110. doi: 10.1136/bmjstel-2016-000143

Tafe, L. J., Gorlov, I. P., de Abreu, F. B., Lefferts, J. A., Liu, X., Pettus, J. R., et al. (2015). Implementation of a molecular tumor board: the impact on treatment decisions for 35 patients evaluated at Dartmouth-Hitchcock Medical Center. *Oncologist* 20, 1011–1018. doi: 10.1634/theoncologist.2015-0097

Tangirala, S., and Ramanujam, R. (2012). Ask and you shall year (but not always): examining the relationship between manager consulting and employee voice. *Pers. Psychol.* 65, 251–282. doi: 10.1111/j.1744-6570.2012.01248.x

Tannenbaum, S. I., Beard, R. L., and Cerasoli, C. P. (2013). "Conducting team debriefings that work: lessons from research and practice," in *Developing and Enhancing Teamwork in Organizations: Evidence-Based Best Practices and Guidelines*, eds E. Salas, S. I. Tannenbaum, J. Cohen, and G. Latham (San Francisco, CA: Jossey-Bass), 488–519.

Tannenbaum, S. I., and Cerasoli, C. P. (2013). Do team and individual debriefs enhance performance? A meta-analysis. *Hum. Factors* 55, 231–245. doi: 10.1177/0018720812448394

Tannenbaum, S. I., and Goldhaber-Fiebert, S. (2013). "Medical team debriefs: simple, powerful, underutilized," in *Improving Patient Safety through Teamwork and Team Training*, eds E. Salas and K. Frush (New York, NY: Oxford University Press), 249–256.

Tannenbaum, S. I., Mathieu, J. E., Salas, E., and Cohen, D. (2012). Teams are changing: are research and practice evolving fast enough? *Ind. Organ. Psychol.* 5, 2–24. doi: 10.1111/j.1754-9434.2011.01396.x

The Center for Medical Simulation (2010). *Debriefing Assessment for Simulation in Healthcare (DASH)©. Rater's Handbook*. Available at: https://harvardmedsim.org/wp-content/uploads/2017/01/DASH.handbook.2010.Final.Rev.2.pdf (accessed September 23, 2013).

Thenappan, A., Halaweish, I., Mody, R. J., Smith, E. A., Geiger, J. D., Ehrlich, P. F., et al. (2017). Review at a multidisciplinary tumor board impacts critical management decisions of pediatric patients with cancer. *Pediatr. Blood Cancer* 64, 254–258. doi: 10.1002/pbc.26201

Thürmer, J. L., Wieber, F., Schultze, T., and Schulz-Hardt, S. (2018). "Hidden profile discussion coding," in *The Cambridge Handbook of Group Interaction Analysis*, eds E. Brauner, M. Boos, and M. Kolbe (Cambridge: Cambridge University Press), 565–574. doi: 10.1017/9781316286302.038

Tschan, F., Seelandt, J. C., Keller, S., Semmer, N. K., Kurmann, A., Candinas, D., et al. (2015). Impact of case-relevant and case-irrelevant communication within the surgical team on surgical-site infection. *Br. J. Surg.* 102, 1718–1725. doi: 10.1002/bjs.9927

Tschan, F., Semmer, N. K., Gautschi, D., Hunziker, P., Spychiger, M., and Marsch, S. U. (2006). Leading to recovery: group performance and coordinative activities in medical emergency driven groups. *Hum. Perform.* 19, 277–304. doi: 10.1207/s15327043hup1903_5

Tschan, F., Semmer, N. K., Gurtner, A., Bizzari, L., Spychiger, M., Breuer, M., et al. (2009). Explicit reasoning, confirmation bias, and illusory transactive memory. A simulation study of group medical decision making. *Small Group Res.* 40, 271–300. doi: 10.1177/1046496409332928

Tschan, F., Semmer, N. K., Hunziker, P. R., and Marsch, S. C. U. (2011a). "Decisive action vs. joint deliberation: different medical tasks imply different coordination requirements," in *Advances in Human Factors and Ergonomics in Healthcare*, ed. V. G. Duffy (Boca Raton, FL: Taylor & Francis), 191–200.

Tschan, F., Semmer, N. K., Vetterli, M., Gurtner, A., Hunziker, S., and Marsch, S. U. (2011b). "Developing observational categories for group process research based on task and coordination-requirement analysis: examples from research on medical emergency-driven teams," in *Coordination in Human and Primate Groups*, eds M. Boos, M. Kolbe, P. Kappeler, and T. Ellwart (Heidelberg: Springer), 93–118.

Tschan, F., Semmer, N. K., Hunziker, S., Kolbe, M., Jenni, N., and Marsch, S. U. (2014). Leadership in different resuscitation situations. *Trends Anaesth. Crit. Care* 4, 32–36. doi: 10.1016/j.tacc.2013.12.001

Undre, S., Sevdalis, N., Healey, A. N., Darzi, A., and Vincent, C. A. (2007). Observational teamwork assessment for surgery (OTAS): refinement and application in urological surgery. *World J. Surg.* 31, 1373–1381. doi: 10.1007/s00268-007-9053-z

Undre, S., Sevdalis, N., and Vincent, C. (2009). "Observing and assessing surgical teams: the observational teamwork assessment for surgery (OTAS)," in *Safer Surgery. Analysing Behaviour in the Operating Theatre*, eds R. Flin and L. Mitchell (Aldershot: Ashgate), 83–101. doi: 10.1201/9781315607436-6

Valentine, M. A., Nembhard, I. M., and Edmondson, A. C. (2015). Measuring teamwork in health care settings: a review of survey instruments. *Med. Care* 53, e16–e30.

Vankipuram, M., Kahol, K., Cohen, T., and Patel, V. L. (2011). Toward automated workflow analysis and visualization in clinical environments. *J. Biomed. Inform.* 44, 432–440. doi: 10.1016/j.jbi.2010.05.015

Vashdi, D. R., Bamberger, P. A., and Erez, M. (2013). Can surgical teams ever learn? The role of coordination, complexity, and transitivity in action team learning. *Acad. Manag. J.* 56, 945–971. doi: 10.5465/amj.2010.0501

Vincent, C., and Amalberti, R. (2016). *Safer Healthcare. Strategies for the Real World*. Heidelberg: Springer.

Wageman, R., Fisher, C. M., and Hackman, J. R. (2009). Leading teams when the time is right. Finding the best moments to act. *Organ. Dyn.* 38, 192–203. doi: 10.1016/j.orgdyn.2009.04.004

Wageman, R., Hackman, J. R., and Lehman, E. (2005). Team Diagnostic Survey: development of an instrument. *J. Appl. Behav. Sci.* 41, 373–398. doi: 10.1177/0021886305281984

Weaver, S. J., Sydney, M. D., and Rosen, M. A. (2014). Team-training in healthcare: a narrative synthesis of the literature. *BMJ Qual. Saf.* 23, 359–372. doi: 10.1136/bmjqs-2013-001848

Weiss, M., Kolbe, M., Grote, G., Spahn, D. R., and Grande, B. (2017a). We can do it! Inclusive leader language promotes voice behavior in multi-professional teams. *Leadersh. Q.* 29, 389–402. doi: 10.1016/j.leaqua.2017.09.002

Weiss, M., Kolbe, M., Grote, G., Spahn, D. R., and Grande, B. (2017b). Why didn't you say something? Using after-event reviews to affect voice behavior and hierarchy beliefs in multi-professional action teams. *Eur. J. Work Organ. Psychol.* 26, 66–80. doi: 10.1080/1359432X.2016.1208652

West, M. A. (2004). *Effective Teamwork. Practical Lessons from Organizational Research*, 2nd Edn. Oxford: BPS Blackwell.

West, M. A., Markiewicz, L., and Dawson, J. F. (2006). *Aston Team Performance Inventory: Management Set*. London: ASE.

Woolley, A. W., Aggarwal, I., and Malone, T. W. (2015). Collective intelligence and group performance. *Curr. Dir. Psychol. Sci.* 24, 420–424. doi: 10.1177/0963721415599543

Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., and Malone, T. W. (2010). Evidence for a collective intelligence factor in the performance of human groups. *Science* 330, 686–688. doi: 10.1126/science.1193147

Yule, S., Flin, R., Paterson-Brown, S., Maran, N., and Rowley, D. (2006). Development of a rating system for surgeons' non-technical skills. *Med. Educ.* 40, 1098–1104. doi: 10.1111/j.1365-2929.2006.02610.x

Zijlstra, F. R. H., Waller, M. J., and Phillips, S. I. (2012). Setting the tone: early interaction patterns in swift-starting teams as a predictor of effectiveness. *Eur. J. Work Organ. Psychol.* 21, 749–777. doi: 10.1080/1359432X.2012.690399

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Kolbe and Boos. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

HYPOTHESIS AND THEORY
published: 03 July 2019
doi: 10.3389/fpsyg.2019.01441

Beyond Separate Emergence: A Systems View of Team Learning Climate

Jean-François Harvey[1], Pierre-Marc Leblanc[2] and Matthew A. Cronin[3]*

[1] HEC Montréal, Montreal, QC, Canada, [2] Université de Montréal, Montreal, QC, Canada, [3] George Mason University, Fairfax, VA, United States

In this paper, we consider how the four key team emergent states for team learning identified by Bell et al. (2012), namely psychological safety, goal orientation, cohesion, and efficacy, operate as a system that produces the team's learning climate (TLC). Using the language of systems dynamics, we conceptualize TLC as a stock that rises and falls as a joint function of the psychological safety, goal orientation, cohesion, and efficacy that exists in the team. The systems approach highlights aspects of TLC management that are traditionally overlooked, such as the simultaneous influence of and feedback between the four team emergent states and the inertia that TLC can have as a result. The management of TLC becomes an issue of controlling the system rather than each state as an independent force, especially because changing one part of the system will also affect other parts in sometimes unintended and undesirable ways. Thus the value is to offer a systems view on the leadership function of team monitoring with regards to team emergent states, which we term *team state monitoring*. This view offers promising avenues for future research as well as practical wisdom. It can help leaders remember that TLC represents an equilibrium that needs balance, in addition to pointing to the various ways in which they can influence such equilibrium.

Keywords: team learning, systems view, team emergent states, team leadership, team dynamics, team monitoring

OPEN ACCESS

Edited by:
Eduardo Salas,
Rice University, United States

Reviewed by:
Georgia T. Chao,
Michigan State University,
United States
Jennifer Feitosa,
Claremont McKenna College,
United States

****Correspondence:***
Jean-François Harvey
jfharvey@hec.ca

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *07 March 2019*
Accepted: *04 June 2019*
Published: *03 July 2019*

Citation:
Harvey JF, Leblanc PM and Cronin MA (2019) Beyond Separate Emergence: A Systems View of Team Learning Climate. Front. Psychol. 10:1441. doi: 10.3389/fpsyg.2019.01441

INTRODUCTION

Team emergent states are defined in terms of beliefs that team members hold about the team's goals, team member abilities, and interpersonal norms. They emerge early after team formation and continue to develop over time as the team's work unfolds (Marks et al., 2001; Cronin et al., 2011; Edmondson and Harvey, 2018). They tend to stabilize as beliefs become relatively coherent across team members (Kozlowski and Chao, 2012), ultimately guiding behaviors within the team (e.g., Edmondson, 1999). Yet their emergence is described as dynamic because they form in response to experiences and observations of team member interactions, and these experiences and observations both shape and are shaped by the accumulating beliefs. We know a fair amount about what makes particular team states emerge, and how team leadership can influence such emergence (e.g., Edmondson and Harvey, 2017), but we know significantly less about the feedback among team states when they are linked as a system, and what this means for team leadership seeking to control that system.

In this paper, we focus on team learning because it is one of the most critical team processes, and team leaders have significant impact on creating conditions that support it (Koeslag-Kreunen et al., 2018). We draw from Bell et al. (2012) to consider four key emergent states for team learning, namely psychological safety, goal orientation, cohesion, and efficacy, and we argue that collectively these states bring about the team's learning climate (TLC). We conceptualize TLC as a capacity that rises and falls as a joint function of the psychological safety, goal orientation, cohesion, and efficacy that exist in the team. If the four emergent states can increase or decrease the level of TLC, then collectively TLC can be conceptualized as a control system (cf. Vancouver, 2005). If the level in any one component of the system (e.g., cohesion) affects but is also affected by other components (e.g., psychological safety), then there is feedback in this system. If the levels of a component can persist over time, then there is inertia. It is these two conditions that make a system dynamic (Cronin and Vancouver, 2018), and dynamics increase the challenge of maintaining control of a system (Cronin et al., 2009).

Because leadership activities may influence multiple team emergent states at once, it is fundamental to take a systems view (Sterman, 2000) of how the various states affect the rates of increase and decrease to TLC. It is when leaders are conscious of their influence on emergent states as a system that they come to realize that their interventions can simultaneously affect the various parts of the system in distinct ways (Shuffler et al., 2018), or that their interventions can have little impact because of the inertia found in the system (Ericksen and Dyer, 2004). A focus on one particular emergent state to the exclusion of others is often why practices intended to help wind up being net negative (Sterman, 2000). Leaders can overlook the side effects that would be visible had they taken a broader view of the entire system. This is particularly important in teams because most teams encounter turbulences, and it is during turbulences that their leaders intervene. It is also during such times that a leader's focus can narrow (Staw et al., 1981).

The systems view helps further elaborate on the leadership function of team monitoring. Functional leadership doesn't prescribe individual traits to good or bad leaders, but rather informs on the interventions required to satisfy team needs. The core idea is not to emphasize "what leaders should do" but rather "what needs to be done for effective performance" (Hackman and Walton, 1986, p. 77). From this perspective, team leadership is about identifying and solving problems with the aim of ensuring team effectiveness. Team monitoring is a key leadership function that refers to examining a team's internal activity, progress toward the achievement of the team task, and its environment (Morgeson et al., 2010). While some studies have examined the relationship between team monitoring and team learning—e.g., both De Jong and Elfring (2010) and Otte et al. (2017) have shown the positive and significant relation between team monitoring and team reflexivity (reflexivity is a learning process)—the emergent states described as part of TLC have not been considered in any of these studies. Our systems approach helps provide an understanding of how team states influence TLC, and how TLC can be effectively controlled over time. Thus monitoring TLC is better understood when we view teams as systems where inertia and feedback inform leadership.

Specifically, we propose that *team state monitoring* is a key leadership function that encompasses the routine evaluation of how a team evolves to identify and correct dysfunctional imbalances in a collection of team states. Because we take a systems view of team emergent states' development, we not only focus on how changes to one state might propagate throughout the system, we also consider the unintended consequences that can be created as leaders attempt to manage these states. We argue that monitoring is effectively the means to manage TLC over time, but such monitoring can be myopic and lead to actions that enhance one part of the system while degrading others. It can be beneficial, however, when leaders take a systems view.

In the sections that follow, we review the literature on team emergent states and team learning to develop a systems view of TLC. Then, we operationalize this view through a vignette that helps illustrate why it matters for team leadership before deepening the notion of team monitoring as a leadership function. This takes us to a discussion of team state monitoring and its implications for team research and leadership practice.

TEAM LEARNING CLIMATE

Since the seminal work of Senge (1990), learning has become a central part of the literature in management (Huber, 1991; Edmondson, 2002; Wilson et al., 2007). Many researchers and practitioners have adopted Senge's view that organizations need to learn in order to achieve and maintain superior performance. His argument is that fixed commitment to a leader's vision is ultimately a bad strategy. The business environment inevitably changes over time, and thus organizations need to be able to adapt. As a result, Senge advocates for developing reflection and inquiry skills throughout the organization, hence facilitating the continuous emergence of new ways of thinking. Organizations are then better able to adapt quickly and effectively by matching (or creating) radical changes in their environment. He argues that work teams are a key unit for such learning to occur in organizations because learning begins with dialogue, a dialogue that allows individuals to make sense of complex situations and discover insights not attainable individually. Team learning has since been studied extensively in organizational behavior to explain team effectiveness.

Edmondson et al. (2007) find three perspectives on team learning in the literature, and each one of them considers features of TLC to be important. The first one, outcome improvement, examines the progression that teams go through as they gain cumulative experience performing the same set of tasks. The outcome improvement research shows clearly that teams learn at a different rate, and such differences have been attributed to various factors, such as team composition stability

(Edmondson et al., 2003) or communication networks (Argote et al., 2018), and the learning climate (Edmondson et al., 2001). These studies demonstrate that team performance increases over time as teams learn how to improve their coordination (Reagans et al., 2005).

The second perspective, task mastery, suggests that team learning occurs when teams develop shared knowledge about each other and the task during the process of discussing and coordinating effort. Teams are seen as information-processing systems that may be better or worse at encoding, storing, retrieving, and communicating knowledge (Hinsz et al., 1997; Wilson et al., 2007). Better teams are said to develop a more elaborate "transactive memory system," which enhances performance on interdependent tasks (Liang et al., 1995). For instance, Ellis and colleagues define team learning as "the team's collective level of knowledge and skill produced by the shared experience of the team members" (Ellis et al., 2003, p. 822). Interventions that involve training team members together on the task (e.g., Moreland et al., 1996) and facilitating face-to-face communication (Lewis, 2004) are demonstrative of this perspective on team learning. Scholars also find that the learning climate is a factor to consider in teams developing such shared knowledge (Hammedi et al., 2013).

Finally, the third perspective defines team learning in terms of the activities of the learning process instead of its outcomes. It is deeply rooted in the input-process-output (IPO) model first developed by McGrath (1964). In this model, team member behaviors and interactions are the processes that transform input conditions into performance outputs (e.g., Hackman and Morris, 1975). As such, team learning comprises many different sorts of learning behaviors that reflect the particular needs and goals of the specific team (Edmondson, 2002). They include four behaviors: (a) building prototypes, drawing sketches, and running trials (e.g., Lee et al., 2004), (b) questioning goals or methods to reach them, suggesting alternatives, reflecting on new information (e.g., West, 1996), (c) engaging with experienced others outside the team (e.g., Bresman, 2010), and (d) seeking information about the environment (e.g., Ancona and Caldwell, 1992). Put together, these behaviors take place inside or outside the team, and may serve exploration or exploitation purposes (see Harvey et al., 2018). In this paper, we focus on learning behaviors that take place inside the team because they are more dependent on TLC (e.g., Wong, 2004).

Drawing on these three perspectives, we define team learning as team members' behaviors related to processing knowledge that allows the team to improve. We argue that while team leaders can control inputs, they actually spend most of their time managing processes as they change in response to alterations in tasks and environment. In other words, individuals are the agents of learning, and the agents that initiate team learning. Because of that, leaders do not really affect the individuals as much as they set up conditions that enable individual/team learning. This is why Senge (1990) suggests that leaders in organizations should first and foremost enable individuals to adopt learning behaviors within their respective teams. Such enabling conditions usually relate to the beliefs that are shared by team members with regards to the team and its task, which have been termed "team emergent states."

Key Team Emergent States in Support of Team Learning

A lot of the scholarly conversation on team learning focuses on understanding the conditions that facilitate learning in teams; that is, the states that emerge over time as individuals engage in teamwork and facilitate or constrain learning behaviors. The distinction between states and processes was a critical step toward understanding the dynamics of teamwork. As Marks et al. (2001) have argued, the conditions of states are what influence a team and can persist over time. For example, the level of trust today will maintain itself over time until some other process changes that level. States allow explicit consideration of inertia in contrast to processes, like communication, that only affect the team when they are engaged and thus do not have inertia. The levels in the states alter the processes that take place in the team. Continuing with our example, a high level of trust may lead to more frequent and open communication, while a low level would make communication less frequent and more guarded. Processes also change states, so the open communication may further increase the level of trust. Taken together, Marks et al. (2001) highlight the feedback between states and processes that affect the dynamics of team conditions over time.

While Marks and colleagues' model has offered a conceptual path toward further precision in the exploration of team dynamics, much of the research that has followed does not take advantage of these. Most research focuses on the substance of emergent states, and largely studies them as moderators of other relationships without considering how they emerge and evolve in the first place (Waller et al., 2016). In particular, the ways in which emergent states dynamically interact with each other to explain certain team outcomes remains underexplored (Cronin et al., 2011), despite research demonstrating their joint effects in creating pathways that spur team learning (Harvey et al., in press). Before we can describe such dynamic interrelationships, we must briefly review the functionality of the four emergent states that have received most attention in team learning scholarship—psychological safety, goal orientation, efficacy, and cohesion (Bell et al., 2012), summarized in **Table 1**. It is the fact that each emergent state has a different functionality but that these states may jointly affect common processes that justifies the need to consider them as a dynamic system.

Psychological Safety

Edmondson (1999) has examined team psychological safety – the shared belief that a team is a safe place to take interpersonal risks – as a variable that would affect team learning. She has shown that learning behaviors translate effective team leadership into performance outcomes when team members feel able to question assumptions and discuss difficult issues. For instance, engaging in trial-and-error experimentation is extremely difficult when there is a sense that team members' participation is being scrutinized or evaluated because chance of success is uncertain and failure is a strong possibility (Lee et al., 2004). The open

TABLE 1 | Team emergent states, influences on team learning, and supportive leadership practices.

Team emergent state	Psychological safety	Goal orientation	Cohesion	Efficacy
Definition	The shared belief that the team is safe for interpersonal risk taking.	The shared belief of the extent to which a team emphasizes learning or performance goals.	The shared belief of commitment from team members to the task or to each other.	The shared belief that the team can successfully perform the task.
Influences on team learning	Moderate to high levels of psychological safety influence positively the adoption of learning behaviors.	Moderate to high levels of learning orientation influence positively the adoption of learning behaviors. High levels of learning orientation can be ineffective because teams mistakenly abandon effective strategies to pursue novel ones. Moderate to high levels of performance orientation negatively influence the adoption of team learning behaviors.	Moderate to high levels of cohesion influence positively the adoption of learning behaviors. High levels of cohesion can negatively influence the adoption of learning behaviors because teams suffer from groupthink.	Moderate to high levels of efficacy influence positively the adoption of learning behaviors. High levels of efficacy can negatively influence the adoption of learning behaviors because teams succumb to overconfidence and complacency.
Supportive leadership practices	Displaying genuine interest in team member's particular needs and challenges in completing the task. Inviting and showing appreciation for others' contributions. Creating clear structures. Establishing shared rewards.	Offering feedback on behaviors or reward certain outcomes. Encouraging discussion of opposing views.	Explicating shared values and articulating the team goal. Shaping leader-member relationships in ways that lower perceptions of differentiation. Requesting task-relevant information, pointing to flaws in task procedures, and questioning the team's output.	Displaying the belief that one is capable of achieving good performance. Designing the team's work in order to achieve early wins.

discussion of errors, just as voicing ideas and concerns, requires a psychologically safe environment that encourages team members to engage in candid conversation focused on improving team task performance (Carmeli and Gittell, 2009), instead of succumbing to defensive routines such as self-censoring (Argyris, 1990).

Today, psychological safety is the most common emergent state studied in relation to team learning (Sanner and Bunderson, 2015). It has been shown to have a positive relationship with team learning in a great variety of settings (for reviews, see Edmondson and Lei, 2014; Newman et al., 2017). Companies as influential as Google have pointed to psychological safety as the most important feature of high-performing work teams (Duhigg, 2016).

Leaders can nurture psychological safety by inviting and showing appreciation for others' contributions (Nembhard and Edmondson, 2006), creating clear structures (Bresman and Zellmer-Bruhn, 2013), and establishing shared rewards (Chen and Tjosvold, 2012). Edmondson and Harvey's (2017) multiple case study of extreme teaming projects also offers an in-depth account of what leaders can do to foster rapport that gives rise to psychological safety. The authors find that successful project leaders are not solely focused on task completion and project progress when they interact with team members, but also display genuine interest in team members' needs and challenges in completing the task.

Psychological safety should be thought of as having inertia. It is a belief that builds over time (Edmondson, 1999), and while behaviors can subtract from its level, the prior level should persist over time. For example, one angry outburst at a team member for a mistake would not destroy all psychological safety, though it would probably reduce the level (Edmondson, 2018). Also, a team that was temporarily disbanded and then re-assembled would be unlikely to restart from zero in terms of expectations about psychological safety.

Goal Orientation

Drawing on the work of Dweck (1986) and others (e.g., Button et al., 1996; VandeWalle, 1997) on individuals' psychological traits, Bunderson and Sutcliffe (2002, 2003) have shown that teams may approach achievement situations from two angles: learning and performance. When teams are oriented toward learning, their members take a proactive approach to solving new, complex problems and are more likely to engage in behaviors that facilitate learning (Alexander and Van Knippenberg, 2014). Since they are not particularly interested in relying on prior capabilities, these teams invest considerable time and energy in planning their work (Mehta et al., 2009) and their members continue to exchange information with each other during execution (Gong et al., 2013). In contrast, in achievement situations where teams are oriented toward performance, novel or puzzling insights tend to prompt irritation or discomfort rather than enthusiasm, because they undermine the team's strongly rooted commitment to the collective expression of competence and the favorable judgment that comes with it (Mehta and Mehta, 2018). Mistakes are far less welcome on such teams, since they prize concrete progress or tangible results. For instance, highly performance-oriented teams are unlikely to continue

pursuing radical innovation after they encounter challenges, because they realize that doing so increases their chances of failure (Alexander and Van Knippenberg, 2014).

Leadership influences the emergence of a learning or performance orientation on teams. Dragoni and Kuenzi (2012) show that the leader's individual goal orientation influences that of the team. Leaders are likely to induce learning or performance orientation when they offer feedback on behaviors or reward certain outcomes (Alexander and Van Knippenberg, 2014). For their part, Chen et al. (2011) show that leaders facilitate the emergence of a learning orientation by encouraging discussion of opposing views, while Bunderson and Boumgarden (2010) show that conflicts and disagreements between team members reduce the odds that a learning orientation will emerge within the team.

While some team research treats goal orientation as a team composition variable (an input in the ISPO model) (e.g., LePine, 2005; Porter, 2005), the research above along with several other team studies (e.g., DeShon et al., 2004; Mehta et al., 2009) conceptualize it as a team emergent state. The reason to conceptualize goal orientation as a state is that while individuals may have goal orientations when they join a team, such individual orientations are not immediately manifest by the collective, and the collective level may change over time given leadership behaviors and incentives (Dragoni and Kuenzi, 2012). Again, because team goal orientation is an intangible property, individuals' beliefs about it are more likely to have inertia. We could also imagine team factions that diverge in their goal orientations; it would make goal orientation more "compilational" in structure (Klein and Kozlowski, 2000), but it would still make it a state with inertia.

Cohesion

Team cohesion, defined as the shared belief or commitment from team members to the task, or to each other, has been extensively studied (Beal et al., 2003). Both the integration or "bonding" of individual team members into the group (social cohesion) as well as their desire to accomplish the team task (task cohesion) have been argued to increase team members' willingness to invest time and energy within the team (Hackman, 1990). This is important for team learning because adopting learning behaviors is demanding for team members (Edmondson, 2003; Edmondson and Harvey, 2018).

Leaders can play a significant role in influencing the degree of cohesion in teams. Edmondson and Harvey (2017) find that leaders may facilitate its development by explicating shared values in articulating the team goal. Similarly, Chiniara and Bentein (2018) show that shaping leader-member relationships in ways that lower perceptions of differentiation positively influences team cohesion. The degree of participation from team members in key facets of the team endeavor is another factor that affect team cohesion (Bergman et al., 2012) and that leaders can enable. Leaders can also strategically request task-relevant information, point out flaws in task procedures, and question the team's output. Monitoring task complexity in such a way brings team members together (Kane et al., 2002).

Once again, because cohesion takes time to build (Mathieu et al., 2015) and is stored in individuals' beliefs, we posit that it will not necessarily dissipate without some event and that it has inertia. However, such a state may have the possibility for more drastic change in a moment than, for example, goal orientation (which is rooted in individual proclivities). For example, some huge violation or betrayal by team members could destroy team cohesion (Mach et al., 2010). Yet the level of cohesion would move from its prior level to the new level, meaning that cohesion at time t+1 is a function of the event plus cohesion's level at time t. This is how one operationalizes inertia (Cronin and Vancouver, 2018).

Efficacy

Researchers have theorized that team members' confidence in their capability *vis-á-vis* one particular task—team efficacy—is an important determinant of team performance (e.g., Gibson and Earley, 2007). This is primarily due to the fact that team members are more likely to engage in learning behaviors when they share a belief that the team can do anything it sets out to accomplish (Edmondson, 1999). As a result, teams that rate high on efficacy are prone to persist in the face of a challenging goal, and even tend to push themselves to surpass such a goal when they come close to achieving it (Gully et al., 2002).

Research has shown how leadership can enable team efficacy. For instance, one way is to embody the belief that the team is capable of achieving good performance—especially shortly after team formation, since teams have little information to support such assessments (Pescosolido, 2001). Likewise, designing the team's work in order to achieve early wins is another way for leaders to facilitate the emergence of team efficacy (Lester et al., 2002). Finally, leaders can closely monitor goal achievement to counter the negative effects associated with high levels of team efficacy (Rapp et al., 2014).

Efficacy can be said to be rooted in individuals' beliefs (Bandura, 1997). Like goal orientation, such beliefs aggregate and can be focused on teams, and team scholars have picked up on this assumption (Gully et al., 2002). Also like goal orientation, they can represent proclivities and habits. They too are likely to have inertia, and to have a persistent influence on individual and team activities even when such beliefs are not actively being discussed. Efficacy thus fits the profile of a construct with inertia.

Interplay Among Team Emergent States

Each of these four emergent states contributes significantly to team learning. However, they have usually been studied in isolation from each other. There are two reasons to be concerned about this. The first is that when it comes to the levels of team states, it is not always "more is better." For example, high levels of cohesion have detrimental effects due to increased pressure for conformity (Lott and Lott, 1965; Hackman, 1976). Alternately, if team members believe *too* strongly in their ability to accomplish a task (efficacy), theory suggests that they can succumb to overconfidence and complacency (Gist, 1987). They tend to make poorer decisions by taking uncalculated risks, spending less time on information-processing activities, and rejecting negative feedback (Whyte, 1998). While such curvilinear relationships have not been investigated with respect to psychological safety, it would not be hard to imagine a team where effectiveness suffers

because mistakes are so welcome. Similarly, there are contexts where performance orientation is more appropriate (Alexander and Van Knippenberg, 2014). The bottom line is that each emergent state has an optimum setting that may change with task and context.

This leads to the second point, efforts to influence one state may affect the utility of the others. For example, moderate level of team efficacy is recommended for teams to engage in learning behaviors that enhance performance (e.g., Tasa and Whyte, 2005), unless they monitor their goal closely—then, high level of team efficacy is beneficial (Rapp et al., 2014). Such contingencies mean that beneficial effects of one state might be counteracted by negative effects on another. It would explain why some researchers find a positive relationship between cohesion and team learning (e.g., Schippers et al., 2008), and others find no relationship (e.g., van Ginkel and van Knippenberg, 2008). What is unknown is whether some attempts to increase cohesion might not cancel out the benefits by also increasing a negative effects like groupthink (Janis, 1972). The bottom line is that if team emergent states affect each other, then research needs to address how to manage an equilibrium among them in order to maximize positive behaviors and outcomes such as learning in teams. We lack such an understanding of how the four team emergent states *collectively* influence team learning.

Research on the dynamics of teams is still in its infancy (Bowers et al., 2017), and conceptual work must therefore take a step forward and develop more dynamic models of team learning (Bell et al., 2012). Inertia is a foundation for dynamics – without inertia there is no way for the past to influence the future (Cronin and Vancouver, 2018). Above we have discussed why each emergent state could exhibit inertia. Yet to truly understand the *dynamics* of TLC, we must consider the feedback loops within the system. That is, how the change to emergent states produced by some leadership action may set into motion a causal chain that loops back to perpetuate or even reinforce the current conditions. Such feedback loops can diminish the intended effect of leaders' actions or even worsen the problem via unintended consequences. What leaders really need to do is to promote virtuous cycles within the system. In all cases, one cannot control a system by focusing only on one part of it (i.e., one emergent state).

To be clear, when we discuss feedback, we are talking about circular chains of causality (Cronin and Vancouver, 2018). Feedback loops are what Marks et al. (2001) and others (e.g., Ilgen et al., 2005) have recognized as inherent in teams: An "output" at time 1 becomes the "input" at time 2. Such feedback is how non-linear growth and change can continue within a system even after a leadership action (or any other process intended to affect the team) has stopped. Feedback when coupled with inertia is also how systems as a whole resist change. To articulate how to control systems with inertia and feedback, it is often helpful to model them as *stock and flow systems* (Forrester, 1968). A stock is like a tank that maintains its water level over time unless it is filled or emptied. Thus it has inertia like other emergent states. But importantly, the stock and flow structure highlights that what causes TLC to increase may not be what causes it to decrease—the inflow to TLC can represent a different set of processes or actions from the outflow (Cronin and Vancouver, 2018).

This decoupling of inflows from outflows allows for greater prediction and control of TLC both within and between emergent states. For example, efficacy opens the inflow to TLC, for example, by increasing the motivation to perform. Yet after a certain point, efficacy might also open the outflow to TLC as well, albeit through a different process such as the discarding of new knowledge (i.e., "our way works, why would we change it?"). Such a characterization still fits with the conceptualization of efficacy, but it suggests that to control the system a leader should focus on counteracting the tendency to ignore new knowledge. The broader point is that the emergent states act as a collective to alter the inflow and outflow to TLC.

The systems view implies that to truly understand how leadership can manage TLC, research must conduct studies that will simultaneously monitor the equilibration among the different emergent states. To use another analogy, consider a vegetable garden. To achieve the highest yield, the gardener must balance soil quality, sunlight, watering, and pest control. The relative levels of all these factors in concert determine the garden's potential to produce a healthy crop. Moreover, addressing one factor might influence another (e.g., using pesticides might impair soil quality). Further, the relationships are not linear: Some watering is needed, but not too much, and this also depends on the amount of sunshine. TLC is like the yield of the garden. It represents the team's potential to learn effectively, based on the current levels of the important factors that support or inhibit team learning. In many ways, leaders must be capable gardeners.

Figure 1 provides a more graphical illustration of the kinds of questions a systems view would warrant, and why these would be useful. The bottom of **Figure 1** shows the stock of TLC with a single inflow and a single outflow, the arrows with hourglass symbols. Based on what we know about team learning, the inflow would represent experimentation and reflection processes (those that increase knowledge), while the outflow might represent forgetting and discounting processes (those that reject new knowledge). The emergent states are represented above the inflow and outflow arrows, and these have the capacity to influence each other as well as to open or close the flows. For simplicity, let us focus on psychological safety, and let us further assume that leaders are going to attempt to increase psychological safety through policy about the importance of always speaking up. The direct effect (represented by the bold arrow to the TLC inflow) should increase the rate of speaking up, which will encourage others in the team to do so as well, thus increasing the stock of TLC. Such an immediate effect can be tested and verified, but if one ignores the longer term effects, the understanding of the utility of this policy is incomplete.

For one thing, thinking about the growth of TLC over time leads one to realize that it would not be reasonable to expect that psychological safety will increase TLC forever. There is likely to be some control function, possibly emanating from the limits on psychological safety itself, that could eventually cause diminishing returns on the accumulation of TLC. We might conjecture that people will get used to the policy of speaking

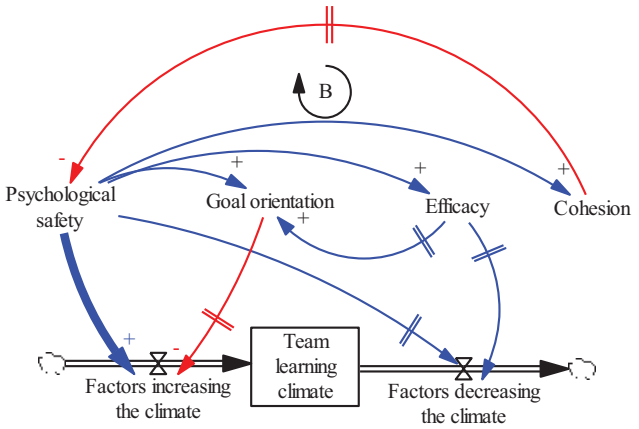

FIGURE 1 | Dynamic model of team learning climate. Note that this model conforms to systems dynamics modeling conventions (Sterman, 2000). Boxed variables are stocks, and the hourglass shapes are flows. Cloud shapes represent factors exogenous to the model. Causal influence arrows are all directional, and denote either positive (blue) or negative (red) relationships. Arrows with "| |" on the stem denote delayed influence (e.g., it may take time before goal orientation starts to influence the team learning inflow).

up, and thus its influence on behavior will fade over time as it becomes taken for granted. Alternately, after a certain point, psychological safety may start to decrease TLC if teammates feel no need to consider their ideas before voicing them; it may lead to a kind of information overload. This kind of influence is represented by the arrow from psychological safety to the outflow of TLC, and may only emerge after psychological safety grows to a certain point, which is why there is a delay mark (| |) on the arrow.

As we discussed above, psychological safety can affect or be affected by the other states as well (Harvey et al., in press). These would be represented by the other curved arrow in **Figure 1**. Perhaps more important is that such effects can be delayed and can have second and even third order effects on TLC (i.e., the effect of psychological safety on TLC goes through two or three pathways). Consider first that while psychological safety can increase cohesion, as cohesion grows beyond a certain point it may increase conformity pressures which loopback to limit psychological safety (Kahn, 1990; Edmondson, 2018). This is a balancing loop (denoted by B). This would be another way that the impact of the policy that encourages speaking up might fade over time (as cohesion grows).

Sometimes the second order effects are harder to identify. Psychological safety may lead to increased efficacy, and as we discussed above, this might lead to overconfidence that decreases TLC as team members reject new knowledge (Rapp et al., 2014). This effect might also be delayed (represented by the two perpendicular lines on the arrow) because efficacy takes time to grow. However, once the effect of overconfidence surfaces and TLC starts to decrease, it may cause leaders to try to further increase psychological safety. Yet this will not fix the problem, and because of the delay between the change to psychological safety and the effect of overconfidence, leaders might overlook efficacy as the cause of the problem.

As the feedback loops get longer and causes and effects become more distal in time, the potential for perverse outcomes increases. Continuing with our example, if psychological safety improves efficacy, it might eventually change the goal orientation to a performance one (especially if performance is rewarded and the team gets used to "winning"). This is a second order effect that might produce the third order effect whereby performance orientation reduces the willingness to experiment and possibly fail, thus shutting the TLC inflow.

The important point about a systems view is that all of these things may co-occur. Thus, while initially psychological safety is a boon to TLC, over time its influence becomes more limited because of increased cohesion, and possibly even detrimental if the dark side of efficacy and goal orientation takes over. Managing this system thus requires managing all four emergent states, not just one.

TEAM STATE MONITORING

We posit that TLC is produced and maintained by the joint effects of psychological safety, learning orientation, cohesion, and efficacy; they collectively affect team members' engagement in learning behaviors. Team leaders have been shown to influence each of these emergent states (e.g., Edmondson and Harvey, 2017), but the emergent states operate as part of a system. In **Figure 1** we described how leadership actions targeted at any one emergent state can have multiple, and sometimes unintended, consequences. To further illustrate this interplay and the collective influence of the emergent states that bring about TLC, we use a vignette of a teamwork situation where a leader attends to team needs, influencing subsets of TLC and, as a result, team learning.

We use the vignette to draw from the systems view in relation to TLC in order to extend the leadership function of team monitoring to *team state monitoring*. Team state monitoring brings the essential lessons of the systems view (i.e., inertia, feedback loops, etc.) together in an operational

theory of TLC. This is useful because team research has been almost silent about the monitoring of a set of emergent states as an equilibrium that needs balance, and the various ways in which leaders can influence such equilibrium. Even though team monitoring has been shown to have a positive effect on some emergent states when taken separately (LePine et al., 2008), the original focus of these studies has not been the monitoring of emergent states *per se*, let alone the dynamic interplay found in the equilibrium such as the one that TLC represents. As argued above and further illustrated in the vignette that follows, a leader's action intended to enhance one emergent state may also influence the trajectory of several others.

As presented above, team learning is conceptualized as the behaviors team members adopt internally such as experimenting and reflecting, which help the team transform inputs such as new team members or a novel task environment into performance outputs. This cycle creates dynamics that can affect TLC. The vignette in **Box 1** illustrates what leaders should consider if they are to be capable gardeners, cultivating team learning.

BOX 1 | The challenge of team state monitoring.

This vignette concerns a team of five nurses with a reputation for taking on new challenges to improve quality of care. One winter, the hospital faces an influx of new patients, and the team is asked to integrate two young newcomers to deal with it. During a team meeting, the two new nurses appear nervous as the rest of the team skim through the workload, and make adjustments to implement a new procedure. As the team disperses, its manager overhears senior members sharing doubts regarding the team's ability to deal with the increased demands, since the new recruits are so inexperienced. Over the next few days, several problems crop up. Team members seem to lack the drive to deal with the heavy workload. The manager, noticing the drop in performance, decides to join the next team meeting in the hope of instilling some self-belief.

In the meeting, the manager quickly realizes that the team is experimenting with a new procedure. Thinking that such a change may be too challenging for the new recruits, she takes over. She underlines the exceptional workload the team is facing and the importance of showing full competence during such peaks. She highlights the monetary incentives management offer for good performance, and lists the strengths that should help the team succeed. A team member interjects to list the benefits of the new procedure, but the manager dismisses her point. She reiterates the experience and knowledge of the team, maintaining that it has everything it needs to deliver right away. Her words seem to energize the team members as they prepare for their next shift. The team channels its energy toward getting the job done, and proves equal to the surge in patients. Over the next few weeks, team members continue to pay close attention to the performance indicators, and start receiving accolades. The atmosphere within the team is changing, as nobody wants to report a mistake that would affect team performance. Some members start "forgetting" to report certain errors. Months later, management trials a digital technology aimed at improving global health by syncing information across organizations. Due to its exemplary performance, the team is chosen for the "pilot." The manager invites the team to use the technology even if it makes things difficult at first, emphasizing the benefits for patients. The team members nod in agreement. On the ward, however, none of them is particularly excited about experimenting with the new technology, and they avoid it whenever they can. If they made mistakes, it would affect team performance—and nobody wants that. Unsurprisingly, the manager learns little from the pilot. Thus, she ends the next meeting by urging the team to give her feedback so she can adjust things before rolling out the technology. Yet, very little changes the following week...

This vignette shows a team with a strong learning orientation that struggles to integrate newcomers while dealing with a particularly demanding workload, and therefore starts doubting its capability to improve. The leader intervenes to enhance the team's shared belief of efficacy, but in doing so she also impacts the goal orientation of the team (performance starts overriding learning) and psychological safety (team members are now afraid to speak up or report mistakes that would affect short-term performance). While the team can handle the additional workload, the increase in efficacy is ultimately detrimental to TLC. The team may be less prepared to adopt new routines than it was before the leader's intervention, meaning that they fail to learn continuously and improve the quality of care at the hospital. Worse, if performance suffers, newcomers may be blamed (e.g., "We were innovators until *they* showed up!").

Using the systems view, we can model how this particular system might evolve in unexpected ways should the leader not monitor the four emergent states simultaneously. We display this in **Figure 2**. The exogenous shock of the higher workload and new team members reduces efficacy, and the leader responds to correct this. She continues to bolster efficacy (the positive link), and as it duly increases, she can scale back her intervention (the negative link). This is a type of self-efficacy control system, except the leader is the driver, rather than performance (cf. Vancouver et al., 2002). When the leader focuses on efficacy, it is easy to overlook the unintended effects on goal orientation and psychological safety. The variation in goal orientation increases resistance to change, decreasing the inflow to TLC. The decrease in psychological safety causes people to ignore errors from which they might learn, increasing the outflow from TLC. The joint effect is that TLC declines, making the team less innovative. Should this continue long enough, the decreased innovation may be blamed on the leader or even the newcomers, decreasing cohesion while also decreasing efficacy and perpetuating the cycle as the leader attempts to re-establish efficacy.

We recognize that newcomers do not always decrease efficacy, or alter goal orientation. The point is to illustrate how such a system works in this particular context, and to emphasize that if research is to discover the common patterns in TLC systems, research on TLC will need to start trying to model the systems, not just specific pieces of it. This is not merely a theoretical issue; it is a practical one as well. Understanding how emergent states can interact, balance and evolve gives leaders more flexibility in how they aim to sustain TLC. In the following section, we build on this viewpoint to develop avenues for future research and consider practical insights for leaders.

DISCUSSION

Taking a systems view on TLC opens up avenues for future research while also offering practical insights. Specifically, our work offers three main contributions to theory. First, we still know little about whether some of the emergent

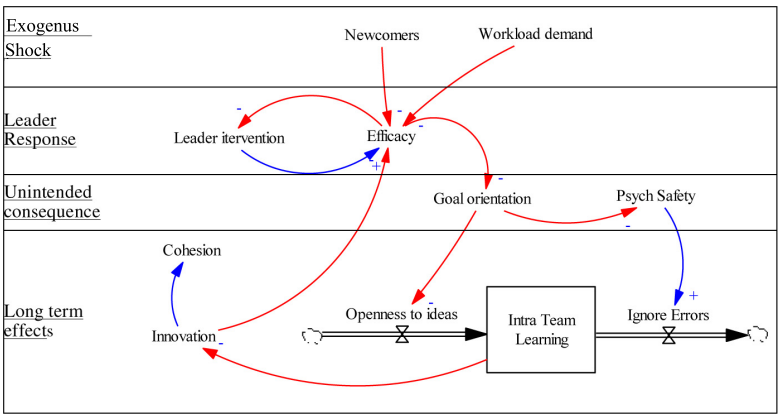

FIGURE 2 | Dynamic model of team learning climate in the hospital vignette.

states that bring about TLC are more amenable to leadership interventions. Scholars have distinguished between task- and person-focused leadership (Koeslag-Kreunen et al., 2018) but TLC, while being rooted in persons' beliefs, also relates to features of the team task. Thus it is unclear what focus would be recommended to influence TLC. One direction for future research is to examine whether the four emergent states are more (or less) likely to evolve over time—and, if so, under what conditions. Doing so may require a move away from cross-sectional designs toward special research designs and new measurement tools. For instance, experience sampling methodology (ESM), which demands that research participants complete several surveys over a relatively short period of time, could enable the investigation of the dynamics and coevolution we aim to delineate in this paper. Such *in situ* momentary assessments of team emergent states could show which ones are more or less event-contingent (see Kozlowski, 2015). The knowledge generated with this research can provide leaders with actionable insights into how to approach TLC monitoring.

Second, our work also provides grounds to think more deeply about who is best positioned to monitor TLC. The functional theory of leadership is inclusive when it comes to who should undertake leadership functions (Morgeson et al., 2010). Anyone inside and around the team can exert leadership, whether they assume a formal or informal role. Is there a difference between a longstanding team leader and a newly integrated team member intervening to influence TLC? This raises questions such as whether team members are more effective at monitoring emergent states, given their proximity to fellow members, or whether appointed leaders may provide greater stimulus to TLC trajectory by dint of their formal authority. Recent work by Koeslag-Kreunen et al. (2018) has shown that leadership from both formally appointed leaders and team members can influence team learning. Future research could look into team member interactions and how they might boost, maintain, or impair TLC. Computational methods would be particularly useful in leading such endeavors by modeling various team member characteristics and behaviors (see Cronin and Vancouver, 2018). The use of wearable wireless sensors designed to measure human social interactions is yet another way to give us cues about the respective influence of distinctive sources of leadership actions in real time (Kozlowski and Chao, 2018; Zhang et al., 2018). This could also shed light on the conditions underlying the changes—for example, whether team-level features such as task interdependence, or features associated with the work environment such as virtual communication, interact with monitoring practices to affect TLC.

Finally, while much has been written about TLC, what it actually represents has remained unclear. We hope to have provided more clarity to this important construct. However, we based our work on Bell et al. (2012) and therefore focused on psychological safety, goal orientation, cohesion, and efficacy. Other emergent states may need to be included in TLC. One avenue for future research in that direction is to validate TLC as a second-order construct, similar to what Mathieu et al. (in press) have done with the action, transition, and interpersonal processes of teamwork proposed by Marks et al. (2001). Researchers need to map the many emergent states that have proliferated throughout the past decades or so, put them under larger umbrellas (second-order constructs), and test them empirically. This likely means reducing the number of items used to measure each emergent state and reassessing validity (Smith et al., 2000), but this is necessary to start exploring the dynamics between these key constructs. Only then will team research be able to fully embrace the systems view that we propose here.

In terms of practical implications, taking a systems view on TLC can help managers interpret the potential multivariate effect of their actions. For instance, a manager who wishes to cultivate psychological safety by modeling openness and asking feedback from team members can affect the goal orientation, efficacy, and cohesion of the team depending on the content of the feedback that is provided and the exchanges that ensue. Training managers in systems thinking could be useful to develop their holistic conception of management practice and leadership, which goes beyond the logical thinking that is usually taught in

business schools. In general, this should lead managers to better appreciate the complexity of their impact and reduce the impression of direct connectedness between their actions and the desired outcomes.

Thinking of TLC as an equilibrium that needs balance also brings the notion of time to the fore. It moves away from the perception of TLC as a starting point or a definite state represented as an intrinsic dialectical quality (learning vs. non-learning climate). Managers can then better understand why TLC is never a *fait accompli* and rather an enduring accomplishment that revolves around managing several emergent states over time. Going back to Senge (1990), this is at the foundation of the reflexivity and inquiry skills necessary for organizations to thrive over the long haul.

CONCLUSION

Team scholarship has primarily focused on emergent states in isolation, limiting our understanding of the proper "milieu" among them or our insights into how they operate jointly. Therefore, it is not immediately apparent how the various emergent states differ from each other, or where they overlap (Bell et al., 2012). This has led to scholarship that does not always take into account the complexity of the bundle of emergent states present in TLC. We hope that our efforts in this paper offers the opportunity for scholars to take more of a systems view in their research on TLC, and for leaders to embrace the complex, yet crucial, role they play in continuously shaping team members' beliefs. This is all very challenging, but the rewards are well worth it, as teams continue to flourish in science and in the field.

DATA AVAILABILITY

No datasets were generated or analyzed for this study.

AUTHOR CONTRIBUTIONS

JFH and MC developed the research idea and wrote most of the manuscript. PML assisted them on parts of the manuscript, particularly the literature review.

FUNDING

This research was supported by funding from the Social Sciences and Humanities Research Council of Canada (Grant No. 430-2017-00527).

REFERENCES

Alexander, L., and Van Knippenberg, D. (2014). Teams in pursuit of radical innovation: a goal orientation perspective. *Acad. Manag. Rev.* 39, 423–438.

Ancona, D. G., and Caldwell, D. F. (1992). Bridging the boundary: external activity and performance in organizational teams. *Adm. Sci. Q.* 37, 634–665.

Argote, L., Aven, B. L., and Kush, J. (2018). The effects of communication networks and turnover on transactive memory and group performance. *Organ. Sci.* 29, 191–206.

Argyris, C. (1990). *Overcoming Organizational Defenses: Facilitating Organizational Learning*. Boston, MA: Allyn and Bacon.

Bandura, A. (1997). *Self-Efficacy: The Exercise of Control*. New York, NY: W. H. Freeman.

Beal, D. J., Cohen, R. R., Burke, M. J., and McLendon, C. L. (2003). Cohesion and performance in groups: a meta-analytic clarification of construct relations. *J. Appl. Psychol.* 88, 989–1004.

Bell, B. S., Kozlowski, S. W., and Blawath, S. (2012). "Team learning: a theoretical integration and review," in *The Oxford Handbook of Organizational Psychology*, Vol. 1, ed. S. W. Kozlowski (Oxford: Oxford University Press), 859–909.

Bergman, J. Z., Rentsch, J. R., Small, E. E., Davenport, S. W., and Bergman, S. M. (2012). The shared leadership process in decision-making teams. *J. Soc. Psychol.* 152, 17–42.

Bowers, C., Kreutzer, C., Cannon-Bowers, J., and Lamb, J. (2017). Team resilience as a second-order emergent state: a theoretical model and research directions. *Front. Psychol.* 8:1360. doi: 10.3389/fpsyg.2017.01360

Bresman, H. (2010). External learning activities and team performance: a multimethod field study. *Organ. Sci.* 21, 81–96.

Bresman, H., and Zellmer-Bruhn, M. (2013). The structural context of team learning: effects of organizational and team structure on internal and external learning. *Organ. Sci.* 24, 1120–1139.

Bunderson, J. S., and Boumgarden, P. (2010). Structure and learning in self-managed teams: why "bureaucratic" teams can be better learners. *Organ. Sci.* 21, 609–624.

Bunderson, J. S., and Sutcliffe, K. M. (2002). "Why some teams emphasize learning more than others: evidence from business unit management teams," in *Toward Phenomenology of Groups and Group Membership*, eds H. Sondak, M. Neale, and E. Mannix (Bingley: Emerald Group Publishing), 49–84.

Bunderson, J. S., and Sutcliffe, K. M. (2003). Management team learning orientation and business unit performance. *J. Appl. Psychol.* 88, 552–560.

Button, S. B., Mathieu, J. E., and Zajac, D. M. (1996). Goal orientation in organizational research: a conceptual and empirical foundation. *Organ. Behav. Hum. Decis. Process.* 67, 26–48.

Carmeli, A., and Gittell, J. H. (2009). High-quality relationships, psychological safety, and learning from failures in work organizations. *J. Organ. Behav.* 30, 709–729.

Chen, G., and Tjosvold, D. (2012). Shared rewards and goal interdependence for psychological safety among departments in China. *Asia Pac. J. Manag.* 29, 433–452.

Chen, G., Tjosvold, D., Zhao, H., Ning, N., and Fu, Y. (2011). Constructive controversy for learning and team effectiveness in China. *Asia Pac. J. Hum. Resou.* 49, 88–104. doi: 10.1177/1038411110391708

Chiniara, M., and Bentein, K. (2018). The servant leadership advantage: when perceiving low differentiation in leader-member relationship quality influences team cohesion, team task performance and service OCB. *Leadersh. Q.* 29, 333–345.

Cronin, M. A., Gonzalez, C., and Sterman, J. D. (2009). Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. *Organ. Behav. Hum. Decis. Process.* 108, 116–130.

Cronin, M. A., and Vancouver, J. B. (2018). "The only constant is change: expanding theory by incorporating dynamic properties into one's models," in *The Handbook of Multilevel Theory, Measurement, and Analysis*, eds S. E. Humphrey and J. M. LeBreton (Washington, DC: American Psychological Association), 89–114.

Cronin, M. A., Weingart, L. R., and Todorova, G. (2011). Dynamics in groups: are we there yet? *Acad. Manag. Ann.* 5, 571–612.

De Jong, B. A., and Elfring, T. (2010). How does trust affect the performance of ongoing teams? The mediating role of reflexivity, monitoring, and effort. *Acad. Manag. J.* 53, 535–549.

DeShon, R. P., Kozlowski, S. W. J., Schmidt, A. M., Milner, K. R., and Wiechmann, D. (2004). A multiple-goal, multilevel model of feedback effects on the regulation of individual and team performance. *J. Appl. Psychol.* 89, 1035–1056.

Dragoni, L., and Kuenzi, M. (2012). Better understanding work unit goal orientation: its emergence and impact under different types of work unit structure. *J. Appl. Psychol.* 97, 1032–1048. doi: 10.1037/a0028405

Duhigg, C. (2016). *What Google Learned from its Quest to Build the Perfect Team*, Vol. 26. New York, NY: The New York Times.

Dweck, C. S. (1986). Motivational processes affecting learning. *Am. Psychol.* 41, 1040–1048.

Edmondson, A. C. (1999). Psychological safety and learning behavior in work teams. *Adm. Sci. Q.* 44, 350–383. doi: 10.1186/1748-5908-7-77

Edmondson, A. C. (2002). The local and variegated nature of learning in organizations: a group-level perspective. *Organ. Sci.* 13, 128–146.

Edmondson, A. C. (2003). Speaking up in the operating room: how team leaders promote learning in interdisciplinary action teams. *J. Manag. Stud.* 40, 1419–1452.

Edmondson, A. C. (2018). *The Fearless Organization: Creating Psychological Safety in the Workplace for Learning, Innovation, and Growth*. Hoboken, NJ: Wiley.

Edmondson, A. C., Bohmer, R. M., and Pisano, G. P. (2001). Disrupted routines: team learning and new technology implementation in hospitals. *Adm. Sci. Q.* 46, 685–716.

Edmondson, A. C., Dillon, J. R., and Roloff, K. S. (2007). 6 three perspectives on team learning: outcome improvement, task Mastery, and group process. *Acad. Manag. Ann.* 1, 269–314.

Edmondson, A. C., and Harvey, J. F. (2017). *Extreme Teaming: Lessons in Complex, Cross-Sector Leadership*. Bingley: Emerald Publishing Limited.

Edmondson, A. C., and Harvey, J. F. (2018). Cross-boundary teaming for innovation: integrating research on teams and knowledge in organizations. *Hum. Resour. Manag. Rev.* 28, 347–360.

Edmondson, A. C., and Lei, Z. (2014). Psychological safety: the history, renaissance, and future of an interpersonal construct. *Annu. Rev. Organ. Psychol. Organ. Behav.* 1, 23–43.

Edmondson, A. C., Winslow, A. B., Bohmer, R. M., and Pisano, G. P. (2003). Learning how and learning what: effects of tacit and codified knowledge on performance improvement following technology adoption. *Decis. Sci.* 34, 197–224.

Ellis, A. P., Hollenbeck, J. R., Ilgen, D. R., Porter, C. O., West, B. J., and Moon, H. (2003). Team learning: collectively connecting the dots. *J. Appl. Psychol.* 88, 821–835.

Ericksen, J., and Dyer, L. (2004). Right from the start: exploring the effects of early team events on subsequent project team development and performance. *Adm. Sci. Q.* 49, 438–471.

Forrester, J. W. (1968). *Principles of System*. Cambridge, MA: Productivity Press.

Gibson, C. B., and Earley, P. C. (2007). Collective cognition in action: accumulation, interaction, examination, and accommodation in the development and operation of group efficacy beliefs in the workplace. *Acad. Manag. Rev.* 32, 438–458.

Gist, M. E. (1987). Self-efficacy: implications for organizational behavior and human resource management. *Acad. Manag. Rev.* 12, 472–485.

Gong, Y., Kim, T. Y., Lee, D. R., and Zhu, J. (2013). A multilevel model of team goal orientation, information exchange, and creativity. *Acad. Manag. J.* 56, 827–851.

Gully, S. M., Incalcaterra, K. A., Joshi, A., and Beaubien, J. M. (2002). A meta-analysis of team-efficacy, potency, and performance: interdependence and level of analysis as moderators of observed relationships. *J. Appl. Psychol.* 87, 819–832.

Hackman, J. R. (1976). "Group influence on individuals," in *Handbook of Industrial and Organizational Psychology*, ed. M. D. Dunnette (Chicago, IL: Rand-McNally), 1455–1525.

Hackman, J. R. (1990). *Groups That Work (and Those That Don't): Creating Conditions for Effective Teamwork*. San Francisco, CA: Jossey-Bass.

Hackman, J. R., and Morris, C. G. (1975). Group tasks, group interaction process, and group performance effectiveness: a review and proposed integration. *Adv. Exp. Soc. Psychol.* 8, 45–99.

Hackman, J. R., and Walton, R. E. (1986). "Leading groups in organizations," in *Designing Effective Work Groups*, ed. P. S. Goodman (San Francisco, CA: Jossey-Bass), 72–119.

Hammedi, W., van Riel, A. C., and Sasovova, Z. (2013). Improving screening decision making through transactive memory systems: a field study. *J. Prod. Innov. Manag.* 30, 316–330.

Harvey, J. F., Bresman, H., and Edmondson, A. C. (2018). *Team Learning Capabilities: A Meso Model of Sustained Innovation and Superior Firm Performance*. Harvard Business School Technology & Operations Mgt. Unit Working Paper No. 19–059.

Harvey, J. F., Johnson, K. J., Roloff, K. S., and Edmondson, A. C. (in press). From orientation to behavior: the interplay between learning orientation, open-mindedness, and psychological safety in team learning. *Hum. Relat.*

Hinsz, V. B., Tindale, R. S., and Vollrath, D. A. (1997). The emerging conceptualization of groups as information processors. *Psychol. Bull.* 121, 43–64.

Huber, G. P. (1991). Organizational learning: the contributing processes and the literatures. *Organ. Sci.* 2, 88–115.

Ilgen, D. R., Hollenbeck, J. R., Johnson, M., and Jundt, D. (2005). Teams in organizations: from input-process-output models to IMOI models. *Annu. Rev. Psychol.* 56, 517–543.

Janis, I. L. (1972). *Victims of Groupthink: A Psychological Study of Foreign-Policy Decisions and Fiascoes*. Boston, MA: Houghton Mifflin.

Kahn, W. A. (1990). Psychological conditions of personal engagement and disengagement at work. *Acad. Manag. J.* 33, 692–724.

Kane, T. D., Zaccaro, S. J., Tremble, T. R. Jr., and Masuda, A. D. (2002). An examination of the leader's regulation of groups. *Small Group Res.* 33, 65–120.

Klein, K. J., and Kozlowski, S. W. (2000). *Multilevel Theory, Research, and Methods in Organizations: Foundations, Extensions, and New Directions*. San Francisco, CA: Jossey-Bass.

Koeslag-Kreunen, M., Van den Bossche, P., Hoven, M., Van der Klink, M., and Gijselaers, W. (2018). When leadership powers team learning: a meta-analysis. *Small Group Res.* 49, 475–513. doi: 10.1177/1046496418764824

Kozlowski, S. W. J. (2015). Advancing research on team process dynamics: theoretical, methodological, and measurement considerations. *Organ. Psychol. Rev.* 5, 270–299.

Kozlowski, S. W. J., and Chao, G. T. (2012). The dynamics of emergence: cognition and cohesion in work teams. *Manage. Decis. Econ.* 33, 335–354.

Kozlowski, S. W. J., and Chao, G. T. (2018). Unpacking team process dynamics and emergent phenomena: challenges, conceptual advances, and innovative methods. *Am. Psychol.* 73, 576–592. doi: 10.1037/amp0000245

Lee, F., Edmondson, A. C., Thomke, S., and Worline, M. (2004). The mixed effects of inconsistency on experimentation in organizations. *Organ. Sci.* 15, 310–326.

LePine, J. A. (2005). Adaptation of teams in response to unforeseen change: effects of goal difficulty and team composition in terms of cognitive ability and goal orientation. *J. Appl. Psychol.* 90, 1153–1167.

LePine, J. A., Piccolo, R. F., Jackson, C. L., Mathieu, J. E., and Saul, J. R. (2008). A meta-analysis of teamwork processes: tests of a multidimensional model and relationships with team effectiveness criteria. *Pers. Psychol.* 61, 273–307.

Lester, S. W., Meglino, B. M., and Korsgaard, M. A. (2002). The antecedents and consequences of group potency: a longitudinal investigation of newly formed work groups. *Acad. Manag. J.* 45, 352–368.

Lewis, K. (2004). Knowledge and performance in knowledge-worker teams: a longitudinal study of transactive memory systems. *Manag. Sci.* 50, 1519–1533.

Liang, D. W., Moreland, R., and Argote, L. (1995). Group versus individual training and group performance: the mediating role of transactive memory. *Pers. Soc. Psychol. Bull.* 21, 384–393.

Lott, A. J., and Lott, B. E. (1965). Group cohesiveness as interpersonal attraction: a review of relationships with antecedent and consequent variables. *Psychol. Bull.* 64, 259–309.

Mach, M., Dolan, S., and Tzafrir, S. (2010). The differential effect of team members' trust on team performance: the mediation role of team cohesion. *J. Occup. Organ. Psychol.* 83, 771–794.

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manag. Rev.* 26, 356–376.

Mathieu, J. E., Kukenberger, M. R., D'innocenzo, L., and Reilly, G. (2015). Modeling reciprocal team cohesion–performance relationships, as impacted by shared leadership and members' competence. *J. Appl. Psychol.* 100, 713–734.

Mathieu, J. E., Luciano, M. M., D'Innocenzo, L., Klock, E. A., and LePine, J. A. (in press). The development and construct validity of a team processes survey measure. *Organ. Res. Methods*

McGrath, J. E. (1964). *Social Psychology: A Brief Introduction*. New York, NY: Holt Rinehart & Winston.

Mehta, A., Feild, H., Armenakis, A., and Mehta, N. (2009). Team goal orientation and team performance: the mediating role of team planning. *J. Manag.* 35, 1026–1046.

Mehta, A., and Mehta, N. (2018). Knowledge integration and team effectiveness: a team goal orientation approach. *Decis. Sci.* 49, 445–486.

Moreland, R. L., Argote, L., and Krishnan, R. (1996). "Socially shared cognition at work: transactive memory and group performance," in *What's Social About Social Cognition? Research on Socially Shared Cognition in Small Groups*, eds J. L. Nye and A. M. Brower (Thousand Oaks, CA: Sage), 57–84.

Morgeson, F. P., DeRue, D. S., and Karam, E. P. (2010). Leadership in teams: a functional approach to understanding leadership structures and processes. *J. Manag.* 36, 5–39.

Nembhard, I. M., and Edmondson, A. C. (2006). Making it safe: the effects of leader inclusiveness and professional status on psychological safety and improvement efforts in health care teams. *J. Organ. Behav.* 27, 941–966.

Newman, A., Donohue, R., and Eva, N. (2017). Psychological safety: a systematic review of the literature. *Hum. Resour. Manag. Rev.* 27, 521–535.

Otte, K. P., Konradt, U., Garbers, Y., and Schippers, M. C. (2017). Development and validation of the REMINT: a reflection measure for individuals and teams. *Eur. J. Work Organ. Psychol.* 26, 299–313.

Pescosolido, A. T. (2001). Informal leaders and the development of group efficacy. *Small Group Res.* 32, 74–93.

Porter, C. O. (2005). Goal orientation: effects on backing up behavior, performance, efficacy, and commitment in teams. *J. Appl. Psychol.* 90, 811–818.

Rapp, T. L., Bachrach, D. G., Rapp, A. A., and Mullins, R. (2014). The role of team goal monitoring in the curvilinear relationship between team efficacy and team performance. *J. Appl. Psychol.* 99, 976–987. doi: 10.1037/a0036978

Reagans, R., Argote, L., and Brooks, D. (2005). Individual experience and experience working together: predicting learning rates from knowing who knows what and knowing how to work together. *Manag. Sci.* 51, 869–881.

Sanner, B., and Bunderson, J. S. (2015). When feeling safe isn't enough: contextualizing models of safety and learning in teams. *Organ. Psychol. Rev.* 5, 224–243.

Schippers, M. C., Den Hartog, D. N., Koopman, P. L., and van Knippenberg, D. (2008). The role of transformational leadership in enhancing team reflexivity. *Hum. Relat.* 61, 1593–1616.

Senge, P. (1990). *The Fifth Discipline: The Art and Practice of the Learning Organization*. New York, NY: Doubleday.

Shuffler, M. L., Diazgranados, D., Maynard, M. T., and Salas, E. (2018). Developing, sustaining, and maximizing team effectiveness: an integrative, dynamic perspective of team development interventions. *Acad. Manag. Ann.* 12, 688–724. doi: 10.5465/annals.2016.0045

Smith, G. T., McCarthy, D. M., and Anderson, K. G. (2000). On the sins of short-form development. *Psychol. Assess.* 12, 102–111. doi: 10.1037//1040-3590.12.1.102

Staw, B. M., Sandelands, L. E., and Dutton, J. E. (1981). Threat rigidity effects in organizational behavior: a multilevel analysis. *Adm. Sci. Q.* 26, 501–524.

Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. New York, NY: Irwin.

Tasa, K., and Whyte, G. (2005). Collective efficacy and vigilant problem solving in group decision making: a non-linear model. *Organ. Behav. Hum. Decis. Process.* 96, 119–129.

van Ginkel, W. P., and van Knippenberg, D. (2008). Group information elaboration and group decision making: the role of shared task representations. *Organ. Behav. Hum. Decis. Process.* 105, 82–97.

Vancouver, J. B. (2005). The depth of history and explanation as benefit and bane for psychological control theories. *J. Appl. Psychol.* 90, 38–52.

Vancouver, J. B., Thompson, C. M., Tischner, E. C., and Putka, D. J. (2002). Two studies examining the negative effect of self-efficacy on performance. *J. Appl. Psychol.* 87, 506–516.

VandeWalle, D. (1997). Development and validation of a work domain goal orientation instrument. *Educ. Psychol. Meas.* 57, 995–1015.

Waller, M. J., Okhuysen, G. A., and Saghafian, M. (2016). Conceptualizing emergent states: a strategy to advance the study of group dynamics. *Acad. Manag. Ann.* 10, 561–598.

West, M. A. (1996). "Reflexivity and work group effectiveness: a conceptual integration," in *Handbook of Work Group Psychology*, ed. M. A. West (Chichester: Wiley), 555–579.

Whyte, G. (1998). Recasting Janis's groupthink model: the key role of collective efficacy in decision fiascoes. *Organ. Behav. Hum. Decis. Process.* 73, 185–209.

Wilson, J. M., Goodman, P. S., and Cronin, M. A. (2007). Group learning. *Acad. Manag. Rev.* 32, 1041–1059.

Wong, S. S. (2004). Distal and local group learning: performance trade-offs and tensions. *Organ. Sci.* 15, 645–656.

Zhang, Y., Olenick, J., Chang, C. H., Kozlowski, S. W. J., and Hung, H. (2018). TeamSense: assessing personal affect and group cohesion in small teams through dyadic interaction and behavior analysis with wearable sensors. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 2, 1–22.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Harvey, Leblanc and Cronin. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

ORIGINAL RESEARCH
published: 12 July 2019
doi: 10.3389/fpsyg.2019.01633

Learning From the Past to Advance the Future: The Adaptation and Resilience of NASA's Spaceflight Multiteam Systems Across Four Eras of Spaceflight

Jacob G. Pendergraft[1], Dorothy R. Carter[1], Sarena Tseng[1], Lauren B. Landon[2], Kelley J. Slack[3] and Marissa L. Shuffler[4]*

[1] Department of Psychology, University of Georgia, Athens, GA, United States, [2] KBRwyle, Houston, TX, United States, [3] National Aeronautics and Space Administration, Washington, DC, United States, [4] Department of Psychology, Clemson University, Clemson, SC, United States

OPEN ACCESS

Edited by:
Igor Portoghese,
University of Cagliari, Italy

Reviewed by:
Jared B. Kenworthy,
The University of Texas at Arlington,
United States
Shane Connelly,
The University of Oklahoma,
United States

***Correspondence:**
Jacob G. Pendergraft
jakependergraft2@gmail.com

Specialty section:
This article was submitted to
Organizational Psychology,
a section of the journal
Frontiers in Psychology

Received: 13 December 2018
Accepted: 27 June 2019
Published: 12 July 2019

Citation:
Pendergraft JG, Carter DR, Tseng S, Landon LB, Slack KJ and Shuffler ML (2019) Learning From the Past to Advance the Future: The Adaptation and Resilience of NASA's Spaceflight Multiteam Systems Across Four Eras of Spaceflight. Front. Psychol. 10:1633. doi: 10.3389/fpsyg.2019.01633

Many important "grand" challenges—such as sending a team of humans on a voyage to Mars—present superordinate goals that require coordinated efforts across "multiteam systems" comprised of multiple uniquely specialized and interdependent component teams. Given their flexibility and resource capacity, multiteam system structures have great potential to perform *adaptively* in dynamic contexts. However, these systems may fail to achieve their superordinate goals if constituent members or teams do not adapt their collaboration processes to meet the needs of the changing environment. In this case study of the National Aeronautics and Space Administration (NASA)'s *Spaceflight Multiteam Systems* (SFMTSs), we aim to support the next era of human spaceflight by considering how the *history* of manned spaceflight might impact a SFMTS's ability to respond adaptively to future challenges. We leverage archival documents, including Oral History interviews with NASA personnel, in order to uncover the key attributes and structural features of NASA's SFMTSs as well as the major goals, critical events, and challenges they have faced over 60 years of operation. The documents reveal three distinct "eras" of spaceflight: (1) *Early Exploration*, (2) *Experimentation*, and (3) *Habitation*, each of which reflected distinct goals, critical events, and challenges. Moreover, we find that within each era, SFMTSs addressed new challenges adaptively by modifying their: (1) technical capabilities; (2) internal collaborative relationships; and/or (3) external partnerships. However, the systems were sometimes slow to implement needed adaptations, and changes were often spurred by initial performance failures. Implications for supporting future SFMTS performance and future directions for MTS theory and research are discussed.

Keywords: teams, multiteam systems, spaceflight, adaptive performance, organizational practices, evolution and adaptability

INTRODUCTION

The United States' National Aeronautics and Space Administration (NASA) and directives from the President have set an ambitious goal: send manned Long-Duration Exploration Missions (LDEMs) to deep-space destinations like Mars within the next two decades (National Aeronautics and Space Administration [NASA], 2014; Trump, 2017). LDEMs represent a new frontier for humanity, and could be one of the greatest achievements in human history. However, these missions will also present immense difficulties and test the capabilities of all involved. Factoring prominently among the anticipated difficulties of LDEMs is the *team risk* or the "risk of performance and behavioral health decrements due to inadequate cooperation, coordination, communication, and psychosocial adaptation within a team" (Landon et al., 2016, p. 5). The "team risk" in a LDEM is not limited to the risks of collaboration failures within the spaceflight *crew*. LDEMs will require unprecedented levels of collaboration across complex *"spaceflight multiteam systems"* (i.e., "SFMTSs") comprised of the space flight crew and numerous teams on Earth (Mesmer-Magnus et al., 2016).

In fact, *many* of the most important problems facing today's organizations and societies —including responding to natural disasters (DeChurch et al., 2011), uncovering major scientific discoveries (Falk-Krzesinski et al., 2010), and translating medical breakthroughs to practice (Asencio et al., 2012)—represent "grand challenges" (George et al., 2016) that require intensive collaboration across interdependent systems comprised of multiple uniquely specialized groups or teams. These *"teams of teams"* or *"multiteam systems"* (i.e., "MTSs"; Mathieu et al., 2001) are increasingly prevalent in today's world because these structures offer greater resource capacity than single teams but more flexibility than traditional organizations and thus, are expected to respond *adaptively* to complex and evolving task demands (Marks et al., 2005; Porck et al., 2018).

Despite their potential to achieve important goals, extant research suggests that MTSs often fail due to breakdowns in collaboration and coordination within and/or across component teams (Zaccaro et al., 2012). For example, MTS theory argues that *interteam* collaboration breakdowns are particularly likely in systems comprised of teams with very different areas of expertise, backgrounds, norms, priorities, or organizational memberships (Luciano et al., 2018). Furthermore, MTSs often appear in contexts that are ambiguous, dynamic, multi-faceted, and require rapid responses (Shuffler and Carter, 2018). Yet, research on dynamic task contexts suggests that dynamism and uncertainty can present added problems for collaboration (Luciano et al., 2018) and members and teams may fail to shift their processes and procedures adaptively to meet evolving task demands (Moon et al., 2004; Hollenbeck et al., 2011). Therefore, when MTSs face an important grand challenge, like a LDEM, which has critical consequences for failure, it is often necessary to understand the specific features of the system (e.g., team characteristics, evolving task demands) that might present barriers to effective collaboration within and across teams and develop strategies for mitigating those barriers.

This case study aims to lay a foundation for supporting SFMTS performance in the future by analyzing the *history* of SFMTS performance over the past 60 years of NASA's spaceflight program. We argue that considering the collaboration practices and procedures that have been established *previously* within a MTS or its embedding environment is an important first step when attempting to facilitate future adaptive performance. Indeed, scholars have long argued that teams' histories can substantially impact their futures (McGrath et al., 2000; Hollenbeck et al., 2014). Through a review of archival documents, we uncover the key features of SFMTSs and the major focuses, critical events, and challenges SFMTSs have contended with in the past. Further, we consider the ways in which SFMTSs have *adapted* to meet the challenges of previous eras of spaceflight. In doing so, we align with previous research on teams that acknowledges "adaptation lies at the heart of team effectiveness" (Burke et al., 2006, p. 1189) and identify aspects of prior adaptations within the spaceflight context that must shift or advance further in order to achieve the goals of LDEM.

CASE STUDY APPROACH

The purpose of this research is to better understand how NASA's SFMTSs have learned from and adapted in response to pivotal events and transitions in the space program over the past 60 years of space exploration. Toward these ends, we reviewed publicly available archival documents that provide first-hand information regarding how NASA's SFMTSs responded to critical events. Our case study was guided by three research questions which were grounded in extant theory and research on MTSs (Zaccaro et al., 2012; Shuffler et al., 2015). These research questions, our data collection, and analysis procedures are described below.

Research Questions

Research Question 1

Our first research question *How are NASA's SFMTSs structured?* (e.g., What teams are involved? What interteam relationships are relevant?) is based in prior theoretical work which has identified the key definitional features of MTSs (Mathieu, 2012) and delineated the attributes of these systems that might impact performance (Zaccaro et al., 2012). Defined formally, MTSs are: "two or more teams that interface directly and interdependently in response to environmental contingencies toward the accomplishment of collective goals" (Mathieu et al., 2001, p. 289). All MTSs have in common two features: two or more component teams, and a hierarchical goal structure whereby component team pursue separate team-level goals in addition to one or more shared "superordinate" goal.

However, as Zaccaro et al. (2012) argue MTSs can vary widely with regard to the types of "compositional," "linkage," and "developmental" attributes affecting MTS functioning. *Compositional attributes* are descriptive aspects of the individuals and teams comprising the system and can include demographic features of the MTS, the size of the system (e.g., number

of teams), the relative characteristics of the component teams (e.g., the functional specialization of component teams), and the degree to which the system crosses organizational boundaries. *Linkage attributes* reflect the formal and informal connections among members and teams and can include patterns of task interdependence driven by the MTS goal hierarchy, communication, trust, and leadership structures. Finally, *developmental attributes* are the properties of the system connected to temporal development such as the system's genesis (e.g., if the system was appointed or emergent), and the stability of the membership over time.

As a guiding theoretical framework, MTSs researchers typically leverage classic *input-process-output* (Steiner, 1972; McGrath, 1984; Hackman, 1987) or *input-mediator-output-input* (IMOI model; Ilgen et al., 2005) views of team functioning and performance to understand multiteam functioning. Within these models, inputs reflect factors affecting team functioning (e.g., personality, knowledge, training, attitudes). The effects of inputs are transmitted through mediators, such as teamwork processes (e.g., coordination behaviors, information sharing, backup behaviors; Marks et al., 2001) or emergent psychological states (e.g., trust, shared cognition; Kozlowski and Ilgen, 2006) to team outputs (e.g., performance, viability). In MTSs, inputs (e.g., compositional attributes; Zaccaro et al., 2012) residing at the individual, component team, and system level shape the interactions and relationships within and across teams (e.g., linkage attributes), and MTS outcomes. These performance outcomes then become inputs during subsequent phases of performance.

In summary, extant research argues that MTSs can vary widely in their structures and other compositional, linkage, and developmental attributes. Moreover, the structures and attributes of MTSs are significant determinants of systems performance. For example, drawing from a long history of research on intergroup relations (Sherif, 1958; Tajfel et al., 1979), Luciano et al. (2018) argue that the degree to which component teams differ from one another with regard to their functional capabilities, norms, work processes, and priorities, can create boundary-enhancing forces between teams that stifle interteam collaboration and system performance. Therefore, our first research question is based in the understanding that MTS structures and other attributes are critical to system performance.

Research Questions 2 and 3

Although research on organizational teams has often treated team tasks, composition, and environments as though they were stable over time (Ilgen, 1999; Mathieu et al., 2017), scholars have also pointed out that teams and MTSs are complex adaptive systems that experience evolving task demands, shifting group memberships, and feedback loops with their embedding environments (Kozlowski and Klein, 2000; McGrath et al., 2000; Mathieu et al., 2014). The prior experiences, outcomes, memories, and practices that have accumulated within a team or system in response to evolving task demands are likely to shape subsequent behaviors and outcomes (e.g., McGrath et al., 2000; Hollenbeck et al., 2014). Moreover, a team or system's ability to *adapt* to major changes is a hallmark of effective performance (LePine, 2005; Burke et al., 2006; Baard et al., 2014). Therefore, the second two research questions guiding our case study of NASA's SFMTSs acknowledge that teams' *histories* (and their prior adaptations) matter to their futures: (2) *What are major goals, critical events, and challenges have NASA's SFMTSs faced in the past?*; and (3) *In what ways have NASA's SFMTSs adapted over time in response to evolving goals, events, and challenges?* (e.g., What organizational practices have been implemented?).

The history of a MTS might facilitate subsequent performance or constrain it. In some instances, when future challenges share similar features to those encountered in the past, prior adaptations represent a valuable resource which teams may draw on to inform their options for future adaptation. Where anticipated challenges diverge from those encountered previously, a thorough understanding of past challenges and the adaptations made in response to them may guide subsequent adaptation strategies by allowing team members to identify the areas where further improvement on existing systems may be needed. Conversely, circumstances may require teams to change their behaviors, but reliance on past approaches may prevent adaptation. For example, research has shown that it is much easier for teams to shift from loosely coupled or decentralized task decision-making structures toward more tightly coupled or centralized structures than it is to shift in the opposite direction (Moon et al., 2004; Hollenbeck et al., 2011).

Therefore, we consider the ways in which NASA's SFMTSs have previously adapted to evolving challenges. We suggest that considering the history of SFMTS adaptations could provide a foundation for future LDEMs. First, an awareness of past adaptations may provide guidelines for the types of adaptations that may benefit the system in the future. Second, understanding prior challenges may allow for better prediction of the performance decrements that may result from the challenges of LDEMs if further adaptations are not instituted. Finally, an advance awareness of potential performance decrements may allow NASA and organizational researchers to apply countermeasures, correcting for these challenges before their consequences can manifest. Examining the past to inform the future may be particularly important in multiteam settings like an SFMTS, which could differ appreciably from less complex stand-alone teams studied in laboratory settings or other types of organizations.

Data Collection Approach

We used transcripts from NASA's JSC Oral History Project (JSC OHP) as the foundation of our archival document search. The purpose of the JSC OHP was to "capture the history from the individuals who first provided the country and the world with an avenue to space and the moon" (Madison, 2010). The JSC OHP transcripts represent interviews with individuals spanning a wide range of roles within NASA, including managers, engineers, technicians, astronauts, and other employees. Our review was conducted entirely using publicly available documents. As such, additional IRB, NASA, or interview participant approval was not required for the use of these resources.

We used the JSC OHP as the foundation of our archival analysis for three key reasons. First, by virtue of their inclusion in the JSC OHP, the events described in the transcripts can be assumed to be of importance to the organization, from the perspective of NASA itself. These events often represented critical milestones in NASA's spaceflight legacy. In many cases, this was because the events described were pivotal in prompting altered patterns of action that were key to later successes, or marked the surmounting of persistent and lasting problems which would establish a template for future action. Often, the focus of the interviews could be described as "crisis" events, although significant successes were also frequent topics. Therefore, although the documents largely exclude day-to-day functioning of NASA and MCC which is sure to have substantial impacts on the operation of the system as well, the OHP provides an ideal basis for identifying pivotal events and transitions within the space program. Although the events that are the focus of the JSC OHP represent a small proportion of the totality of NASA's 60-year history, these events continue to exercise disproportionate impact on NASA's operations.

Second, the JSC OHP documents represented first-hand accounts of pivotal events and NASA transitions from the perspective of interview subjects who were intimately familiar with and/or played a prominent role in the events described. The selection of oral history project subjects was often guided by the familiarity of the subject with one or more formative events or periods in the history of the organization. The interview transcripts are presented with limited revisions to preserve their conversational tone, and typically range between approximately 30 and 60 pages per interview. Participants were prompted by a NASA oral historian—whose questions are recorded in the transcripts—to recall their personal experiences and perceptions of prominent events or periods in NASA's history.

Third, the subjects of the oral histories tended to provide a substantial amount of detail in terms of the intrapersonal states (e.g., stress levels, motivation, affect, etc.) and interpersonal relationships and behaviors (e.g., trust, shared cognition, information sharing) acting on the system at the time of the events in question. Details about internal states and interpersonal relationships and motivational factors are frequently omitted from more formal technical records but are highly relevant to the functioning of MTSs (Zaccaro et al., 2012; Rico et al., 2017; Luciano et al., 2018). The type of unique insights into the internal and interpersonal states gleaned through the JSC OHP documentation are exemplified by the following quote from astronaut Michael Foale, regarding the aftermath of the collision of an unmanned *Progress* resupply spacecraft with the *Mir* station:

> *"So that was a pretty hard time, because we got very tired. And that was the hardest time I ever had on the station, was that period, because we just got so tired. Of course, the commander's morale was pretty – he was just shot, stunned."* – Foale (1998, 16 June), astronaut.

Collection of Archival Documents

Our collection of archival documents progressed in a series of three steps and leveraged an adapted snowballing review technique (Wohlin, 2014). In the first step, we began by compiling all available transcripts from the JSC OHP (n = 374 transcripts). Then, the first and third authors read through each transcript and removed all transcripts that did not contain references to one or more *manned* space mission and/or did not make multiteam interactions a central focus of the interview. This resulted in a much smaller subset of 30 focal JSC OHP transcripts containing information relevant to our research questions. These sources explicitly discussed SFMTS collaboration during a manned space mission. The decision to focus on multiteam collaboration involving members of NASA's MCC, along with our restricted focus on manned spaceflight missions, was guided by the recognition that "crew-ground" relations—between members of the spaceflight crew and MCC personnel—will be critical to the success of future space exploration missions to deep space destinations (Landon et al., 2018).

In many cases, the JSC OHP interviewees referenced events and mission details but did not explain the technical details of the events and/or the longer-term decisions that were made in response to the events thoroughly. For example, the following quote from an oral history interview with NASA flight engineer Christopher Kraft regarding the early stages of the Spacelab program demonstrates the type of statement which required more explanation:

> *"It just was sort of a long arduous task to get anything done. . .<u>You know what the arrangement was.</u>"* – Kraft (1991, 28 June), Flight Engineer (underlined emphasis added).

Therefore, in the second step of our data collection, we generated a list of all of the manned spaceflight missions referenced in the 30 focal JSC OHP transcripts. Then, we gathered official NASA- or government agency-produced documentation (e.g., investigation reports, government announcements, international agreements, etc.) related to the focal events in order to supplement our understanding of these events (n = 18 official documents). In cases where these documents also lacked sufficient detail, we gathered additional sources (n = 60 additional sources) that provided more detail about the events in question. These additional sources included NASA articles (e.g., online blogs), mission archives (i.e., overview descriptions of mission goals, technical aspects, and task focus), other NASA documents (e.g., NASA history office gallery entries), and articles from external news sources. The additional NASA documentation was instrumental in helping us establish a clearer view of the situational facts of many events, particularly the granular details of individual missions. In total, these first two data collection steps resulted in a total of 108 sources.

In a third step, two Subject Matter Experts (SMEs), who are intimately familiar with the history of NASA, refined the initial set sources by eliminating sources which referenced events the SMEs did not believe had played a significant role in the history of the organization and/or any sources that they deemed to be unreliable or inaccurate. Specifically, the majority of excluded documents were removed due to their irrelevance to central developments in the history of NASA (n = 22), while a smaller proportion were removed due to inaccuracies or inconsistencies (n = 6). The majority of these six cases were excluded due to

inconsistencies with other NASA documentation regarding the chief causes of events, as well as factual inconsistencies identified by comparison with other sources in a minority of cases. This SME evaluation process resulted in a final set of 80 sources. **Appendix A** provides a complete list of these sources. These sources discussed events occurring between 1960 and the present day, roughly spanning the operational history of NASA's MCC. **Table 1** and **Figure 1** summarize the types of resources identified and their frequencies by year, respectively.

Analysis of Archival Documents

Our research team coded each of the events described in the identified sources in order to identify the answers to our three research questions. To begin, the first three co-authors read each of the sources and generated answers to the research questions independently. Then, the coding team met and came to a group consensus regarding the answers to the three research questions. Lastly, the coding team's findings were then evaluated and refined by two SMEs familiar with the functioning and history of NASA.

Answers to the research questions were primarily derived from the oral history interview documents and were extracted for each of the focal events. For example, information about the structure of the system and the nature of the component teams was frequently available from the oral histories themselves as was a great deal of information pertaining to the interteam relationships within the system. The following quote from William Reeves exemplifies this:

> *"They assigned me to head up the first consultant group that went over to Russia, to their Control Center, to support from their Control Center, real time. At the same time, there was a group of Russians that came over here, Russian flight controllers, that formed a consultant group that was in our Control Center."* – Reeves (1998, 22 June), flight controller.

Likewise, the goals and challenges of relevant missions were frequently discussed by the interviewees, who were typically acutely aware of them. For example, Michael Barratt responds to a prompt to discuss challenges early in an interview:

> *"I think some of the most significant challenges, of course, were working with our international partners. In particular working with our former Cold War adversaries, our Russian friends."* – Barratt (2015, 30 July), flight surgeon and medical systems designer.

When additional information on mission goals was required, the supplemental documents (e.g., mission logs) frequently provided sufficient detail through stated mission objectives. System adaptations were frequently described in the oral histories as well, although these also tended to appear in more explicit detail in investigation reports following performance failures. For example, the *Report of the Presidential Commission on the Space Shuttle Challenger Accident* contains sections explicitly detailing the actions taken to implement the recommendations of the commission (Presidential Commission on the Space Shuttle Challenger Accident, 1986). Throughout, where quoted material appears in the text, bracketed material represents sparingly added text to provide clarity (drawing from statements elsewhere in the interview) and allow for concise quotation. Ellipses represent omitted text from the original statement, similarly used to limit the quotation to the required information.

TABLE 1 | Summary of resources included in archival analyses.

Source Type	Count
NASA Oral Histories	30
Official NASA or government reports	11
NASA articles, NASA mission archives, other NASA documents, articles from external news outlets	39

CASE STUDY FINDINGS: SFMTS STRUCTURES, CHALLENGES, AND ADAPTATIONS

Research Question 1: How Are NASA's SFMTSs Structured?

To Research Question 1, we evaluated the MTS structures in use during the manned spaceflight missions discussed in the JSC OHP transcripts and the relationships within and across teams that appear to be pivotal to SFMTS success. Prior work has identified the spaceflight crew and the teams comprising NASA's Mission Control Center (MCC) as key component teams in a SFMTS and argued that *ground-crew* relations are critical to spaceflight mission performance (Landon et al., 2018). Located at Johnson Space Center (JSC) in Houston, Texas, United States, NASA's MCC is the organization primarily responsible for directing a space exploration mission and monitoring the vehicle during manned space missions. The staff of MCC is chiefly tasked with ensuring the safety of the crew and the completion of mission objectives. Indeed, we identified many references to ground-crew relations in the archival documents. For example, astronaut Bonnie Dunbar discussed communication regarding various systems:

> *"We had a Mission Control Center for the payloads in southern Germany, so that's where we talked... to their engineers when we were operating the payloads, or we would talk to their researchers if they were enabled. If we wanted to talk about Spacelab systems, then we'd talk back to Houston... and so I would talk to both Houston and to* München." — Dunbar (2005, 20 January), astronaut.

Interestingly, we also identified multiple references to ground-*ground* relations between members of distinct but interdependent component teams on Earth—particularly between front room and *backroom* teams in the MCC. For example, another quote from astronaut Bonnie Dunbar illustrates the importance of ground-ground relations to the success of the Shuttle-*Mir* program and the subsequent ISS:

> *"I think flight crews are probably the easiest to integrate across the board—because they share a common goal... But we integrated researchers, we integrated flight controllers, we integrated managers, and it was a necessary thing to do before we actually*

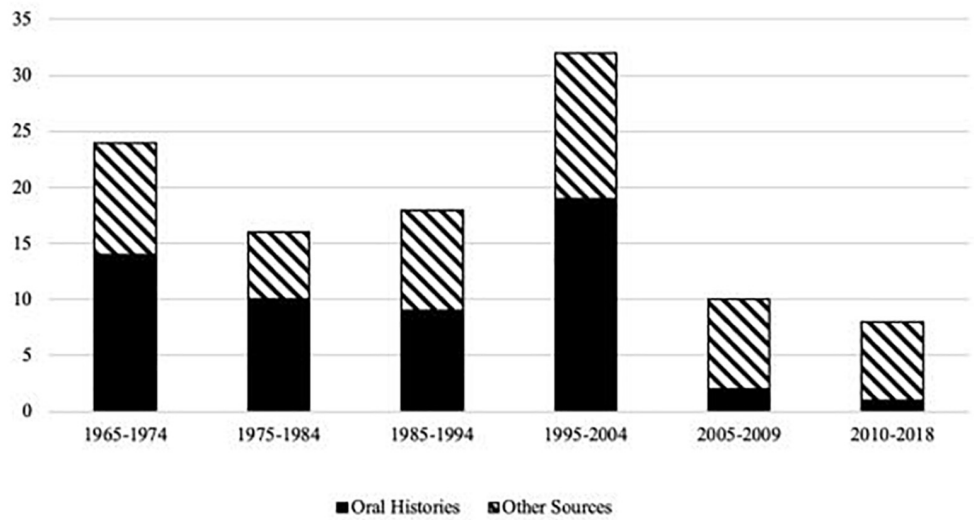

FIGURE 1 | Frequency of critical events across decades and source type.

started the International Space Station." – Dunbar (1998, 16 June), astronaut.

In fact, as the following quote from David C. McGill illustrates, since the beginning of NASA's space program, spaceflight missions have involved large and complex systems integrating different areas of expertise:

"Building large systems is very much a team sport. It takes a lot of people to do it that range all the way from the architects at the top to the software developers and procurement organizations. There's a large number of people involved, and there's decisions being made all up and down this hierarchy." – McGill (2015, 22 May), MCC Lead System Architect.

McGill goes on to further discuss the challenges of communicating across a large network of individuals collaborating on a project, while communicating ambiguous demands to all involved. The challenges of arriving at effective and flexible solutions, discussed throughout the interview, characterize much of spaceflight.

Originally influenced by military organizations, NASA organized its early structures using a hierarchical structure of specialized teams reporting to a central authority. Within MCC, this structure is comprised primarily of *frontroom* and *backroom* teams. Specifically, the MCC is organized into several disciplines, each assuming responsibility for a hardware system or a specific aspect of the vehicle and mission. Each discipline is represented on the frontroom team by a *flight controller*, who is a discipline specialist. The appointed leader of the frontroom team, overseeing and coordinating all flight systems, is called the *flight director*. During a mission, the flight controllers monitor their assigned system using telemetry data from the vehicle and direct radio communication with the crew. Each flight system's frontroom flight controller is supported by additional personnel in that system's backroom team. Given this interdependent arrangement of teams, NASA's MCC operates as a smaller MTS embedded in the broader SFMTS involved in a mission. **Figure 2** provides a simplified depiction of the MTS structure *within* the MCC.

The SFMTS structures and relationships in these systems are governed by the nature of the goals pursued by constituent members and teams. That is, constituent members and teams complete different proximal (e.g., individual-level, team-level) goals, which contribute to the overall, superordinate goal of the system (Mathieu et al., 2001). The accomplishment of the superordinate goal (mission success and crew safety, in the case of MCC) requires interdependent interactions among the component teams. In pursuit of this superordinate goal, the component teams within the system will exhibit some form of *functional process interdependence*, meaning that the component teams must work interdependently while accomplishing goals. The exact form and nature of this interdependence will vary according to the needs of the system, and may change over the course of a given mission. An example of a goal hierarchy within MCC is depicted in **Figure 3**, using the console positions presently in use with the ISS.

National Aeronautics and Space Administration's front room team serves as a hub for the integration of information from wide ranging disciplines within the organization. Internally, backroom personnel typically communicate with their flight controller on the frontroom team; information passed between backroom teams is most often routed through their respective flight controllers, who confer directly. These interactions are represented in **Figure 2** by the dashed lines within the MCC. The backroom teams are located in separate rooms from the frontroom team of flight controllers. Communication between frontroom flight controllers and backroom flight controllers occurs through audio and computer-based methods including email and internal web pages.

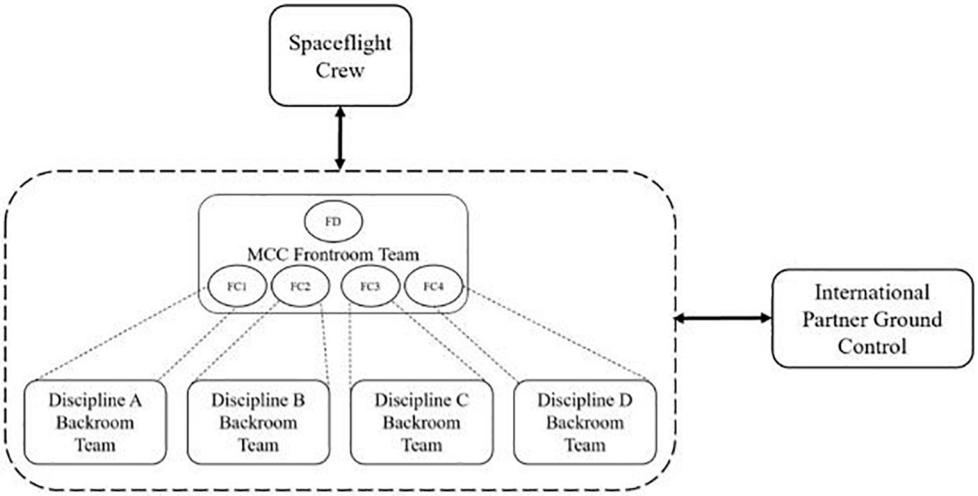

FIGURE 2 | Simplified depiction of NASA's MCC MTS structure. MCC frontroom team is comprised of the flight director (FD) and flight controllers (FC). Dashed lines indicate supporting relationships between FC and disciplinary backroom teams. Relationships between the MCC MTS and outside teams are depicted as solid double headed arrows.

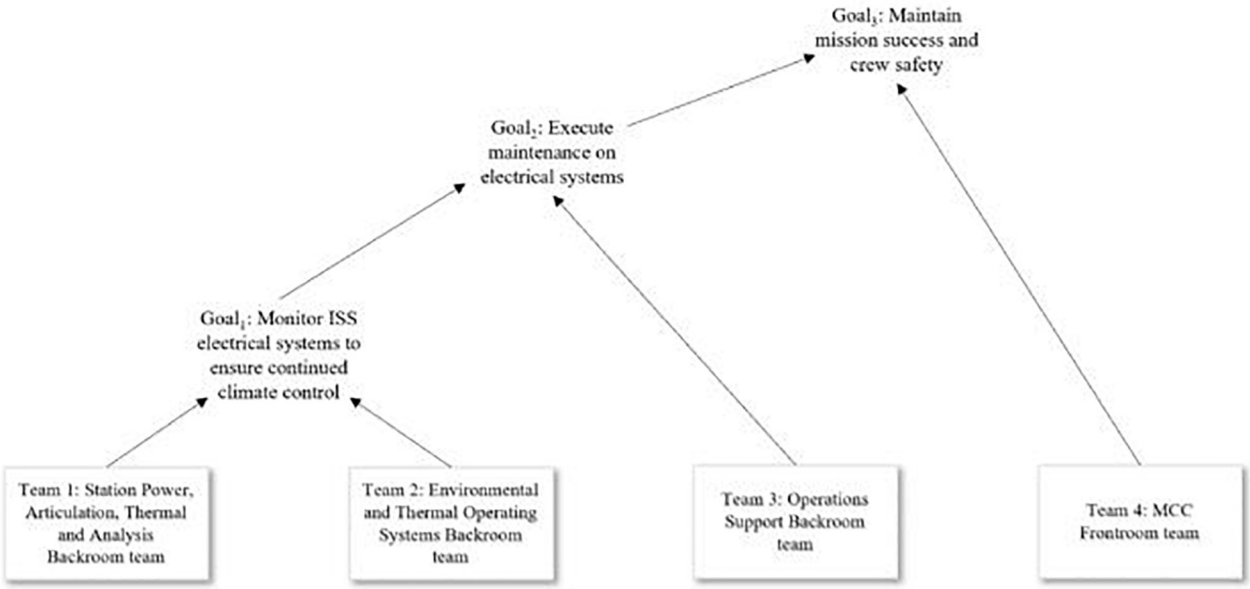

FIGURE 3 | Example goal hierarchy within MCC during an ISS expedition with a need for integration of efforts between frontroom team (Team 4) and backroom teams (Teams 1–3).

This SFMTS structure remains the basis for the organization of MCC, although the composition of the MTS and the distribution of tasks within it have shifted in response to the needs of the missions at the time. Under the present SFMTS organization, crew and frontroom teams must interact efficiently to share information on current and upcoming states of the crew and their taskwork. The discretionary monitoring of this information sharing is largely in the hands of the flight director to determine, a decision role which has notably shaped communication in the midst of past crisis events. Effective communication between the backroom and frontroom team is critical, to ensure that information is effectively transmitted from the backroom teams through to the crew as needed and in a timely manner.

In addition to the frontroom and backroom team interactions, MCC teams interact with the spaceflight crew, with other teams within the broader organization (e.g., management teams), and in more recent years (see findings related to Research Question

2), with teams from international partner (IP) organizations. Frontroom flight controllers are usually the only members of MCC who communicate directly with IP flight controllers or with the crew. Information originating within the backroom teams that must be transmitted to the crew is therefore first relayed through the frontroom team. These patterns of interactions (indicated by solid double-headed arrows in **Figure 2**) shape and restrict the coordination actions taking place within the SFMTS.

Research Questions 2 and 3: What Are the Major Goals, Events, and Challenges and How Have NASA's SFMTSs Adapted?

In order to address our second research question (i.e., *What major goals, events, and challenges have NASA's SFMTSs encountered?*), our coding team began by identifying the key features of each of the events and/or missions described in the focal JSC OHP transcripts. We also searched for commonalities across the events/missions. Through subsequent discussions with NASA SMEs, our coding team determined that the spaceflight missions undertaken over the past 60 years of the space program can be organized into three distinct eras: (1) *Early Exploration*, (2) *Experimentation*, and (3) *Habitation*. These eras are distinguishable by the goals, events, and challenges encountered by SFMTSs during each period. **Table 2** identifies the manned spaceflight programs within each era. **Table 3** summarizes the major goals, events, and challenges. With regard to our third research question (i.e., *In what ways have NASA's SFMTSs adapted over time in response to evolving goals, events, and challenges?*), we determined that during each of the three eras, the SFMTSs exhibited adaptations which corresponded to the major challenges the systems encountered (summarized in **Table 4**). These adaptations were centered primarily around shifts and/or enhancements in: (1) *technical expertise;* (2) *internal relationships*; and/or (3) *external partnerships*. The following sections provide narrative descriptions of the major goals, events, challenges and adaptations within the three eras.

Era 1: Early Exploration

Major Goals

In the first era, *Early Exploration*, missions including Projects Mercury, Gemini, and the Apollo Program were focused on early forays into space exploration, and required rapid improvements in technical expertise. Further, an intense environment of international competition with rival states (often referred to as the "Space Race") during the Cold War factored prominently in the motivations and goals of this era. Beginning with early achievements in flight beyond the Earth's atmosphere (e.g., Shepard's, 1961 Mercury flight) and continuing through the lunar landings of the Apollo missions and the early forays into extended space habitation through the Skylab station, the superordinate goals pursued by NASA's SFMTSs centered on developing and applying a significant corpus of technical expertise in a very short period of time in an environment characterized by uncertainty and competition. William Anders captured this focus on exploration and the development of technical expertise in

TABLE 2 | Spaceflight eras and corresponding NASA programs.

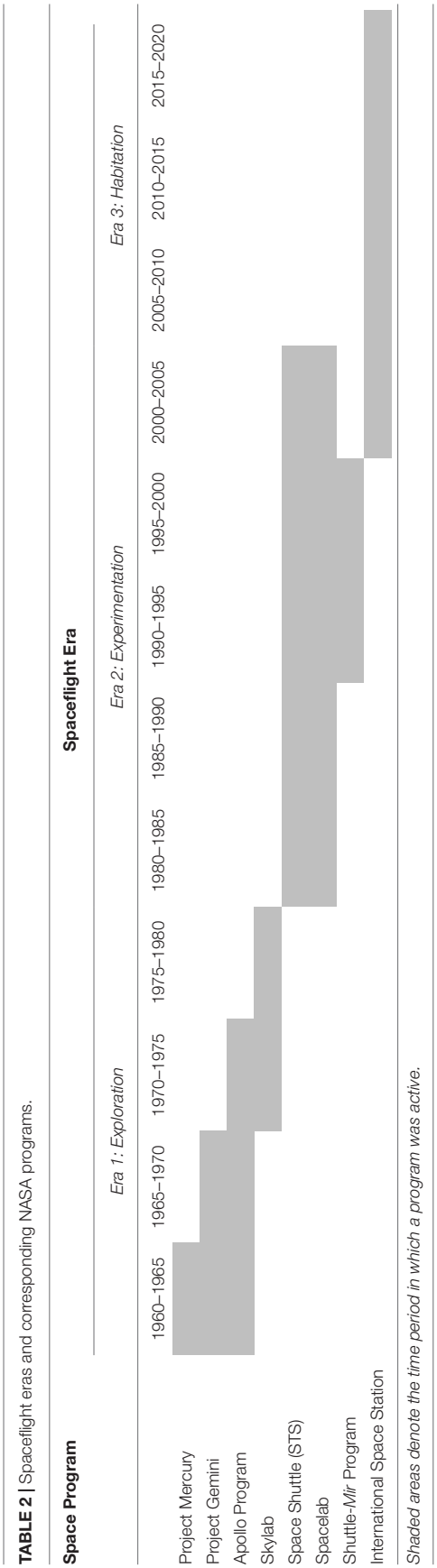

TABLE 3 | Major goals, critical events, and key challenges within three eras of spaceflight (Research Question 2).

Era 1: Early Exploration (1960–1980)	
Major Goals/Objectives	• Establish the technical competency needed to overcome the fundamental challenges of spaceflight • Compete effectively with international rivals ("Space Race")
Critical Events/Mission Milestones	• First manned orbital flights (Project Mercury) • Development of intra-lunar manned spacecraft (Project Gemini) • Moon landings (Apollo Program) • Loss of the AS-204 crew (Apollo 1 fire) • Apollo 11 moon landing • Apollo 13 "successful failure" • Launch and maintenance of the Skylab station
Key Challenges	• Rapidly overcoming basic challenges of manned spaceflight while *competing* internationally • Overall, progression was anticipated (e.g., Mercury and Gemini programs centered primarily around development of technical capabilities; Apollo missions were the culmination of that development) • However, unforeseen setbacks occurred (e.g., Apollo 1 fire, Apollo 13 explosion)
Era 2: Experimentation (1980–2005)	
Major Goals/Objectives	• Capitalize on the technical advancements of the previous era to engage in a program of scientific experimentation in space (international competition no longer a key issue)
Critical Events/Mission Milestones	• Space shuttle development and missions (STS) • Hubble telescope maintenance in orbit • Loss of Shuttle Challenger • Loss of Shuttle Columbia • Shuttle-Mir Program/Phase I
Key Challenges	• Highly complex and technically challenging missions • Notable performance decrements occur as the result of rigid, unclear, and inefficient communication structures; these decrements presented an unanticipated area of challenge
Era 3: Habitation (2000-present)	
Major Goals/Objectives	• Create and maintain an orbital platform to support continuous human occupation. • Collaborate with an array of international partners to accomplish this shared superordinate goal.
Critical Events/Mission Milestones	• The establishment of the International Space Station (ISS) program • The component launches and orbital assembly of the International Space Station • Multiple missions executed in support and supply of the station • Retiring of the space shuttle program • Increased integration of private partnerships for the supply and maintenance of the station • Expedition missions of unprecedented duration (approximately a year in the longest cases)
Key Challenges	• Much longer duration missions (presents both technical and interpersonal challenges) • Work successfully with international partners with different norms and work processes • Most of the challenges during this period were not unexpected, but were persistent and critical (e.g., relations between international partners must be maintained continually)

his oral history, and conveyed the extremely uncertain nature of spaceflight at this time:

> *"I didn't think it was risk free but I thought that the [national] reasons for doing it were important, [as well as] the patriotic and... exploration... [This] all made me decide that... there was [probably] one chance in three that [we] wouldn't make it back, that there was probably two chances in three that we wouldn't go there either because we didn't make it back or [we had to abort] and one chance in three we'd have a successful mission, [that this was a risk worth taking]."* – Anders (1997, 8 October), Apollo 8 Lunar Module Pilot.

Critical Events, Challenges, and Adaptations

Era 1 was marked by a number of prominent events, including the first manned orbital flights (the focus of Project Mercury), the development of the first effective intra-lunar manned spacecraft (the chief goal of Project Gemini), and the six successful moon landings (the focus of the Apollo Program). These events represent a planned progression from early orbital flight to manned lunar landings. The challenges and successes described during this era related to discovering a need to build and, subsequently, master an expanding body of technical expertise in the realm of spaceflight. In addition, this era was marked by unexpected events that prompted significant adjustments within the system, notably the Apollo 1 fire and the "successful failure" during Apollo 13.

The severe physical and technical challenges inherent to early exploration strained NASA's capabilities throughout the first era. Tasked with operating in an unfamiliar environment, NASA personnel needed to collaborate intensively to arrive at novel solutions, often in response to problems that were unforeseen at the outset of the mission. In many cases, these challenges were addressed successfully. Nonetheless, this era was also marked by significant failures and tragedies aboard American space vehicles. In many cases, the failures engendered significant changes, improvements, and/or adaptations during subsequent missions.

Prominent among the tragedies driving change within this period is the on-board fire and subsequent total loss of the Apollo 1 (AS-204) crew. During a preflight rehearsal on January 27, 1967,

TABLE 4 | Key SFMTS adaptations across three eras of spaceflight.

Era 1: Early Exploration (1960–1980)
Summary of Adaptations: NASA's SFMTSs met the technical competency and external competitiveness demands of Era 1 by establishing and emphasizing formal hierarchies and formalized communication, technical training, and planning procedures ***Examples:*** • Established MTS structures based on military organizations. • Established communication processes leveraging technology (e.g., vacuum tube messages; headsets). • Established new training procedures – focused particularly on taskwork (e.g., high-fidelity simulation training for both crew and the ground control teams). • Established contingency planning procedures – by the time of the Apollo missions there was an emphasis on planning for all eventualities and rehearsing/training these scenarios.
Era 2: Experimentation (1980–2005)
Summary of Adaptations: NASA's SFMTSs evolved to meet the added complexity of Era 2 task demands by shifting their internal communication, collaboration, and oversight structures and practices. ***Examples:*** • Communication processes and structures (particularly internally) changed substantially, in response to unexpected failures. • Center directors were empowered to make more direct contact with NASA management. • An Independent Technical Authority was established to make impartial judgements of launch readiness. • The responsibility of all component teams and contractors to raise concerns related to crew safety or launch readiness was reaffirmed, and reporting practices were articulated. • Training practices now included additional information about communication and coordination processes – ground control teams received updated training on reporting practices based on the recommendations of the Challenger and CAIB reports. • Initial steps toward greater collaboration with the Russian space agency made during Shuttle-Mir program; the number of personnel trained to speak Russian and coordinate with international partners began to increase toward the end of this era. • Technical practices (taskwork training, contingency planning) established during the previous era were refined and expanded.
Era 3: Habitation (2000-present)
Summary of Adaptations: NASA's SFMTSs evolved to meet the challenges of multinational collaboration and long-term habituation within Era 3 by enhancing external communication and collaboration structures and practices. ***Examples:*** • Frontroom team elements comprised of international partner flight controllers were integrated directly into the NASA and ROSCOSMOS frontroom teams. • NASA crew members learn to speak Russian prior to transport to the station to aid in communication with crewmembers. • Substantial improvements to interagency communication practices/procedures. • Enhanced teamwork training procedures to facilitate shared understanding, collaboration, etc.

a fire broke out in the cabin of the Apollo 1 Command Module, resulting in the death of all three crew members (astronauts Grissom, White, and Chaffee). Failures in basic protocol as the disaster unfolded revealed critical weaknesses in the planning of missions and tests.

In response to the AS-204 fire, NASA conducted a formal inquiry into the incident, under the *Apollo 204 Review Board*. The report of the board concluded that among other major causes of the accident, emergency preparedness during the test had been inadequate because of the unfueled condition of the rocket and perceived low risk of the test. the disaster instigated a change in the behavioral procedures of NASA. On the day following the disaster, flight control operations branch chief Gene Kranz issued what is now known as the "Kranz Dictum," which would come to exemplify the future identity of MCC. Kranz is quoted in part as having delivered the following words in response to the disaster:

> *"From this day forward, Flight Control will be known by two words: 'Tough' and 'Competent.' Tough means we are forever accountable for what we do or what we fail to do... Competent means we will never take anything for granted. We will never be found short in our knowledge and in our skills."* – Gene Kranz, Flight Director, 28 January, 1967.

Kranz's specified focus on Flight Control as being "tough and competent" directed a continuing tradition of accountability, teamwork, and technical mastery that would continue to mark MCC throughout NASA's subsequent history. The first adaptation made by MCC, in response to this episode, was a clear delineation of component team responsibilities and accountability. As Kranz's quote emphasizes, teams and individuals within the system were to be directly accountable for the systems under their control. Combined with the functional specialization of frontroom and backroom teams established early in MCC's history, this responsibility directed individual component teams to work collectively to support the overall success of the mission, while directing their own internal efforts toward the success of their respective systems. The central issue of accountability and control over launch progress would continue to be a point of struggle for MCC during future missions, as the later loss of the *Challenger* and *Columbia* Shuttles would show. Nonetheless, the incorporation of this lesson following the AS-204 fire represents a critical turning point in the history of MCC.

In contrast to the Apollo 1 fire, the Apollo 13 emergency represented a successful response to an unforeseen technical challenge that required MCC teams to collaborate extensively with a spaceflight crew to arrive at a novel solution. Dubbed a "successful failure" by NASA, the retrieval of the Apollo 13 crew following this severe failure evidences MCC's growing technical competency. On April 14, 1970, an oxygen tank

aboard the Apollo 13 spacecraft exploded. The chaotic atmosphere following the explosion is captured by flight director Glynn Lunney:

> *"I [returned to the frontroom] and plugged in at the flight director console to hear a confusing array of multiple indications of problems... The fact of a really serious condition began to dawn on the team as the crew reported the spacecraft venting particles as seen out the window... EECOM was concluding that this was not an instrumentation problem and two fuel cells were indeed lost."* – Lunney (2010), Flight Director.

The subsequent days required substantial innovation on the part of both the crew and ground teams, perhaps shown most memorably in the construction of the "mailbox" device to aid in removing carbon dioxide from the Lunar Module (LM). In spite of significant technical challenges in even voice communication with the crew, MCC frontroom teams were able to collaborate with both the spaceflight crew and backroom support teams to develop and implement this solution.

The contrast between the AS-204 disaster and the "successful failure" of Apollo 13 highlights a second adaptation instituted within MCC and NASA more broadly. In the years prior to Apollo 13, NASA and MCC had engaged in significant contingency planning and simulation training. The crew's use of the LM as a "lifeboat" represents an observable outcome of increased planning and preparation, as it had been rehearsed during a training simulation despite the perceived unlikelihood of the plan's implementation. This contingency planning and simulation reduced the demands on interteam coordination within the system, allowing teams to respond to unfolding events quickly and effectively, without the need to rely on time-consuming direction from central leadership. This freed up communication channels between teams to focus on the transmission of new information, a critical factor in the system's success.

Representing a third adaptation during this era, rapid communication between component teams and reliance on the largely independent operations of MCC backroom teams allowed MCC personnel to rapidly develop solutions to complex unfolding problems over the course of Apollo 13's return to Earth. Glynn Lunney captures this developing ability to rapidly respond to new information:

> *"The MCC pipeline was regularly delivering a number of new and non-standard checklists for required activities. There were some very effective leaders of specific areas and probably hundreds of operations and engineering personnel evaluating all options and astronaut crews testing each procedure in the simulators."* – Lunney (2010), Flight Director.

As NASA advanced through Era 1, SFMTSs continued to capitalize on accrued technical and behavioral expertise. This leveraging of technical competency resulted in the first successful lunar landing during the Apollo 11 mission in 1969, as well as five subsequent successful lunar landings. In many ways, the base structure of MCC established during this era has not changed until the present day. The missions MCC has been tasked with supporting over the course of NASA's history have continued to place similar demands on knowledge integration and coordination of efforts among diverse personnel that prompted the organization of MCC as an MTS initially.

Summary of Era 1 Adaptations

As **Table 4** summarizes, during Era 1, NASA adapted primarily to meet the technical competency and external competitiveness demands of the period by establishing and emphasizing *formal* hierarchies, communication, training, and planning procedures. Early in this era, NASA adopted rigid, hierarchical organizational structures—and the initial use of the MTS structure—to remain decisive and ensure new information would be rapidly actionable in this uncertain and highly competitive environment. The basic organization of a frontroom team tasked with integrating information among functionally diverse backroom support teams was established early in this era, in response to the technical demands of spaceflight itself. Further, including the role of a flight director as a formalized leadership role within this MTS was recognized as critical to accomplishing the system's goal of integrating knowledge and coordinating efforts among the various component teams and teams outside MCC.

Additionally, NASA implemented rapid communication practices facilitated by technology (during this era aided by radio headsets and vacuum message tubes), and the extensive documentation of process which is still observable within MCC finds its origins during this first era. Exemplified by the crew's rapid response to the explosion aboard the Apollo 13 spacecraft described above, MCC personnel acknowledged a need for extensive rehearsal of even unlikely scenarios, given the uncertain nature of spaceflight. Thus, MCC developed extensive training programs which emphasized *technical* competencies and contingency planning to prepare for the uncertain demands of a complex and evolving mission environment.

Era 2: Experimentation Overview

Major Goals

During the second era, *Experimentation,* which included endeavors such as the Space Shuttle missions and the Shuttle-*Mir* Program (i.e., a collaboration between NASA and the Russian space agency ROSCOSMOS), the tasks conducted aboard the spacecrafts became more complex. During this period NASA's SFMTSs' efforts centered around capitalizing on the technical advancements of the previous era and conducting research in the unique environment of space. Moreover, following the successes of the Apollo Program (and the end of the "space race"), international competition declined as a central focus of the space program. As noted by Joseph Allen in his oral history interview, the transition toward a focus on experimentation in space began prior to the start of the Space Shuttle missions (i.e., during the later years of Era 1), but was slow to be adopted:

> *"[Apollo] 14 was Alan Shepard, who wasn't all that keen on a lot of science. But [for Apollo 15, science] really stuck. We had crew members [who] liked the science, and we had all kinds of new [science] equipment, and it wound up being the first lunar [mission with geological] traverses that involved some serious distances across all kinds of geology in the rover."* – Allen (2003, 28 January), Apollo 15 Support Crew Member.

Critical Events, Challenges, and Adaptations

The launch and maintenance of the *Skylab* station, which was designed to serve as a solar observatory and platform to support scientific experiments, marked a transitional point in NASA's mission focus and the event which distinguishes Era 1 from Era 2. This transition represents the beginning of a fusion of both the exploratory focus of the first era and the emphasis on experimentation in space, which would come to dominate the second.

Unfortunately, although it was representative of burgeoning confidence in the ability to execute spaceflight successfully, the station was also plagued by technical difficulties beginning with its initial deployment. During launch, a micrometeoroid shield became dislodged, damaging the solar panels intended to supply power to the station. Archival documents revealed that interview subjects largely focused on the technical challenges of the station's construction, deployment, and maintenance. This is notable in an oral history interview conducted with Arnold Aldrich:

> *"The Skylab 1 first flight had the micrometeoroid protection on the outside of the workshop come off during launch, and it took one solar array with it and pinned down the second one, so that the spacecraft got into orbit without thermal protection and with somewhat limited power... So this temperature was a big concern. Both Marshall and Johnson immediately moved out to figure out how we could quickly ameliorate the overheating in the workshop."* – Aldrich (2000, 24 June), Deputy Manager (Skylab Program).

In spite of these difficulties, maintenance Skylab showcased the increased technical achievement of NASA, with the deployment of a sunshield to prevent overheating and two additional Extravehicular Activity (EVA) repairs being the focus of the first of three manned missions to the station (SL-2).

Although the loss of the station to orbital decay, in some ways, represented the still-present technical challenges faced by NASA, it was also the result of the growing prioritization of the development of the *Space Shuttle Program*, the centerpiece of the second era. The space shuttle program epitomizes the second era. Over the lifetime of the program, the shuttle was used both as an Earth-to-orbit transportation vehicle as well as an orbital experimental platform. Similar to the missions comprising the first era, shuttle missions were short in duration, lasting for days to approximately 2 weeks. To facilitate the experimental mission of the shuttle, a laboratory module called "Spacelab" was sometimes incorporated into the shuttle.

NASA's increasing focus on experimentation was facilitated in large part by the technical competencies accrued during the previous era. In a revealing passage from a NASA mission archive on STS-61, maintenance on the Hubble Space Telescope is described as being completed ahead of schedule, with a few unexpected events being handled smoothly. This characteristically competent mission completion occurs within the context of "*one of the most challenging and complex manned missions ever attempted*" (Ryba, 2010). Interestingly, following the establishment of the shuttle program, NASA's objectives of experimentation often differed from those of IPs, as ROSCOSMOS objectives aboard the station focused more on simply maintaining a manned presence in space (Foale, 1998).

However, this era was also characterized by major disasters. One of the greatest tragedies to occur during this era of spaceflight was the loss of the shuttle *Challenger* and its entire astronaut crew (STS-51L). A series of aborted launches due to a range of weather concerns lead to mounting impatience, and an eventual go-ahead for the launch despite concerns over low temperatures. This push to move forward with the launch was exacerbated by plans to widely televise the launch. The conflict between caution and the mounting pressure to launch within MCC is captured by Steve Nesbitt, a NASA public affairs officer working at MCC at the time:

> *"There had been a couple of scrubs in the days before. That was not unusual. Some of the most conservative people you will ever find are in Mission Control. If something wasn't right, they were quite willing to delay and come back another day. But that mission just went on and on."* – Nesbitt (2016, 28 January), NASA MCC Public Affairs Officer.

Following the loss of the shuttle *Challenger*, President Reagan established a commission to conduct an investigation into the disaster and potential ways in which the disaster might have been averted. The commission concluded that "flaws in (NASA's) decision making process" were a contributing cause of the accident (Presidential Commission on the Space Shuttle Challenger Accident, 1986). The report found that failures in communication resulting from incomplete and misleading information, in conjunction with a NASA management structure which permitted known safety issues to bypass shuttle managers, led to known risks remaining unaddressed in readiness reviews. In the recommendations provided by the commission, improvements to management and communications factor prominently, with an emphasis on managerial integration and improved communication across the organization (recommendations II and V; Presidential Commission on the Space Shuttle Challenger Accident, 1986, p. 199–200).

In response to the commission's recommendations, the hierarchy of organization within the Office of Space Flight was restructured to allow the MCC far more direct access to NASA administration. Regular, formalized communication between the directors of JSC and other organizational components were instituted. Perhaps most notably, the accountability of center directors for the "technical excellence and performance of the project elements assigned to their centers" was reaffirmed (Presidential Commission on the Space Shuttle Challenger Accident, 1987, p. 31). These adjustments in the interteam collaboration processes of the MCC represent the first integration of lessons learned based on the challenges of this era.

Despite the implementation of these recommendations, the subsequent loss of the shuttle *Columbia* would illustrate the need for further adaptations in NASA's internal collaboration. On February 1, 2003, the Shuttle *Columbia* disintegrated while reentering the atmosphere, resulting again in a complete crew loss (STS-107). The failure resulted from damage from foam impacting the wing of the spacecraft during launch. In a subsequent investigation, the Columbia Accident Investigation

Board (CAIB) concluded that NASA engineers had raised concerns following the launch that the foam shedding damage to Columbia may have been more significant than in previous launches. NASA managers did not initiate investigations into this possibility. Notably, the report concluded that flaws within the organizational structure of NASA were significant contributors to the disaster, and the loss would likely have occurred irrespective of which individuals were in the managerial roles.

In a second adjustment, following the recommendations made by the CAIB, NASA and MCC implemented several changes to the structure and behavior of MCC (Columbia Accident Investigation Board [CAIB], 2003). Among these changes was the establishment of an independent Technical Engineering Authority, "responsible for technical requirements and all waivers to them" (Columbia Accident Investigation Board [CAIB], 2003, p. 193). In keeping with the recommendations of the CAIB, the technical authority became the sole authority for all technical standards, and independently verified launch readiness with the ability to reject any scheduled launch should an undue risk be found. Critically, the ITA would be funded directly from NASA headquarters, removing it from any, "connection to or responsibility for schedule or program cost" (Columbia Accident Investigation Board [CAIB], 2003, p. 193). The ability of any component team to raise objections about the readiness of any system for launch was also reaffirmed. These changes increased the safety of future shuttle crews by allowing evaluation of launch readiness not subject to constraints or pressures from other elements within the organization.

Despite these two public failures, the program of experimentation in space continued largely successfully throughout the second era. One of the lasting legacies of the shuttle program is the ability to launch large payloads into orbit, which would be critical during the following era. Moreover, beginning in 1995 and continuing through 1998, NASA collaborated with ROSCOSMOS to host American astronauts aboard the Russian *Mir* space station (the Shuttle-*Mir* Program). Accordingly, astronauts conducted research aboard the orbital platform while the space shuttle continued to be used for resupply and crew transport. During this program, sometimes called *Phase I*, NASA MCC personnel learned to form conducive working relationships with Russian ground control teams, requiring them to overcome challenges arising from language and cultural barriers (Reeves, 2009; Hill, 2015).

However, international collaboration was undoubtedly affected by external socio-political forces. For example, the fall of the USSR in 1991 led to improved relations between the Russian Federation and the United States, and a corresponding increase in the potential for international collaboration. The 1992 agreement between Presidents Bush and Yeltsin solidified plans for cooperation in space exploration, leading to the Shuttle-*Mir* and subsequent programs, although relations between organizations from the two countries would remain challenging.

A clear demonstration of these challenges can be found in astronaut Michael Foale's time aboard the *Mir* station. During that period an unmanned *Progress* spacecraft collided with the station, causing substantial damage and a fire aboard the station. Despite initial trepidations among the Russian ground teams, Foale was allowed to take part in EVAs to repair the station following the development of a medical issue by cosmonaut Tsibliev. Accomplishing this goal required MCC personnel to coordinate rapidly with Russian ground control (TSuP) to secure permission for Foale to conduct the EVAs, as well as effective coordination among both ground control groups and the international members of the crew to quickly familiarize Foale with the Russian-made EVA equipment (Foale, 1998).

Summary of Era 2 Adaptations

During Era 2, NASA's SFMTS adapted to meet the added complexity of task demands by improving internal communication, collaboration, and oversight structures and practices. NASA personnel were empowered to raise concerns in connection with launch readiness directly; the responsibility of all NASA personnel to raise such concerns as they became aware of them was reaffirmed. Training procedures introduced during this era targeted effective internal communication practices directly. Finally, an Independent Technical Authority was established to make impartial judgments about launch readiness, outside the NASA managerial hierarchy.

Where failures occurred, they prompted adaptations to coordination within MCC and the SFMTS. Where challenges were successfully addressed, the outcomes exemplify critical competencies built during the first era of spaceflight: extensive contingency planning, leveraging of large amounts of training to arrive at innovative solutions, and rapid communication among functionally diverse teams. In spite of these successes, structural weaknesses within the MCC resulted in failures during this era, requiring further changes to be made in order to prevent future breakdowns in process.

As was the case during Era 1, SFMTS adaptations in Era 2 were often prompted by unexpected external events—in this case, often socio-political ones. In particular, the challenges in coordination between teams from NASA and ROSCOSMOS demonstrated an increasing need for familiarity both with IP equipment and practices, a need which led to the introduction of more extensive SFMTS training within the subsequent era of habitation. As a result, during the Shuttle-*Mir* program, NASA's MCC evolved in their ability to coordinate effectively with IP organizations. In fact, the MCC MTS expanded to include remote personnel embedded with Russian ground control teams. These international consulting teams represented an early advancement in formalizing the relationship between NASA MCC and Russian ground control personnel, a challenge which would continue to be addressed during the subsequent era of habitation. Subsequently, the success of the Shuttle-*Mir* program laid the groundwork for the International Space Station program—and the increasingly intense international collaborations that would be required by that program. This transition is highlighted in Dr. Michael Barratt's oral history interview:

> *"Those of us that were heavily involved in the Shuttle-Mir Program realized two things. How wonderful it would be, because we found that we could work with our Russian counterparts quite well, and how difficult it would be, because they do things very differently than we do... Without the Shuttle-Mir Program I can't imagine starting from scratch and going into such a large program as the*

International Space Station" – Barratt (1998, 14 April), Human Research Program Manager.

Era 3: Habitation

Major Goals

In the third era, *Habitation*, which consisted primarily of the construction of and expeditions aboard the International Space Station (ISS), mission objectives centered on establishing a continuous human presence in space in collaboration with IP organizations. The major goal of Era 3 was the construction and maintenance of an orbital platform to support continuous human occupation. The primary operational difference between the activities of Era 3 and earlier periods is the extended mission timeframe of ISS expeditions. The ISS has been continuously inhabited since late 2000, with the longest individual crew member stays lasting approximately 1 year.

Critical Events, Challenges, and Adaptations

The challenges facing SFMTSs during Era 3 centered on overcoming difficulties related to international collaboration and the physical challenges of long-duration spaceflight. In Era 3, NASA has needed to collaborate intensively with an array of IPs in pursuit of shared goals. Moreover, whereas previous eras were characterized by missions lasting several days, this era is marked notably longer spans of habitation aboard the ISS (e.g., 6 months).

To support the station, the MCC has engaged in continuous operations for 18 years. This shift from short-duration, high-intensity missions to a long-term mission timeline requires MCC to operate in fundamentally different ways than they did during prior missions and eras of spaceflight. New skills relevant to the monitoring and maintenance of the crew and station have become more salient to the present task, shifting the needs of the system in important ways. Additionally, extended habitation in space places immense strain on astronauts' bodies, including loss of visual acuity, muscle loss, and loss of bone density. In turn, these physical challenges can exacerbate the already intense psychological strain on astronauts. Combined with the challenges of existing for a prolonged period of time in a confined space alongside a diverse, international crew, the confluence of these psychological strains can be intense. The challenges of intensive collaboration with IP organizations are discussed by Dr. Michael Barratt during his 2015 interview for the International Space Station oral history project:

> *"I think if anybody had asked us what a good model for making a Space Station would be, the answer would not have been to choose a major partner who speaks another language, who uses metric system rather than English system, who has a totally different engineering philosophy, safety culture, methods of operation, methods of manning. All of that was different."* – Barratt (2015, 30 July), Human Research Program Manager.

The types of challenges described by Michael Barratt in the above quote required NASA and their IPs to leverage the lessons of the previous two eras of spaceflight. As in the era of experimentation, NASA's SFMTSs in the third era have continued to draw on the technical competencies built during prior eras. Michael Barratt further discusses technical competency in the context of the ISS, with respect to the ISS's usage as a platform for scientific experimentation:

> *"I think one of the main things is that just looking at the Station as a laboratory, it has grown in capability, and it enables science that we could never do before, because it is power-rich, and it has an incredible bandwidth to it... the laboratory that [the ISS has] evolved into is just incredibly capable."* – Barratt (2015, 30 July).

These competencies were combined with the capabilities for launching large orbital payloads developed during the era of Experimentation. Leveraging this knowledge and the lessons of the Shuttle-*Mir* program, NASA collaborated closely with a wide range of IPs to complete the ambitious ISS platform in 2011. As summarized by Michael Suffredini, the legacy of the ISS is to consciously build and demonstrate capabilities to sustain human habitation in space for extended periods of time.

> *"The legacy of ISS will be that we created an environment that allowed us to permanently have humans in low-Earth orbit. That, by its very nature, will mean that the ISS helped us do exploration, because we have the capability permanently in low-Earth orbit to do the things we need to do to safely travel beyond low-Earth orbit."* – Suffredini (2015, 29 September), ISS Program Manager.

Accordingly, NASA SFMTSs have had to develop substantial procedures for coordination among IP ground control teams in order to meet the challenges of international collaboration in spaceflight, as well as building a number of technical competencies to facilitate this relationship. Representing a first adjustment during this era, over the course of the Shuttle-*Mir* program and subsequent phases of the ISS project a large number of NASA engineers learned Russian (Barratt, 1998), and channels of communication were established which grew more developed as communication technologies advanced and communication between the organizations normalized (Reeves, 2009; Hill, 2015). Among these adaptations were the inclusion of a Russian console in MCC, as well as a translator loop allowing MCC flight controllers to listen in on the communications between the Russian ground control teams and their crew members aboard the station. Dr. Barratt discusses this finding of common ground in his oral history interview.

> *"Once you get past the language barrier, people understood that the laws of physics are the same, the laws of orbital mechanics are the same, zero gravity is the same, and it was pretty easy to find common ground amongst the crewmembers and the supporting engineers. Really language was the only thing in the way there. A lot of United States engineers learned Russian, a lot of Russians learned English, which was quite wonderful. Once we got through that, we found that we could work together pretty well."* – Barratt (2015, 30 July), Human Research Program Manager.

Lastly, the challenges in terms of interteam relations between teams in MCC, other NASA teams, and IP teams have resulted in the integration of interpersonal and team skills training into the training regimen of astronauts and flight controllers. Notably, the present iterations of these training practices focus primarily on enhancing teamwork within *individual* teams, rather than teamwork processes spanning across multiple teams.

Summary of Era 3 Adaptations

Adaptations made during this era centered around meeting the challenges of multinational collaboration and long-term habitation by developing greatly improved *external* collaboration practices. Altered practices and competencies aided in more rapid and effective communication across organizational and national boundaries, as did dedicated training in teamwork practices. Interventions aimed at teamwork helped ensure that the multinational crew aboard the station was able to function effectively, and interpersonal conflict resulting from the challenging physical and relational environment was minimized.

DISCUSSION

Drawing from archival sources, this case study identified many of the collective memories (e.g., mission successes, failures), lessons learned, and adaptations or practices implemented within NASA's SFMTSs in the three prior eras of early exploration, experimentation, and habitation. NASA and their IPs are now on the brink of an anticipated *fourth* era of spaceflight, characterized by LDEMs. The "team risk" will play a much larger role than in previous missions, as team and interteam coordination must be sustained for *multiple years* as SFMTSs tackle unexpected and even dangerous challenges (Salas et al., 2015). We expect that whether these systems will be able to address the challenges of future missions will be impacted by the rich history of the organizational environment, the lessons learned in previous missions, and the organizational practices related to teamwork that have been implemented within NASA.

Synthesizing the Adaptations of Previous Eras to Facilitate Adaptive Performance in the Next Era of Spaceflight

As summarized in **Table 4**, our analysis of archival documents revealed three broad categories of adaptations used to meet the evolving task demands of the previous eras of spaceflight: (1) *enhancing technical expertise*, (2) *enhancing or shifting internal collaborative relationships*; and (3) *enhancing external or cross-organizational partnerships*. Interestingly, we find that NASA's SFMTSs emphasized these different categories of adaptations in different ways within each era. During Era 1, the external competition and the massive demands for improved technical competence meant that the primary focus was on enhancing *technical* expertise. In Era 2, NASA complex mission demands continued to require new technical developments, however, unexpected disasters (e.g., the losses of Challenger and Columbia) revealed that adaptations were urgently needed with regard to *internal collaboration* patterns. Lastly, in Era 3, the installation of the ISS necessitated a focus on *external partnerships* with international agencies.

Figure 4 summarizes the emphasis on different categories of adaptive behaviors across the previous three eras. As we enter into the fourth era of spaceflight exploration, NASA's SFMTSs must not lose the gains made in previous eras. The challenges of LDEMs reflect those seen within early exploration, experimentation, and habitation. However, LDEMs also present new challenges that will call for new adaptations. Indeed, as shown in **Figure 4**, NASA's SFMTSs will need to significantly enhance their technical capabilities, internal collaborative relationships, and external partnerships in order to achieve the goals of LDEMs.

In the following, we discuss the anticipated challenges of the upcoming era of human spaceflight, and the adaptations that will be required. Given the complex challenges involved in LDEMs, NASA's SFMTS will need to adapt substantially across all three domains (i.e., technical expertise, internal coordination, and external coordination). This need to reconsider existing practices in the light of new challenges is nothing new to NASA, as our review demonstrates. For example, in an oral history interview conducted in May of 2015, MCC lead system architect David McGill states:

> *"Well, how will your design react if suddenly we have a mission that is going to involve three countries to go fly it? How are you going to tolerate that? How is your system going to respond to all of a sudden wide area networking is twice as fast and half as much money as it is today? Can you take advantage of that?"* – McGill (2015, 22 May), MCC Lead System Architect.

First, echoing Era 1, LDEMs will bring demands for adaptation in *technical* expertise. For example, the distances to be traveled in LDEMs represent a significant technical challenge. A variety of technical approaches to manned Mars missions and other LDEMs have been discussed (e.g., the Lunar Gateway platform; National Aeronautics and Space Administration [NASA], 2014); but all will require substantial technical advancements. Further, the distances involved in LDEMs will require extremely long periods of travel beyond which will place new strains on astronauts. Negative physical effects may become continuously more severe over the greater mission timeframes of LDEMs. The extended time the crew will be isolated from the rest of the system leads to particularly intense concerns around training retention, as technical training is known to degrade over time and the highly autonomous crew will be less able to rely on support from ground-based teams (Landon et al., 2018).

The challenges of LDEMs will also require adaptation with respect to *internal* collaboration practices. As an unavoidable consequence of the massive distances traveled during a LDEM, there will be significant communication delays between the spaceflight crew and earthbound teams. At the greatest distance, communications to or from the crew of a Mars mission could take up to 24 min to arrive at their destination. Such communication delays represent a stark contrast with the effectively instantaneous communications between MCC and the crew of the ISS. In the third previous eras of spaceflight, crews relied heavily on rapid communication with Earthbound teams to arrive at solutions. However, in LDEMs, the crew will need to operate far more independently, as reliance on continuous feedback from MCC will not be feasible. Such *decentralized* authority structures may be necessary for LDEM success but

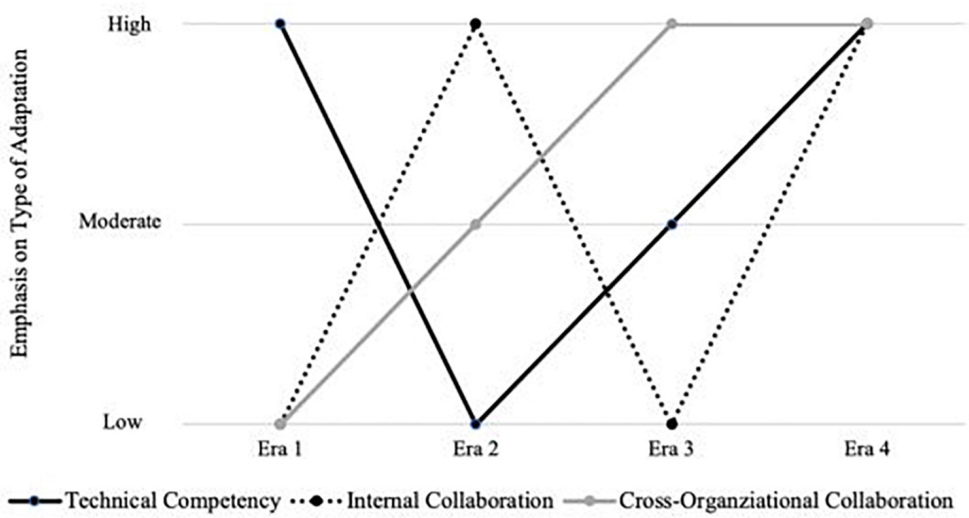

FIGURE 4 | Amount of emphasis on different types of adaptations with each spaceflight era. Emphasis varied across eras with regard to (1) enhancing technical competencies (solid black line); enhancing internal collaboration (dashed black line); and (3) enhancing cross-organizational partnerships (gray line).

may also present challenges for multiteam coordination and performance (Lanaj et al., 2013).

Finally, the upcoming era of spaceflight will require continued adaptation in the domain of *external* coordination and collaboration. LDEMs will reach further than any prior manned spaceflight mission and will require massive inter-agency coordination across national and organizational borders. The SFMTSs involved in LDEMs will be comprised of members from different cultures, backgrounds, nations, and areas of expertise. Such high levels of individual and team differentiation are likely to pose challenges for interteam collaboration (Luciano et al., 2018). Moreover, SFMTSs involved in LDEMs will experience dynamic environments characterized by expected (e.g., increased communication delays) and unexpected challenges. As a LDEM progresses, different areas of technical expertise will become more or less relevant to the task at hand, resulting in shifts in goal priorities and the relative authority of teams over the course of the mission. As these responsibilities may be distributed across IPs teams (as with the current operation of the ISS) these highly dynamic contexts may exacerbate tensions surrounding organizational boundaries and hinder communication and interteam coordination (Luciano et al., 2018).

Moreover, the consequences of longer-duration mission timelines for internal and external collaboration remain in question. Whereas research on team tenure would seem to suggest that performance of the system will increase over time (Bell, 2007), initial evidence from research conducted using NASA analog environments has demonstrated that when crews are restricted to isolated environments for prolonged periods of time, longer team tenure can lead to collaboration and cohesion decrements as interpersonal conflicts becomes more severe (Kozlowski et al., 2016). Indeed, concerns have been expressed around the strain that long-duration spaceflight may place on astronauts and the potential negative effects for interpersonal relations both within the crew and across component teams in SFMTS (Palinkas, 2007; Palinkas and Suedfeld, 2008; Landon et al., 2018).

Beyond LDEMs: Theoretical and Practical Contributions

This case study is focused on the specific context of NASA's SFMTSs. However, there are at least four ways in which the findings from this research might inform MTS research and practices within other contexts. First, our review revealed that adaptations with were driven by the focus and challenges of the periods in which they were enacted and clustered into one of three general categories: (1) technical competency, (2) internal coordination, and (3) external or cross-organizational coordination (see **Figure 4**). Although the adaptations identified in archival documents were generally specific to NASA, the three-category framework may be useful for conceptualizing and advancing MTS adaptations in other contexts. With respect to MTS research, future empirical work may benefit from the greater specificity of these dimensions, and their relationship with situational and task demands. In practice, organizations can target the dimensions of adaptation that have successfully addressed related challenges in the past when preparing for upcoming challenges. In particular, anticipating the needed patterns of adaptation may allow for more successful proactive intervention–thus avoiding the inefficiencies of adapting after needs are revealed by performance decrements. Strategies allowing for more successful proactive adaptation are especially relevant to high-reliability organizations operating in dynamic environments (HROs) like NASA, the military, and disaster response teams. HROs often operate in unforgiving competitive, social, and political environments that are rich in potential

for error, and where the scale of consequences associated with error precludes learning through experimentation (Weick et al., 1999).

Second, consistent with prior theoretical work on MTSs (e.g., Zaccaro et al., 2012), our case study revealed compositional and linkage attributes that factor prominently in the functioning of SFMTSs. For example, our review established that component teams in the MCC (i.e., frontroom and backroom teams) are highly differentiated along a variety of dimensions (e.g., areas of expertise, work processes, geographic locations). Although team differentiation is a necessary element of MTS collaboration which allows these systems to divide complex interdisciplinary tasks into disciplinary subgoals, the extreme levels of differentiation often seen in SFMTSs can also incur performance decrements when relationships are not managed effectively (Luciano et al., 2018). In fact, whereas the SFMTSs within Era 1 emphasized formal structures and separations between teams, in order to tackle new demands in Era 2, the SFMTSs began to permit more direct communication channels between people who were otherwise disconnected (e.g., occasional guidance from specialists to crewmembers conducting experiments). These findings suggest an interesting line of inquiry for MTS researchers–MTSs may need to strike the right balance in terms of emphasizing component team separation and integration. However, the optimal balance point may vary based on evolving task demands.

Third, our analysis of the history of SFMTSs suggests MTS research could benefit from considering MTS performance and adaptation on a longer time scale than has been used in previous research. Empirical studies of MTS functioning have focused primarily on performance as a relatively short-term outcome. Although these studies provide valuable contributions to our understanding of MTS functioning, our review of NASA archival documentation revealed that in several cases, short-term failures in performance led to improved performance in the future (e.g., the structural changes made to NASA's management hierarchy in response to the losses of shuttles Challenger and Columbia).

Our findings also provide insight into how adaptation might manifest in HRO contexts following a performance failure. Unlike many teams in which creative solutions are required (e.g., product development teams), teams and MTSs operating within HROs cannot afford to readily accept short-term failures as a means to facilitating learning and adaptation. Nonetheless, errors and failures in performance are a virtual certainty over the long-term. Our findings indicate that the key to successful adaptation may lie in maximizing the information extracted from the events, and its successful integration into future practices. Illustrating this, NASA conducts unflinching internal examinations following critical events to establish both their immediate and structural causes. Notably such rigorous investigations do not only occur in cases where human life has been lost or placed at great risk; this dedication to intensive examination in the wake of any failure is exemplified by the rigorous investigation following the loss of the unmanned Mars Climate Orbiter (MCO) in 1999 (Mars Climate Orbiter Mishap Investigation Board, 1999). Practices like these may be of benefit to even non-HRO organizations, suggesting a wider application of this approach (Weick et al., 1999).

Lastly, we suggest that our case study approach may be applicable in a range of contexts outside NASA as many teams and MTSs have collective performance experience. This work is in keeping with recommendations to conduct qualitative ethnographic research prior to and following quantitative research within an organization (Ofem et al., 2012). Given the impact of a MTS's history on its future operations, we expect continued qualitative examinations of this type will serve to better inform LDEMs, and could serve as the foundation for broader explorations of MTS temporal dynamics. These benefits could be further expanded in future research through detailed examination of the day-to-day operations of MTSs, with respect to the enduring effects of these events in the future. Although the need to consider the rich history of an organization is often acknowledged by practitioners, there is also a proliferation of "off-the-shelf" interventions available. This case study may serve as a reminder that anchoring organizational interventions in an understanding of the historical context of the organization may increase their effectiveness.

CONCLUSION

In conclusion, scholars have argued that a team's history can significantly impact its future (Marks et al., 2001; Hollenbeck et al., 2014). Our analysis of the evolution and adaptation of NASA's history suggests that the same can be said of a SFMTS. We find the lessons learned in previous eras of spaceflight often carry forward into subsequent phases. Our findings revealed that adaptations typically clustered into one of three general categories and were associated with specific types of task demands and critical events. We suggest that LDEM SFMTSs will need to capitalize on the gains of the past while incorporating additional adaptations in order to succeed. Thus, this case study demonstrates the value of examining prior patterns of adaptation in preparation for future challenges.

AUTHOR CONTRIBUTIONS

All authors contributed substantially to the identification, classification, and analysis of archival documents and to the development of the conceptual framing of this manuscript. LL and KS contributed as subject matter experts, and aided significantly in the development of a conceptual framework for the classification of archival resources. Finally, all authors contributed significant amounts of time and effort to the revision of the text and the refining of the conceptual and historical content.

FUNDING

This study is based in part upon work supported by the National Aeronautics and Space Administration (#80NSSC18K0511). Any opinions, findings, and conclusions or recommendations expressed in this study are those of the authors and do not necessarily reflect the views of the National Aeronautics and Space Administration.

REFERENCES

Aldrich, A. D. (2000). Arnold D. Aldrich (K. Rusnak, Interviewer). NASA Johnson Space Center Oral History Project Oral History Transcript. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/AldrichAD/AldrichAD_6-24-00.htm (accessed October 2, 2018).

Allen, J. P. (2003). Joseph P. Allen (J. Ross-Nazzal, Interviewer). NASA Johnson Space Center Oral History Project Oral History Transcript. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/AllenJP/AllenJP_1-28-03.htm

Anders, W. A. (1997). *William A. Anders (P. Rollins, Interviewer). NASA Johnson Space Center Oral History Project Oral History Transcript*. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/AndersWA/AndersWA_10-8-97.htm

Asencio, R., Carter, D. R., DeChurch, L. A., Zaccaro, S. J., and Fiore, S. M. (2012). Charting a course for collaboration: a multiteam perspective. *Transl. Behav. Med.* 2, 487–494. doi: 10.1007/s13142-012-0170-3

Baard, S. K., Rench, T. A., and Kozlowski, S. W. (2014). Performance adaptation: a theoretical integration and review. *J. Manag.* 40, 48–99. doi: 10.1177/0149206313488210

Barratt, M. R. (1998). *Michael R. Barratt, M. D. (R. Wright, P. Rollins, Interviewers). NASA Johnson Space Center Oral History Project*. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/ISS/BarrattMR/BarrattMR_7-30-15.htm

Barratt, M. R. (2015). *Michael R. Barratt (R. Wright, Interviewer). International Space Station Program oral History Project Edited Oral History Transcript*. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/Shuttle-Mir/BarrattMR/BarrattMR_4-14-98.htm

Bell, S. T. (2007). Deep-level composition variables as predictors of team performance: a meta-analysis. *J. Appl. Psychol.* 92, 595–615. doi: 10.1037/0021-9010.92.3.595

Burke, C. S., Stagl, K. C., Salas, E., Pierce, L., and Kendall, D. (2006). Understanding team adaptation: a conceptual analysis and model. *J. Appl. Psychol.* 9, 1189–1207. doi: 10.1037/0021-9010.91.6.1189

Columbia Accident Investigation Board [CAIB] (2003). *Columbia Accident Investigation Board Report*, Vol. I. Washington, DC: Government Printing Office.

DeChurch, L. A., Burke, C. S., Shuffler, M. L., Lyons, R., Doty, D., and Salas, E. (2011). A historiometric analysis of leadership in mission critical multiteam environments. *Leadersh. Q.* 22, 152–169. doi: 10.1016/j.leaqua.2010.12.013

Dunbar, B. J. (1998). *Bonnie J. Dunbar (R. Wright, interviewer). NASA Johnson Space Center Oral History Project*. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/Shuttle-Mir/DunbarBJ/DunbarBJ_6-16-98.htm (accessed October 2, 2018).

Dunbar, B. J. (2005). *Bonnie J. Dunbar (J. Ross-Nazzal, Interviewer). NASA Johnson Space Center Oral History Project*. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/DunbarBJ/DunbarBJ_1-20-05.htm (accessed October 2, 2018).

Falk-Krzesinski, H. J., Borner, K., Contractor, N., Fiore, S. M., Hall, K. L., Keyton, J., et al. (2010). Advancing the science of team science. *Clin. Transl. Sci.*. 3, 263–266. doi: 10.1111/j.1752-8062.2010.00223.x

Foale, C. M. (1998). *C. Michael Foale (Session 1) (R. Wright, C. Butler, M. Davidson, Interviewers). C. Michael Foale (Session 1)*. Available at: https://history.nasa.gov/SP-4225/oral-histories/foale.pdf (accessed October 2, 2018).

George, G., Howard-Grenville, J., Joshi, A., and Tihanyi, L. (2016). Understanding and tackling societal grand challenges through management research. *Acad. Manag. J.* 59, 1880–1895. doi: 10.5465/amj.2016.4007

Hackman, J. R. (1987). "The design of work teams," in *Handbook of Organizational Behavior*, ed. J. W. Lorsch (Englewood Cliffs, NJ: Prentice-Hall), 315–342.

Hill, P. S. (2015). *Paul S. Hill (R. Wright, Interviewer). International Space Station Program Oral History Project Edited Oral History Transcript*. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/HillPS/HillPS_3-24-15.htm

Hollenbeck, J. R., DeRue, D. S., and Nahrgang, J. D. (2014). The opponent process theory of leadership succession. *Organ. Psychol. Rev.* 5, 333–363. doi: 10.1177/2041386614530606

Hollenbeck, J. R., Ellis, A. P., Humphrey, S. E., Garza, A. S., and Ilgen, D. R. (2011). Asymmetry in structural adaptation: the differential impact of centralizing versus decentralizing team decision-making structures. *Organ. Behav. Hum. Decis. Process.* 114, 64–74. doi: 10.1016/j.obhdp.2010.08.003

Ilgen, D. R. (1999). Teams embedded in organizations: some implications. *Am. Psychol.* 54, 129–139. doi: 10.1037//0003-066x.54.2.129

Ilgen, D. R., Hollenbeck, J. R., Johnson, M., and Jundt, D. (2005). Teams in organizations: from input-process-output models to IMOI models. *Annu. Rev. Psychol.* 56, 517–543. doi: 10.1146/annurev.psych.56.091103.070250

Kozlowski, S. W., and Ilgen, D. R. (2006). Enhancing the effectiveness of work groups and teams. *Psychol. Sci. Public Interest* 7, 77–124. doi: 10.1111/j.1529-1006.2006.00030.x

Kozlowski, S. W. J., Chao, G. T., Chang, C.-H., and Fernandez, R. (2016). "Team dynamics: Using "big data" to advance the science of team effectiveness," in *Big Data at Work: The Data Science Revolution and Organizational Psychology*, eds S. Tonidandel, E. King, and J. Cortina (New York, NY: Routledge Academic Press).

Kozlowski, S. W. J., and Klein, K. J. (2000). "A multilevel approach to theory and research in organizations: Contextual, temporal, and emergent processes," in *Multilevel theory, Research, and Methods in Organizations: Foundations, Extensions, and new Directions*, eds K. J. Klein and S. W. J. Kozlowski (San Francisco, CA: Jossey-Bass), 3–90.

Kraft, C. C. (1991). *Christopher C. Kraft (A. Dunbar & S. Waring, interviewers). Interview with Christopher C. Kraft*. Available at: https://www.nasa.gov/sites/default/files/atoms/files/19910628_christopher_kraft_oral_history_interview.pdf (accessed October 2, 2018).

Kranz, E. F. (n.d.). *Wikiquote*. Available at: https://en.wikiquote.org/wiki/Eugene_F._Kranz. (accessed November 27, 2018).

Lanaj, K., Hollenbeck, J. R., Ilgen, D. R., Barnes, C. M., and Harmon, S. J. (2013). The double-edged sword of decentralized planning in multiteam systems. *Acad. Manag. J.* 56, 735–757. doi: 10.5465/amj.2011.0350

Landon, L. B., Slack, K. J., and Barrett, J. D. (2018). Teamwork and collaboration in long-duration space missions: going to extremes. *Am. Psychol.* 73, 563–575. doi: 10.1037/amp0000260

Landon, L. B., Vessey, W. B., and Barrett, J. D. (2016). *Evidence report: Risk of Performance and Behavioral Health Decrements due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team*. Houston, TX: NASA.

LePine, J. A. (2005). Adaptation of teams in response to unforeseen change: effects of goal difficulty and team composition in terms of cognitive ability and goal orientation. *J. Appl. Psychol.* 90, 1153. doi: 10.1037/0021-9010.90.6.1153

Luciano, M. M., DeChurch, L. A., and Mathieu, J. E. (2018). Multiteam systems: a structural framework and meso-theory of system functioning. *J. Manag.* 44, 1065–1096. doi: 10.1177/0149206315601184

Lunney, G. S. (2010). *Apollo XIII*. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/LunneyGS/Apollo13.htm

Madison, L. (2010). *JSC Oral History Project*. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/oral_histories.htm (accessed October 2, 2018).

Marks, M. A., DeChurch, L. A., Mathieu, J. E., Panzer, F. J., and Alonso, A. (2005). Teamwork in multiteam systems. *J. Appl. Psychol.* 90, 964–971. doi: 10.1037/0021-9010.90.5.964

Marks, M. A., Mathieu, J. E., and Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Acad. Manag. Rev.* 26, 356–376. doi: 10.5465/amr.2001.4845785

Mars Climate Orbiter Mishap Investigation Board (1999). *Mars climate orbiter mishap investigation board phase I report*. Houston, TX: NASA.

Mathieu, J. E. (2012). "Reflections on the evolution of the multiteam systems concept and a look to the future," in *Multiteam Systems: An Organization form for Dynamic and Complex Environments*, eds S. J. Zaccaro, M. A. Marks, and L. A. DeChurch (New York, NY: Routledge), 511–544.

Mathieu, J. E., Hollenbeck, J. R., van Knippenberg, D., and Ilgen, D. R. (2017). A century of work teams in the Journal of Applied Psychology. *J. Appl. Psychol.* 102, 452–467. doi: 10.1037/apl0000128

Mathieu, J. E., Marks, M. A., and Zaccaro, S. J. (2001). "Multi-team systems," in *International Handbook of Work and Organizational Psychology*, Vol. 2, eds N. Anderson, D. S. Ones, H. K. Sinangil, and C. Viswesvaran (Thousand Oaks, CA: Sage), 290.

Mathieu, J. E., Tannenbaum, S. I., Donsbach, J. S., and Alliger, G. M. (2014). A review and integration of team composition models: moving toward a dynamic and temporal framework. *J. Manag.* 40, 130–160. doi: 10.1177/0149206313503014

McGill, D. C. (2015). *David C. McGill (R. Wright, Interviewer). NASA Johnson Space Center Oral History Project Oral History Transcript*. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/McGillDC/McGillDC_5-22-15.htm (accessed October 2, 2018).

McGrath, J. E. (1984). *Groups: Interaction and Performance*, Vol. 14. Englewood Cliffs, NJ: Prentice-Hall.

McGrath, J. E., Arrow, H., and Berdahl, J. L. (2000). The study of groups: past, present, and future. *Personal. Soc. Psychol. Rev.* 4, 95–105.

Mesmer-Magnus, J. R., Carter, D. R., Asencio, R., and DeChurch, L. A. (2016). Space exploration illuminates the next frontier for teams research. *Group Organ. Manag.* 41, 595–628. doi: 10.1177/1059601116668763

Moon, H., Hollenbeck, J. R., Humphrey, S. E., Ilgen, D. R., West, B., Ellis, A. P. J., et al. (2004). Asymmetric adaptability: dynamic team structures as one-way streets. *Acad. Manag. J.* 47, 681–695. doi: 10.5465/20159611

National Aeronautics and Space Administration [NASA] (2014). *NASA's Journey to Mars: Pioneering Next Steps in Space Exploration*. Houston, TX: NASA.

Nesbitt, S. (2016). *An Oral History of the Space Shuttle Challenger Disaster (M. L. Dean, interviewer). Popular Mechanics*. Available at: https://www.popularmechanics.com/space/a18616/an-oral-history-of-the-space-shuttle-challenger-disaster/ (accessed October 2, 2018).

Ofem, B., Floyd, T. M., and Borgatti, S. P. (2012). "Social Networks and Organizations," in *A Companion to Organizational Anthropology*, eds D. D. Caulkins and S. P. Borgatti (Hoboken, NJ: Blackwell Publishing Limited), 147–166.

Palinkas, L. A. (2007). Psychosocial issues in long-term space flight: overview. *Gravitat. Space Res.* 14, 25–33.

Palinkas, L. A., and Suedfeld, P. (2008). Psychological effects of polar expeditions. *Lancet* 371, 153–163. doi: 10.1016/s0140-6736(07)61056-3

Porck, J. P., Matta, F. K., Hollenbeck, J., Oh, J. K., Lanaj, K., and Lee, S. M. (2018). *Social Identification in Multiteam Systems: The Role of Depletion and Task Complexity*. Briarcliff Manor, NY: Academy of Management.

Presidential Commission on the Space Shuttle Challenger Accident (1986). *Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident*. Washington, DC: United States Government Printing.

Presidential Commission on the Space Shuttle Challenger Accident (1987). *Implementation of the Recommendations of the Presidential Commission on the Space Shuttle Challenger Accident*. Washington, DC: United States Government Printing.

Reeves, W. D. (1998). *William D. "Bill" Reeves (M. Davison, R. Wright, C. Butler, interviewers). NASA Johnson Space Center Oral History Project Oral History Transcript*. Available at: https://www.spaceflight.nasa.gov/history/shuttle-mir/people/oral-histories/reeves.pdf (accessed October 2, 2018).

Reeves, W. D. (2009). *William D. Reeves (R. Wright, Interviewer). NASA Johnson Space Center Oral History Project Oral History Transcript*. Available at: https://www.jsc.nasa.gov/history/oral_histories/ReevesWD/ReevesWD_4-17-09.pdf

Rico, R., Hinsz, V. B., Davison, R. B., and Salas, E. (2017). Structural influences upon coordination and performance in multiteam systems. *Hum. Resour. Manag. Rev.* 28, 332–346. doi: 10.1016/j.hrmr.2017.02.001

Ryba, J. (2010). *STS-61*. Available at: https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-61.html (accessed October 2, 2018).

Salas, E., Tannenbaum, S. I., Kozlowski, S. W., Miller, C. A., Mathieu, J. E., and Vessey, W. B. (2015). Teams in space exploration: a new frontier for the science of team effectiveness. *Curr. Dir. Psychol. Sci.* 24, 200–207. doi: 10.1177/0963721414566448

Sherif, M. (1958). Superordinate goals in the reduction of intergroup conflict. *Am. J.Sociol.* 63, 349–356. doi: 10.1086/222258

Shuffler, M. L., and Carter, D. R. (2018). Teamwork situated in multiteam systems: key lessons learned and future opportunities. *Am. Psychol.* 73, 390–406. doi: 10.1037/amp0000322

Shuffler, M. L., Jiménez-Rodríguez, M., and Kramer, W. S. (2015). The science of multiteam systems: a review and future research agenda. *Small Group Res.* 46, 659–699. doi: 10.1177/1046496415603455

Steiner, I. D. (1972). *Group Process and Productivity*. New York, NY: Academic.

Suffredini, M. T. (2015). *Michael T. Suffredini (R. Wright, interviewer). NASA Johnson Space Center Oral History Project Oral History Transcript*. Available at: https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/ISS/SuffrediniMT/SuffrediniMT_9-29-15.htm (accessed October 2, 2018).

Tajfel, H., Turner, J. C., Austin, W. G., and Worchel, S. (1979). "An Integrative theory of Intergroup Conflict," in *Organizational Identity: A reader*, eds W. G. Austin, and S. Worchel (Monterey, CA: Brooks/Cole). 56–65.

Trump, D. J. (2017). *Presidential Memorandum on Reinvigorating America's Human space Exploration Program [Memorandum]*. Washington, DC: Office of the President.

Weick, K. E., Sutcliffe, K. M., and Obstfeld, D. (1999). Organizing for high reliability: processes of collective mindfulness. *Cris. Manag.* 3, 81–123.

Wohlin, C. (2014). "Guidelines for snowballing in systematic literature studies and a replication in software engineering," in *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering*. New York, NY: ACM, 38.

Zaccaro, S. J., Marks, M. A., and DeChurch, L. A. (eds). (2012). "Multiteam systems: An introduction," in *Multiteam Systems*, (New York, NY: Routledge), 18–47.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Pendergraft, Carter, Tseng, Landon, Slack and Shuffler. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

APPENDIX A

TABLE A1 | List of sources used in archival analysis.

Johnson Space Center Oral Histories		
Subject	**Date of interview**	**Retrieved From**
Andrew S.W. Thomas	7/22/1998	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/Shuttle-Mir/ThomasASW/ThomasASW_7-22-98.htm
Arnold D. Aldrich	6/24/2000	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/AldrichAD/AldrichAD_6-24-00.htm
Bonnie J. Dunbar	1/20/2005	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/DunbarBJ/DunbarBJ_1-20-05.htm
Bonnie J. Dunbar	6/16/1998	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/Shuttle-Mir/DunbarBJ/DunbarBJ_6-16-98.htm
Bonnie J. Dunbar	3/23/2005	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/DunbarBJ/DunbarBJ_3-23-05.htm
Bonnie J. Dunbar	9/14/2005	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/DunbarBJ/DunbarBJ_9-14-05.htm
C. Michael Foale	6/16/1998	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/Shuttle-Mir/FoaleCM/FoaleCM_6-16-98.htm
C. Michael Foale	7/7/1998	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/Shuttle-Mir/FoaleCM/FoaleCM_7-7-98.htm
C. Michael Foale	7/31/1998	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/Shuttle-Mir/FoaleCM/FoaleCM_7-31-98.htm
Christopher C. Kraft	6/28/1991	https://www.nasa.gov/sites/default/files/atoms/files/19910628_christopher_kraft_oral_history_interview.pdf
David C. McGill	5/22/2015	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/McGillDC/McGillDC_5-22-15.htm
Donald D. Arabian	2/3/2000	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/ArabianDD/DDA_2-3-00-amended.pdf
Eugene F. Kranz	1/8/1999	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/KranzEF/KranzEF_1-8-99.htm
Gerald P. Carr	10/25/2000	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/CarrGP/CarrGP_10-25-00.htm
Glynn S. Lunney	7/16/2010	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/LunneyGS/Apollo13.htm
Guion S. Bluford	8/2/2004	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/BlufordGS/BlufordGS_8-2-04.htm
Jack R. Lousma	3/15/2010	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/LousmaJR/LousmaJR_3-15-10.htm
John W. Aaron	1/26/2000	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/AaronJW/AaronJW_1-26-00.htm
Joseph P. Allen	1/28/2003	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/AllenJP/AllenJP_1-28-03.htm
Leon T. Silver	5/5/2002	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/SilverLT/SilverLT_5-5-2002.pdf
Michael R. Barratt	7/30/2015	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/ISS/BarrattMR/BarrattMR_7-30-15.htm
Michael R. Barratt	4/14/1998	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/Shuttle-Mir/BarrattMR/BarrattMR_4-14-98.htm
Michael T. Suffredini	9/29/2015	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/ISS/SuffrediniMT/SuffrediniMT_9-29-15.htm
Paul F. Dye	6/16/1998	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/Shuttle-Mir/DyePF/DyePF_5-27-98.htm
Paul S. Hill	3/24/2015	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/HillPS/HillPS_3-24-15.htm

(Continued)

TABLE A1 | Continued

Johnson Space Center Oral Histories		
Subject	**Date of interview**	**Retrieved From**
William D. Reeves	6/22/1998	https://www.spaceflight.nasa.gov/history/shuttle-mir/people/oral-histories/reeves.pdf
William D. Reeves	4/17/2009	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/ReevesWD/ReevesWD_4-17-09.htm
Official NASA or Government Reports		
Report Name	**Relevant Mission or Program**	**Retrieved From**
Phillip L. Engelauf	6/24/1998	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/Shuttle-Mir/EngelaufPL/EngelaufPL_6-24-98.htm
William A. Anders	10/8/1997	https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/AndersWA/AndersWA_10-8-97.htm
Actions to Implement the Recommendations of The Presidential Commission on the Space Shuttle Challenger Accident	STS-51L	https://history.nasa.gov/rogersrep/actions.pdf
Apollo 13 Mission Report	Apollo 13	https://www.hq.nasa.gov/alsj/a13/A13_MissionReport.pdf
Bilateral agreement between NASA and the Russian Space Agency	ISS	https://www.nasa.gov/mission_pages/station/structure/elements/nasa_rsa.html
Columbia Accident Investigation Board [CAIB] (2003). Columbia accident investigation board report.	STS-107	https://www.nasa.gov/columbia/home/CAIB_Vol1.html (http://s3.amazonaws.com/akamai.netstorage/anon.nasa-global/CAIB/CAIB_lowres_full.pdf)
Implementation of the Recommendations of the Presidential Commission on the Space Shuttle Challenger Accident	STS-51L	https://history.nasa.gov/rogersrep/v6index.htm
Investigation of the Challenger Accident Congressional Report	STS-51L	https://www.gpo.gov/fdsys/pkg/GPO-CRPT-99hrpt1016/pdf/GPO-CRPT-99hrpt1016.pdf
President Nixon's 1972 Announcement on the Space Shuttle	Space Shuttle Program	https://history.nasa.gov/stsnixon.htm
Report of Review Board on Apollo mission AS-204	AS-204	https://history.nasa.gov/Apollo204/chro.html
Report of the Committee on Aeronautical and Space Sciences, United States Senate with Additional Views – Apollo 204 Accident, January 30, 1968	AS-204	https://history.nasa.gov/as204_senate_956.pdf
Report of the PRESIDENTIAL COMMISSION on the Space Shuttle Challenger Accident 6/6/1986	STS-51L	https://history.nasa.gov/rogersrep/genindex.htm
Seeking a Human Spaceflight Program Worthy of a Great Nation	Human Spaceflight Program	https://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf

(Continued)

TABLE A1 | Continued

Johnson Space Center Oral Histories		
Subject	**Date of interview**	**Retrieved From**
Other Sources		
Source Name	**Relevant Mission or Program**	**Retrieved From**
"Chronology of Defining Events in NASA history"	Various	https://history.nasa.gov/40thann/define.htm
Apollo 13 Lunar Module 'Mail Box'	Apollo 13	https://www.nasa.gov/image-feature/apollo-13-lunar-module-mail-box
Description of ISS modules	ISS	https://www.nasa.gov/mission_pages/station/structure/elements/space-station-assembly
Description of ISS participants and roles	ISS	https://www.nasa.gov/mission_pages/station/cooperation/index.html
Ed White biography; section on Gemini 4 EVA	Gemini 4	https://history.nasa.gov/Apollo204/zorn/white.htm
ESA article on Soyuz MS-09	Soyuz MS-09	http://www.esa.int/Our_Activities/Human_Spaceflight/International_Space_Station/Liftoff_Alexander_Gerst_returns_to_space
History of Shuttle-Mir	Shuttle-Mir program	https://spaceflight.nasa.gov/history/shuttle-mir/Shuttle-Mir_text-only.htm
International Space Station Status Report – ISS98-03	ISS; launch of Zarya module	https://www.nasa.gov/centers/johnson/news/station/1998/iss98-03.html
NASA chronology of Apollo-Soyuz missions	Apollo-Soyuz	https://history.nasa.gov/40thann/define.htm
NASA mission archive on STS-71	STS-71	https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-71.html
NASA-4: Fire and Controversy	Shuttle-Mir/NASA-4	https://history.nasa.gov/SP-4225/nasa4/nasa4.htm
NASA-4: Failures to Communicate	Shuttle-Mir/NASA-4	https://history.nasa.gov/SP-4225/nasa4/nasa4.htm#communications
NASA history web article on Apollo 13	Apollo 13	https://history.nasa.gov/SP-350/ch-13-4.html
NASA mission archive on STS-9	STS-9	https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-9.html
NASA mission archive on STS-27	STS-27	https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-27.html
NASA mission archive on STS-61	STS-61	https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-61.html
Timeline of notable ISS events	ISS	https://www.issnationallab.org/about/iss-timeline/
NASA mission archive on STS-72	STS-72	https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-72.html
NASA mission archive on STS-74	STS-74	https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-74.html
NASA mission archive on STS-75	STS-75	https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-75.html
NASA mission archive on STS-114	STS-114	https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-114.html
NASA mission archive on STS-2	STS-2	https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-2.html
NASA mission archive on STS-82	STS-82	https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-82.html
NASA mission archive on STS-86	STS-86	https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-86.html
NASA STS-135 Press Kit	STS-135	https://www.nasa.gov/pdf/566071main_STS-135_Press_Kit.pdf
NASA web article on Apollo mission AS-204	Apollo 204 (Apollo 1)	https://nssdc.gsfc.nasa.gov/planetary/lunar/apollo1info.html
New York Times Article on STS-51L	Challenger STS-51L	https://www.nytimes.com/1986/01/29/us/shuttle-explosion-mission-control-silence-grief-fill-day-horror-long-dreaded.html

(Continued)

TABLE A1 | Continued

Johnson Space Center Oral Histories		
Subject	**Date of interview**	**Retrieved From**
NPR web article on Challenger mission STS-51L	Challenger STS-51L	https://www.npr.org/templates/story/story.php?storyId=5175151
NPR web article on Challenger mission STS-51L	Challenger STS-51L	https://www.npr.org/templates/story/story.php?storyId=5174355
SP-4208 Living and Working in Space: A History of Skylab: Chapter 13 – Launching Skylab	Skylab station	https://history.nasa.gov/SP-4208/ch13.htm
SP-4208 Living and Working in Space: A History of Skylab: Chapter 14 – Saving Skylab	SL-2	https://history.nasa.gov/SP-4208/ch14.htm
The Flight of Apollo 13	Apollo 13	https://www.hq.nasa.gov/pao/History/apollo/apo13hist.html
The Gemini Program (1962-1966)	Project Gemini	https://nssdc.gsfc.nasa.gov/planetary/gemini.html
Web article on Columbia STS-107	Space Shuttle Columbia STS 107	http://www.americaspace.com/2015/02/01/lock-the-doors-columbias-final-flight-part-4/
Web article on Gemini VI	Gemini 6	http://www.spacefacts.de/mission/english/gemini-6.htm
Web article on ISS Expedition 54	ISS Expedition 54	http://www.spaceflightinsider.com/missions/iss/space-station-trio-returns-to-earth-after-record-setting-mission/
Web article on ISS spacewalk	ISS Expedition 54	http://www.spaceflightinsider.com/missions/iss/spacewalking-astronauts-finish-canadarm2-work-at-breakneck-speed/
Web article on Soyuz mission MS-07	Soyuz MS-07	http://www.spaceflightinsider.com/missions/iss/soyuz-ms-07-crew-back-on-earth-after-168-days-in-orbit/
Web article on STS-9, Spacelab	STS-9; Spacelab	http://www.spaceflightinsider.com/space-flight-history/spaceflight-heritage-sts-9-first-flight-spacelab/

frontiers in Psychology

ORIGINAL RESEARCH
published: 12 August 2019
doi: 10.3389/fpsyg.2019.01660

Advancing Our Understandings of Healthcare Team Dynamics From the Simulation Room to the Operating Room: A Neurodynamic Perspective

Ronald Stevens[1,2], Trysha Galloway[2] and Ann Willemsen-Dunlap[3]*

[1]UCLA School of Medicine, Brain Research Institute, Culver City, CA, United States, [2]The Learning Chameleon, Inc., Culver City, CA, United States, [3]JUMP Simulation and Education Center, The Order of Saint Francis Hospital, Peoria, IL, United States

OPEN ACCESS

Edited by:
Michael Rosen, Johns Hopkins Medicine, United States

Reviewed by:
M. Teresa Anguera, University of Barcelona, Spain
Sadaf Kazi, Johns Hopkins University, United States

***Correspondence:**
Ronald Stevens
immexr@gmail.com

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *31 October 2018*
Accepted: *01 July 2019*
Published: *12 August 2019*

Citation:
Stevens R, Galloway T and Willemsen-Dunlap A (2019) Advancing Our Understandings of Healthcare Team Dynamics From the Simulation Room to the Operating Room: A Neurodynamic Perspective. Front. Psychol. 10:1660. doi: 10.3389/fpsyg.2019.01660

The initial models of team and team member dynamics using biometric data in healthcare will likely come from simulations. But how confident are we that the simulation-derived high-resolution dynamics will reflect those of teams working with live patients? We have developed neurodynamic models of a neurosurgery team while they performed a peroneal nerve decompression surgery on a patient to approach this question. The models were constructed from EEG-derived measures that provided second-by-second estimates of the neurodynamic responses of the team and team members to task uncertainty. The anesthesiologist and two neurosurgeons developed peaks, often coordinated, of elevated neurodynamic organization during the patient preparation and surgery which were similar to those seen during simulation training, and which occurred near important episodes of the patient preparation and surgery. As the analyses moved down the neurodynamic hierarchy, and the simulation and live patient neurodynamics occurring during the intubation procedure were compared at progressively smaller time scales, differences emerged across scalp locations and EEG frequencies. The most significant was the pronounced suppression of gamma rhythms detected by the frontal scalp sensors during the live patient intubation which was absent in simulation trials of the intubation procedure. These results indicate that while profiles of the second-by-second neurodynamics of teams were similar in both the simulation and live patient environments, a deeper analysis revealed differences in the EEG frequencies and scalp locations of the signals responsible for those team dynamics. As measures of individual and team performance become more micro-scale and dynamic, and simulations become extended into virtual environments, these results argue for the need for parallel studies in live environments to validate the dynamics of cognition being observed.

Keywords: teamwork, healthcare, electroencephalography, team neurodynamics, information, operating room, intubation

INTRODUCTION

A shift is underway in the ways that we study the function and evolution of teams. It is being driven by the generation of multimodal biometric dynamic data streams with seconds' resolutions, and it is expected that analyses of these data will shape our ideas about how teams are assembled, trained, and supported. (Guastello et al., 2006; Aebersold, 2018; Guastello and Peressini, 2018; Stevens et al., 2018b). In healthcare, the initial understandings of how patterns in dynamic biometric data sets relate to team member interactions and task events will likely come from simulation settings.

High-fidelity simulations provide opportunities for skill acquisition and maintenance, team training, as well as high-stakes testing, and are widely accepted today as an essential educational modality for healthcare professionals (Schmidt et al., 2013; Thomas et al., 2015; Staropoli et al., 2018). Simulation provides a mechanism for standardized clinical education across all learners, allowing exposure to critical events that clinicians might never encounter in their career in a live patient. Simulation also provides a mechanism for deliberate practice among learners. Rare but critical and time-pressured events can be recreated in a simulation, so that protocols can be established and communication problems can be identified and improved upon. Finally, simulation provides a safe environment where learners can come together as inter-professional teams to practice critical teamwork skills that are often overlooked in clinical teaching. These accomplishments have been achieved through continual refinements in simulation technology, performance measurement, and training protocols (Magee, 2003).

The shift toward more dynamic biometric models of teamwork provides an opportunity to expand our understanding of the spatial and temporal changes in team and team member cognition at a finer granularity than has been previously possible, and to approach questions that have previously been unapproachable. As these models will most likely be developed from simulation-derived data, it is important to learn how well metrics and models developed from simulated team training reflect those obtained in real-world operating room situations. Knowing if, and under what conditions, the cognitive responses for a task deviated between simulated and live patient tasks environments would provide ecologic validity for the biometric models being developed.

Where along the biometric time scale of team training (i.e., 10^{-3} to over 10^{5} s) (Salas et al., 2015) would differences be expected? The widespread use of simulations in healthcare would argue against major differences being seen between behavioral and biometric measures as these would have likely already been incorporated into simulation developments. Differences might be more expected during the execution of temporally extended episodes of action-control sequences like those found in established surgical procedures or anesthesia induction. Such episodes contain sub-sequences of actions but are mentally instantiated as one program unit (Cooper and Shallice, 2000).

The approach we have taken to investigate the detailed dynamics of such episodes are EEG-derived measures which are capable of resolving cognitive processes occurring at the milliseconds level using electrical oscillations from different regions on the scalp (Buzaki, 2006).

The metric developed, neurodynamic organization (*NO*), is the tendency of team members to enter into prolonged (>10s) metastable neurodynamic relationships as they experience disturbances to their rhythms, i.e., periods of heightened uncertainty. This metric is domain neutral and thought to occur when a team's operating rhythm no longer supports the complexity of the task and the team needs to expend energy to reorganize into structures that better minimize the "surprise" or uncertainty in the environment (Stevens and Galloway, 2017). Consistent with this hypothesis, the frequency and magnitude of neurodynamic organizations were greater in novice teams compared with experienced submarine navigation teams (Stevens et al., 2017a).

Measures of *NO* are grounded in information theory and based on most biological signals having internal patterns and organizations. Symbolic transformations of discrete data can be used to detect and quantitate the fluctuating dynamics of these patterns (Stevens and Galloway, 2014, 2015, 2017), while information theory provides the methods for determining when and how information is created, stored, shared, and destroyed (Shannon, 1948, 1951; James et al., 2011).

A series of studies spanning high school teams to military and healthcare teams (Stevens and Galloway, 2014, 2015, 2017) has indicated that neurodynamic organizations are likely a fundamental property of teamwork. Using information theory metrics, it becomes possible to quantitatively deconstruct the neurodynamic organization of a team into the contributions of each team member (Stevens et al., 2018b). These features provide a quantitative platform for comparing the cognitive activities and live patient healthcare environments.

The goals of this study were to:

1. First, determine whether teams that performed a live patient operation (LPO) developed distinct peaks of neurodynamic organization similar to those we have previously observed during military and healthcare simulated tasks. We hypothesized that the anesthesiologist, primary neurosurgeon, and neurosurgery resident would develop discrete periods of elevated neurodynamic organization during the patient preparation and surgery, and that these elevations would occur near episodes of importance or uncertainty.
2. Second, identify whether there were times when the neurodynamic/cognitive features of the LPO team member performances diverged from those expected from similar events performed during simulations.

MATERIALS AND METHODS

Ethics Statement

The study and the informed consent protocols were reviewed and approved by the Biomedical IRB, San Diego, CA (Protocol EEG01), and the Order of Saint Francis Healthcare Institutional Review Board, Peoria IL. All participating subjects gave

written and informed consent to participate in the EEG data collections and have their data (including images and speech) anonymously analyzed per approved applicable protocols. To maintain confidentiality, each subject was assigned a unique number known only to the investigators of the study, and subject identities were not shared. This design complies with DHHS: protected human subject 45 CFR 46; FDA: informed consent 21 CFR 50.

Simulations and Live Patient

The team members participating in both the simulation and surgery were experienced operating room staff at the Order of Saint Francis Hospital. It is likely some of them have worked together during their professional experiences, but no effort was made to quantify the level of interaction. The simulations performed were part of an integrated curriculum of airway management that was developed following a clinical needs assessment at the Order of Saint Francis Hospital in Peoria, IL. The induction, ventilation, and emergence from anesthesia is a complicated and uncertain process and one where differences in the cognition used between simulated and live patient ventilations would be detected if present.

While we have reported neurodynamic analyses of over a dozen healthcare team performances (Stevens et al., 2016, 2018b; Stevens and Galloway, 2017), in this paper, we highlight the dynamics of two, as the same anesthesiologist who performed the intubation during the live patient surgery performed two previous simulations with three intubation events.

The first simulation involved the preoperative ventilation by the anesthesiologist (AN), assisted by a circulating nurse (CN), and a scrub nurse (SN), where the mannequin exhibited an adverse response to a relative overdose of aerosolized lidocaine; this subsequently caused seizure and cardiac dysrhythmias. The immune hypersensitivity also caused swelling of the larynx which was experienced by the AN as a blockage during an initial intubation (INTB) attempt. When the transient seizure subsided, a second and successful INTB was performed. The total scenario time was 800 s.

The significant training event in the second simulation was a fire in the operating room, which required patient and staff evacuation. Prior to the fire event, the INTB in this simulation was uncomplicated. The total scenario time was 967 s.

The live patient operation to relieve pressure on the peroneal nerve was performed by a highly experienced neurosurgeon and a resident neurosurgeon. Succinctly, the surgery required an incision, an opening of the muscle fascia, the identification of the nerve, the removal of the pressure, and skin closure. The time from the patient entering the operating room (OR) until the completion of the surgery was 2,891 s.

Electroencephalography

Electroencephalography (EEG) data were collected using two EEG 10–20 systems with different sensor options (**Figure 1**). The 10–20 system permits uniform spacing of electrodes, independent of head circumference, in scalp regions known to correlate with specific areas of cerebral cortex. It is the standard electrode location method used to collect EEG data as well as the standard for most current databases. The simulation-derived EEG signals were acquired using a nine-sensor wet electrode system which provided coverage over the anterior, central, and posterior regions of the scalp (**Figure 1A**, open circles). Collecting data for the live patient procedure was constrained by the surgeon requiring a binocular loupe, and (possibly) a light source on the top of his head. Additional clearance around the ears was also needed for the stethoscope. The headband-styled 10-sensor dry electrode system used in the live patient data collection was embedded with sensors

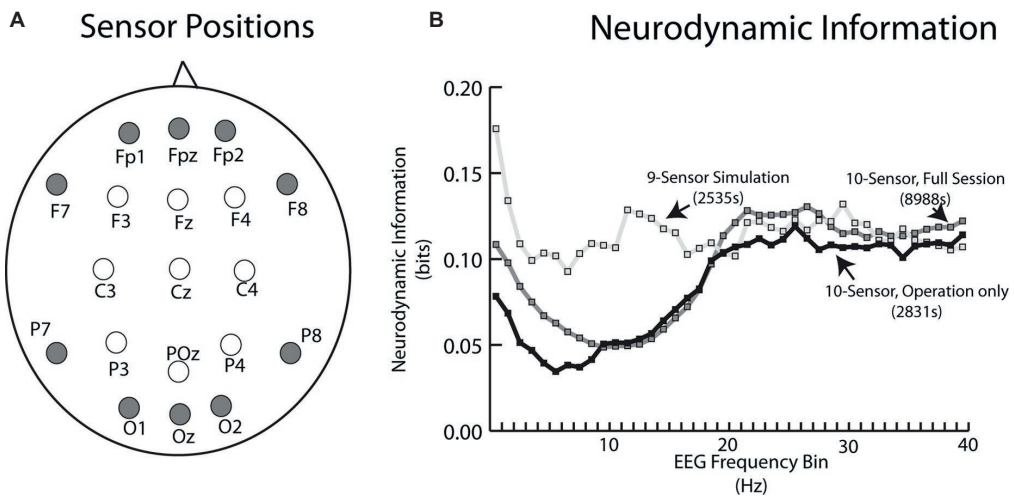

FIGURE 1 | (A) Schematic of EEG sensor placement (looking down on the scalp) for the simulation tasks (open circles) and live patient (closed circles). **(B)** Neurodynamic information vs. EEG frequency plot for the average of the two simulation performances (open circles) and the live patient. The live patient data are plotted both for the whole task including patient removal (gray squares), as well as only during the operation (black circles).

primarily in the anterior and posterior scalp regions (**Figure 1A**, closed circles).

A plot of the neurodynamic information at each EEG frequency bin is shown in **Figure 1B**. There were no significant differences in the average *NI* levels in the 18–40 Hz frequency range. The simulation sensor montage detected higher *NI* levels in the theta and alpha/mu frequency bands, due to the relative enrichment of 10-Hz team *NI* over the central scalp positions. Unless otherwise noted, subsequent comparisons between the simulation and live patient performances were made using *NI* levels from the anterior and posterior regions of the scalp and the 18–40 Hz frequency bands.

For all studies, the data acquisition began shortly after the EEG sensors were adjusted for good contact (<10 Ω). Each person's EEG data stream were cut into segments of the simulated or live patient performance based on electronic markers inserted into the EEG data streams as well as the events observed in videos. The recorded EEG data were preprocessed using Matlab®-based FieldTrip® toolbox (Oostenveld et al., 2011), and processed as described previously (Stevens et al., 2013; Stevens et al., 2016). Signals from outside the brain can be a confounder when interpreting models built from EEG signals, especially signals obtained in complex environments. Commonly found artifacts are generated from speech, eye blinks, heartbeats, breathing rhythms, and other electromyography sources. As neurodynamic organizations regularly occur during silence, speech is an unlikely source for most organizations (Stevens and Galloway, 2014). Regular rhythms associated with eye blinks and heartbeats were identified and removed during data preprocessing (Delorme et al., 2012), and by the interactive Matlab® toolbox EEGLAB CleanLine (Mullen, 2012) plugin, which adaptively estimates and removes sinusoidal artifacts from independent components or scalp sensors using a frequency-domain (multi-taper) regression technique with a Thompson F-statistic for identifying significant sinusoidal artifacts and independent component analysis.

Team Neurodynamic Modeling

The neurodynamic modeling is a physical to organizational – based transformation between what is observed at the team level, to the neurodynamic rhythms responsible for those behaviors. In this transformation, the physical units of EEG dynamics (i.e., microvolts) are transformed into informational units (bits) of organization. The elements of this transformation form a hierarchy that spans temporal scales from milliseconds to hours.

The EEG power levels of each team member are first separated each second into high, medium, or low EEG power ranges (**Figure 2A**). The reporting of team member neurodynamics at a one-second resolution is in the range (250–500 ms) of functional brain connectivity associated with speech or playing guitar in duets (Stephens et al., 2010; Sanger et al., 2012), and nonverbal recognitions (Caetano et al., 2007), or approximately a half a second for a two-person action-response round trip.

For ease of visualization, the high, average, and low EEG power categories are assigned the values 3, 1, and −1. The resulting three-element array, one for each member of a three-person team, is assembled into a three-histogram neurodynamic symbol (*NS*) that represents the neurodynamic state of the team at that second. For instance, the symbol in **Figure 2B** indicates that at this second, team member 1 had below average, team member 2 had above average, and team member 3 had average EEG power levels. The possible combinations of three persons

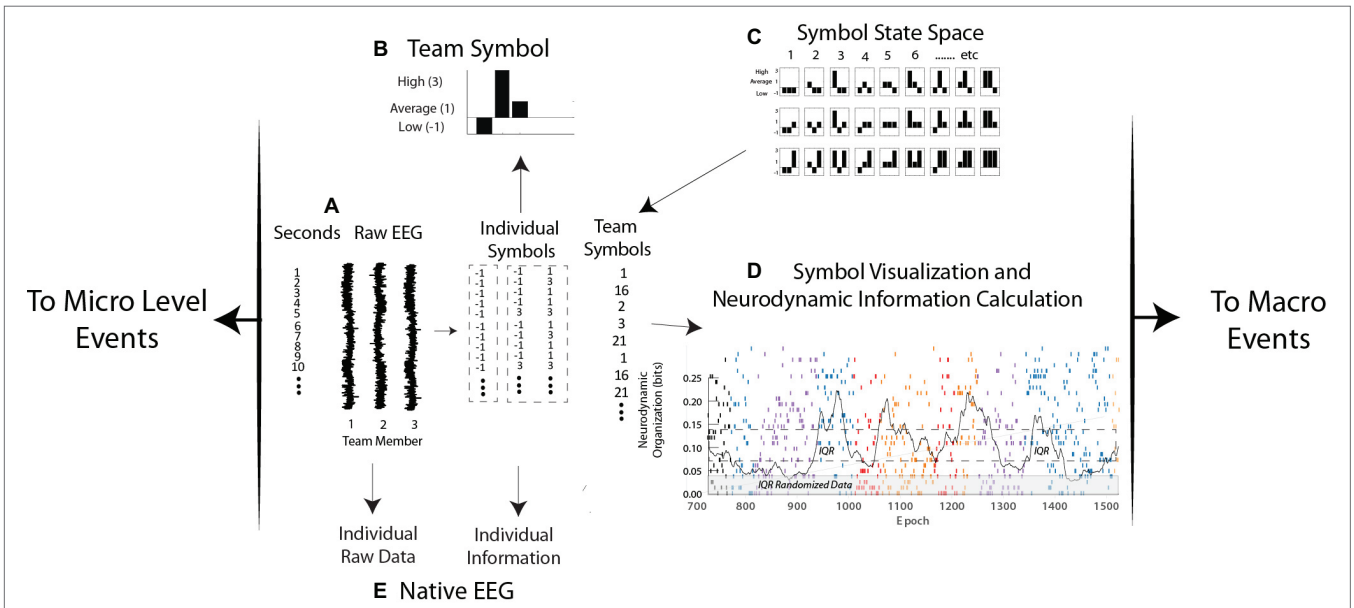

FIGURE 2 | Levels of neurodynamic analyses. **(A,B)** the raw EEG signals from each person are discretized each second into low, average, and high power levels and assembled into a neurodynamic symbol. **(C)** The symbol matching the three-person power array is determined from the symbol state space lookup table and assembled into a neurodynamic data stream, where, **(D)** the team symbols are visually mapped and a moving average of entropy calculated each second. **(E)** Levels of raw EEG and normalized values (i.e., −1, 1, and 3) are calculated from the native EEG data streams.

and three EEG power levels create a 27-symbol neurodynamic state space (*NSS*) (Stevens and Galloway, 2014; Stevens et al., 2017b). Each *NS* in the symbolic state space therefore situates the EEG power levels of each team member in the context of the levels of the other team members and the context of the task. A sequence of these symbols, the neurodynamic data streams (*NDS*) contain a neurodynamic history of the team's performance. The granularity of the analysis can be increased by separating the EEG power into fourths or fifths with the computational costs of an exponentially increasing *NSS*.

The temporal expression of *NS* in all data streams studied has been dynamic with one subset of symbols being expressed for a minute or more, only to be replaced by another symbol subset when the task dynamics changed. These *NS* concentrations produce local variations in the randomness of the neurodynamic data streams, differences that can be quantitated by measuring the entropy over a 60-s moving window over the symbol stream that is updated each second (**Figure 2D**).

Entropy is the average surprise of outcomes sampled from a probability distribution or density. A *NS* density with low entropy means that, on average, the outcome is relatively predictable while a system with higher entropy would be less predictable. In this way, a dynamic and quantitative pattern of organization (in bits) can be constructed and reported with a 1-s granularity for real-time modeling, or aggregated over a performance for comparisons across teams (Stevens and Galloway, 2017).

At this point, the entropy-based units of organization have become detached from the microvolt meaning of the raw EEG signal. For instance, synchronized high-power and desynchronized low-power alpha EEG rhythms have different meanings in the context of attention and memory (Klimesch, 2012), but prolonged periods of either high or low alpha power would produce elevated neurodynamic organization and would be viewed as an organized selection of sequential actions (Cooper and Shallice, 2000).

In practice, the modeling sequence in **Figure 2** first generates the three power categories for individual team members, at each sensor channel and at each of forty 1-Hz frequency bins from 1 to 40 Hz (**Figure 2A**). Entropy calculations across the streams of −1, 1, and 3 symbols of individual data streams produce team member neurodynamic information profiles across regions of their scalp and the EEG frequency spectrum (**Figure 2E**).

The scalp and frequency-wide averages of the team *NDS* initially pinpoint periods of higher neurodynamic organization which can then be linked with task events. This initial step is followed by deconstruction of the team data into each team member's sensor and frequency dynamics around regions of interest (Stevens et al., 2018a). The total number of parallel data streams for a three-person team with every individual wearing a 10-sensor EEG headset, this would be 400 team *NDSs* and 1,200 individual team member *NDSs,* as well as a similar number of parallel entropy data streams.

As increased organization is accompanied by decreased entropy, the individual and team entropy values are subtracted from the maximum entropy for the number of symbols being modeled, i.e., 3.17 bits for 9 symbols or 4.775 bits for 27 symbols, and the resulting values are termed neurodynamic information (*NI*); this procedure makes increased neurodynamic information and increased organization both positive values.

RESULTS

Team and Team Member Neurodynamics During Simulation Training

Tracing the frequency, magnitude, and duration of fluctuations in neurodynamic information provides a quantitative history of a team's neurodynamic responses to events that triggered the team to neurodynamically reorganize. The *NI* fluctuations of an experienced anesthesiology team performing a complicated sequence of ventilation procedures during a simulation are shown in **Figure 3**. The events in this simulation included an early unsuccessful INTB attempt (INTB-1), patient seizures requiring a call for a Crash Cart, and a second (successful) INTB attempt (INTB-2) (**Figure 3A**). This example was chosen from others available (Stevens et al., 2016) as the AN performing this simulation had performed a similar procedure during a second simulation, and was also responsible for intubating the patient during the surgery.

The team *NI* neurodynamic profile was low until 920 s and then increased during the first intubation attempt (**Figure 3B**). After decreasing over the next 100 s, the *NI* again increased in response to the patient seizing, and remained near the top of the interquartile range (IQR) and then decreased before peaking again during the second intubation attempt.

The heterogeneity underlying the team neurodynamic profile was shown by deconstructing the team *NI* into that of each team member using information theory approaches (Stevens et al., 2018b). There were three *NI* peaks where the AN and CN showed coordinated NI dynamics and these were the first intubation attempt (r = 0.75 with AN leading CN at 30 s), the episode of seizure (r = 0.84) and the second intubation (r = 0.70 with AN leading CN at 10 s). This coordinated behavior decreased during the middle of the task, i.e., between the seizure episodes and the second intubation. The *NI* of the SN (**Figure 3D**) showed few defined fluctuations in response to the evolving task, and also little coordination with the dynamics of AN or CN.

For each primary event, the AN made comments indicating uncertainty including:

1. *INTB-1*: "There is pus or something in the trachea or an obstruction, I can't tell which; I think I am going to have to go through it, do it with the trachea tube… It looks like he is seizing."
2. *Seizure V-tach*: "Ok, that's not unexpected. Let's go ahead and take this out if he is going into tach."
3. *Seizure/INTB-2*: "I am not sure what my other options are. Because he has a history of seizures I think we are out of drugs."
4. *INTB-2*: "There is something in the trachea… I am not sure if I can see if it is a foreign body or…"

These results suggest that events likely to increase team or individual uncertainty are also those that raise *NI* levels; in other

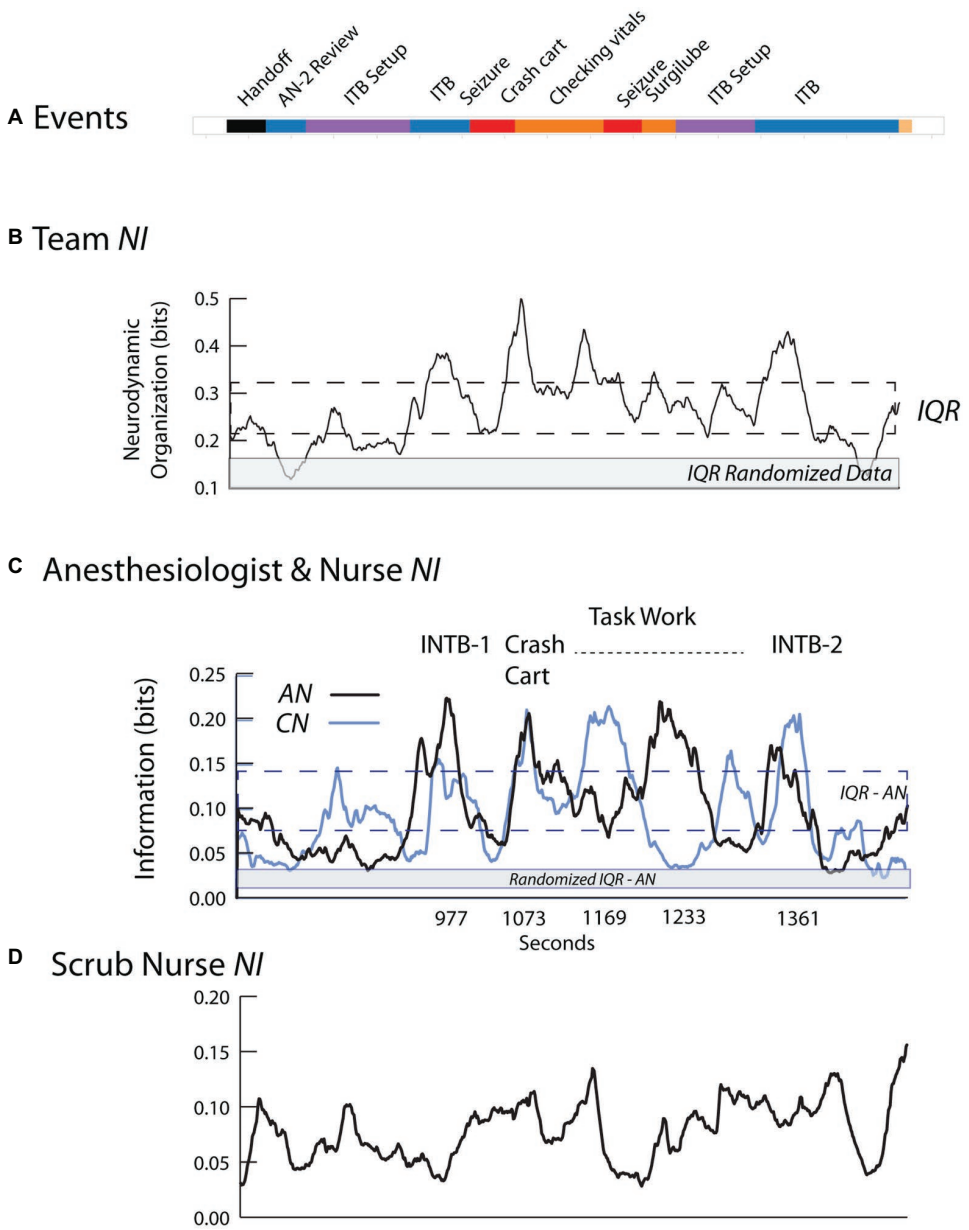

FIGURE 3 | Team and individual neurodynamics during a healthcare simulation. **(A)** The task event segments. **(B)** A quantitative neurodynamic information profile is plotted for the team. The *NI* is a profile of the average bits of information using all sensors and frequencies. The dotted lines indicate the interquartile range (IQR), i.e., 25–75% of the data values, and the gray line indicates the IQR for the randomized data. **(C)** The *NI* traces of the AN (dark) and CN (light) during the simulation with selected events labeled. **(D)** The *NI* trace of the SN.

words, *NI* may act as a barometer for the uncertainty for each member, and by extension, for the team (Stevens et al., 2016).

The coordinated neurodynamics between the AN and CN during events requiring cooperation, yet independent neurodynamics while performing individual tasks, also suggest the possibility of being able to separately identify periods of teamwork and taskwork. Lastly, simulation-based neurodynamics may help refine what meaningful information for a team member might be. While the SN was watching, and likely understood the details of the different task episodes being performed, without her actual involvement, both the neurodynamic coordination with the AN and CN and the peaks of elevated *NI* were missing. That is, the task events that will increase *NI* have to be meaningful for a person, not just interesting.

Team Neurodynamics During a Live Patient Surgery

The surgical team in this example consisted of the AN who had previously performed ventilation procedures during simulation training, an experienced neurosurgeon (NS1) and

a neurosurgery resident (NS2), a surgical nurse (SN) and a circulating nurse (CN); EEG data were collected and modeled for the AN, NS1, and NS2 for this example.

As shown in **Figure 4**, the operating room setting differed from most simulations by lasting three times longer than simulations like that in **Figure 3**. There were also prolonged periods when team members were outside the room as indicated by the dotted lines in the Speakers row (**Figure 4B**). This did not affect EEG collection which was being recorded on a headset chip, but it interfered with the ability to link the EEG with events during those periods.

If the observed simulation neurodynamics were accurate representations of those occurring during surgery, then with the operating room team, we would expect to see:

1. The presence of discrete *NI* peaks near important events.
2. The differential responses of team members to these events.
3. Aligned team member *NI* fluctuations during coordinated activities.

Consistent with the first goal, the neurodynamics of the surgery team showed discrete peaks of increased *NI* during the preoperative patient ventilation as well as surgical preparation and subsequently during the surgery (**Figure 4C**). The deconstruction of the team *NI* into those of the AN, NS1, and NS2 showed periods of individual and coordinated *NI* dynamics, especially during the surgery as shown in the dashed outline (**Figure 4D**). These are investigated further in **Figure 5**.

The surgical sequence for a peroneal nerve decompression begins with an incision, the spreading of the incision, and the opening of the underlying fascia. The nerve is then identified, isolated, and stimulated if necessary. The tissue source of the compression is then identified and removed.

The early surgical segments (until ~2,500 s) were performed by NS2 assisted by NS1. During the surgery, there were three episodes of correlated *NI* between NS1 and NS2 (r = 0.79 at a 20-s cross-correlation lag around 1980s), r = 0.43 at ~2,300 s, and r = 0.75 at ~2,400 s), and these occurred while the neurosurgeons worked closely together. After the nerve was isolated and the source of the nerve compression was identified, NS1 performed the removal of the compressive block (from 2,460 to 2,709 s); during this final procedure, only the *NI* of NS1 was elevated.

The neurodynamic similarities in the *NI* profiles derived from the simulation and live patient-derived conditions indicate that at the level of temporal dynamics, the simulation-acquired data provide an accurate representation of the types of neurodynamics that will be observed in real-world situations. The coordinated *NI* dynamics between NS1 and NS2 are similar to those seen between the AN and CN in **Figure 3**, therefore substantiating simulations cognitive - ability to evoke neurodynamic correlates of teamwork.

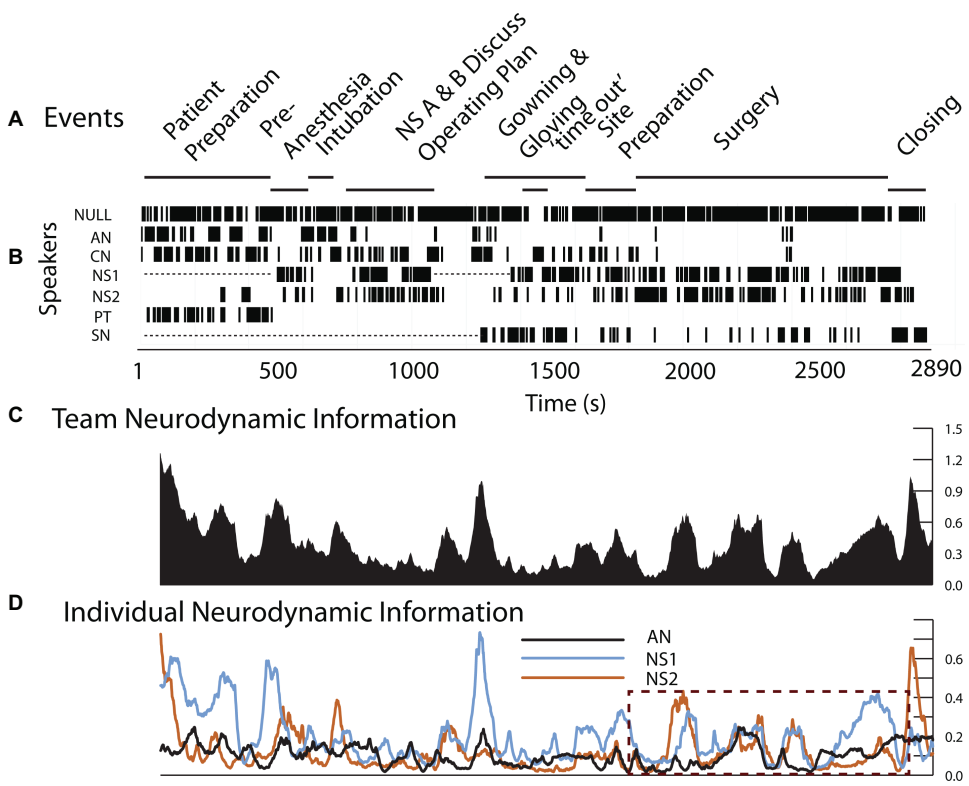

FIGURE 4 | Team and individual neurodynamics during a peroneal nerve decompression surgery. **(A)**. Task events. **(B)**. Team member speech. **(C)**. The team *NI* profile using the average bits of information from all sensors and frequencies. **(D)**. The *NI* traces of the AN, NS1, and NS2. The dotted rectangle indicates the period of the surgery.

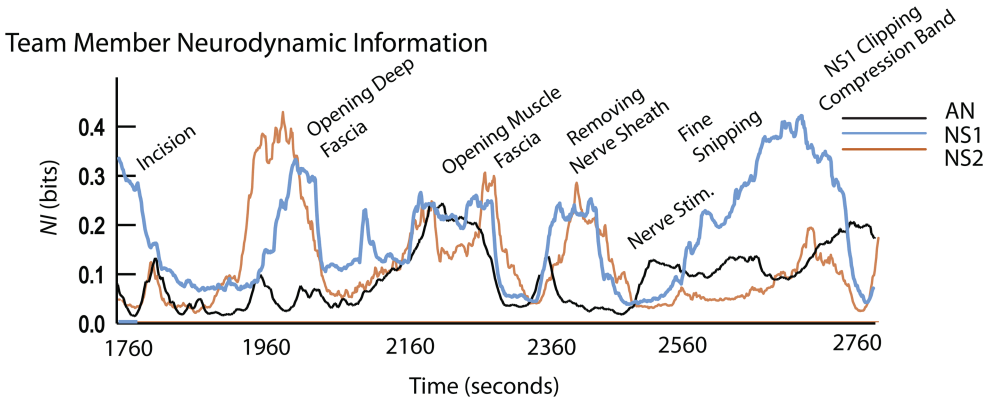

FIGURE 5 | Event details and team member *NI* profiles during surgery.

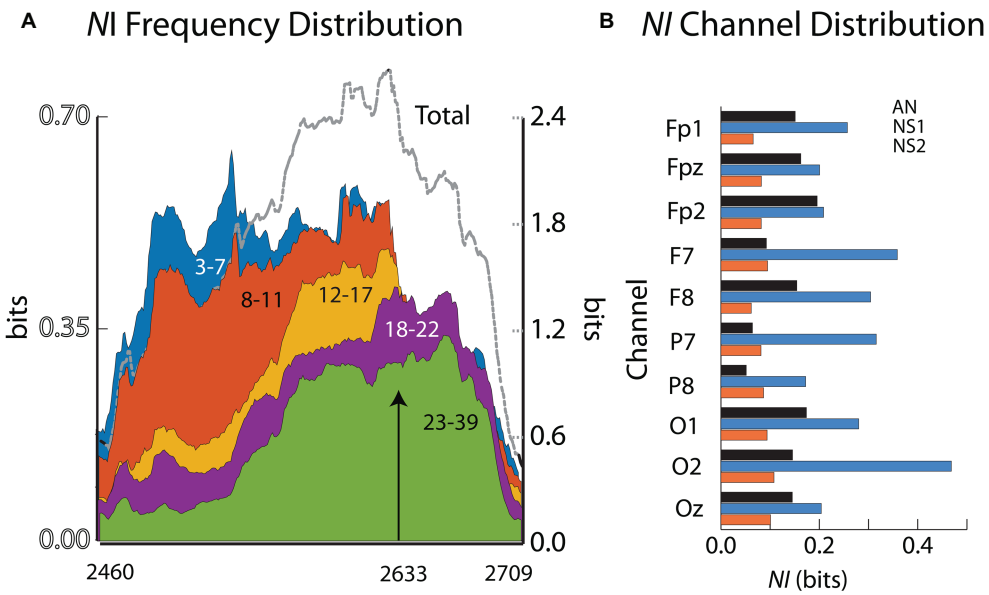

FIGURE 6 | (A) The *NI* values for the different frequency ranges are plotted for the final surgical procedure (2460–2,709 s). The arrow indicates when the surgeon completed his operation. **(B)** The across-frequency and sensor *NI* averages for the 10 EEG sensors. The member order in each bar cluster is AN, NS1, NS2.

The next analysis examined the degree of neurodynamic heterogeneity present in the extended period of *NI* associated with the removal of the source of nerve compression. The analysis during this 4-min period searched for across-frequencies temporal changes as well as across-the-scalp spatial changes in *NI* dynamics.

The aim of these analyses was to determine if there was a neurodynamic trajectory from the initiation of the procedure, through the peak period of neurodynamic information, to the return to a neurodynamic baseline. Neurodynamic information profiles were generated for five EEG frequency bands: delta/theta (3–7 Hz), alpha (8–11 Hz), mu (12–17 Hz), low beta (18–22 Hz), and high beta/gamma (23–40 Hz). The earliest and largest *NI* levels were in the 3–7 Hz (delta/theta) and 8–11 Hz (alpha) frequency bands and these remained high until 2,633 s when they abruptly declined (**Figure 6A**). Coincident with this decrease was NS1 completing the removal of the compressive block on the nerve. The beta and gamma frequency bands predominated after this period and then declined to baseline levels over the next minute.

The *NI* levels during these 4 min were greatest at sensors O2, F7, P7, and F8 (**Figure 6B**). The analyses were refined by generating time x frequency x *NI* plots for the F7, O2, and P7 sensors to explore the temporal and spatial sequencing of *NI* levels across sensors and frequencies (**Figure 7**).

Early *NI* increases were detected at the F7, P7, and O2 sensors ~30s into the final surgical procedure and were mostly in the 3–11 Hz range. The *NI* levels at the P7 sensor were short lived and followed by *NI* decreases at the F7 sensor. In contrast, the O2 *NI* levels continued to

increase during the next 2 min and extended toward higher frequencies. At epoch 2,633 s, the 3–11 Hz *NI* abruptly stopped at the O2 sensor, which, as described earlier, occurred after the alleviation of the nerve compression. During the remaining time before closing the incision, there was an *NI* increase in beta and gamma frequency bands, particularly at the P7 sensor.

Neurodynamics of the Anesthesiologist During the Intubation Events

The analyses of the peroneal nerve decompression surgery in **Figures 6, 7** illustrate the neurodynamic heterogeneity within an extended period of uncertainty, and show how this heterogeneity can be used to describe the surgical procedure in terms of a spatial and temporal neurodynamic trajectory. To explore the generality of these findings, a similar analysis was performed upon another critical event during the operation which was the patient intubation procedure. The anesthesiologist who performed the patient intubation during the operation previously performed three intubations under simulated conditions while acquiring EEG data that allowed neurodynamic comparisons across training modalities.

The simulated and the live patient INTB segments were identified and isolated after bracketing them within 60-s data sections before and after the procedure to provide a dynamic context. Each of the INTB segments were above the IQR range for the performance indicating the procedure was one of importance for the anesthesiologist during both the simulations and in the operating room (**Figure 8A**). The four INTB segments ranged from 40 to 79 s in length and within each of the segments, there were peaks in the *NI*, often biphasic. One of the intubations (#1 of **Figure 8B**) was unsuccessful due to a blockage and the second intubation (#2) could not be confirmed as successful before the simulation ended. The other simulated and live patient intubations were successful. Aside from the elevated *NI* levels, there were no consistent defining features of the INTB procedures, which was not surprising with the temporal and intubation outcome differences among the trials.

The analytic focus next shifted to the sensor *NI* levels during the INTB events. Because of the differences in the simulation and LPO EEG montages (**Figure 1**), these analyses contrasted the *NI* levels of the anterior and posterior sensors. These analyses were performed using the data from the INTB windows shown in **Figure 8B**. The anterior vs. posterior sensor regions' *NI* levels for the simulation INTB events were not significantly different ($Z = 0.77$, $p = 0.44$, Wilcoxon), while the *NI* levels for the live patient INTB were nearly 3-fold greater at the anterior than posterior regions ($Z = 2.02$, $p < 0.05$) (**Figure 9**). The anterior sensor *NI* levels were also significantly greater than the simulation groupings, indicating a skewing of the brain-wide neurodynamic organization toward the anterior regions during the live patient INTB procedure.

The frequency band *NI* distributions were next generated across the 1–40 Hz spectrum shown in **Figure 10**. The *NI* values were binned into the delta/theta (3–7 Hz), alpha (8–11 Hz), mu (12–17 Hz), low beta (18–22 Hz) high beta (23–32 Hz), and gamma (33–40 Hz) bins. These comparisons were made using only the data from the INTB windows shown in **Figure 8**.

As previously described, *NI* is a measure of the organizational patterns in a neurodynamic data stream. As such, they could represent persistent patterns of elevated, depressed, or intermediate EEG power levels by a team member or a team. Making this distinction is important as elevated gamma power

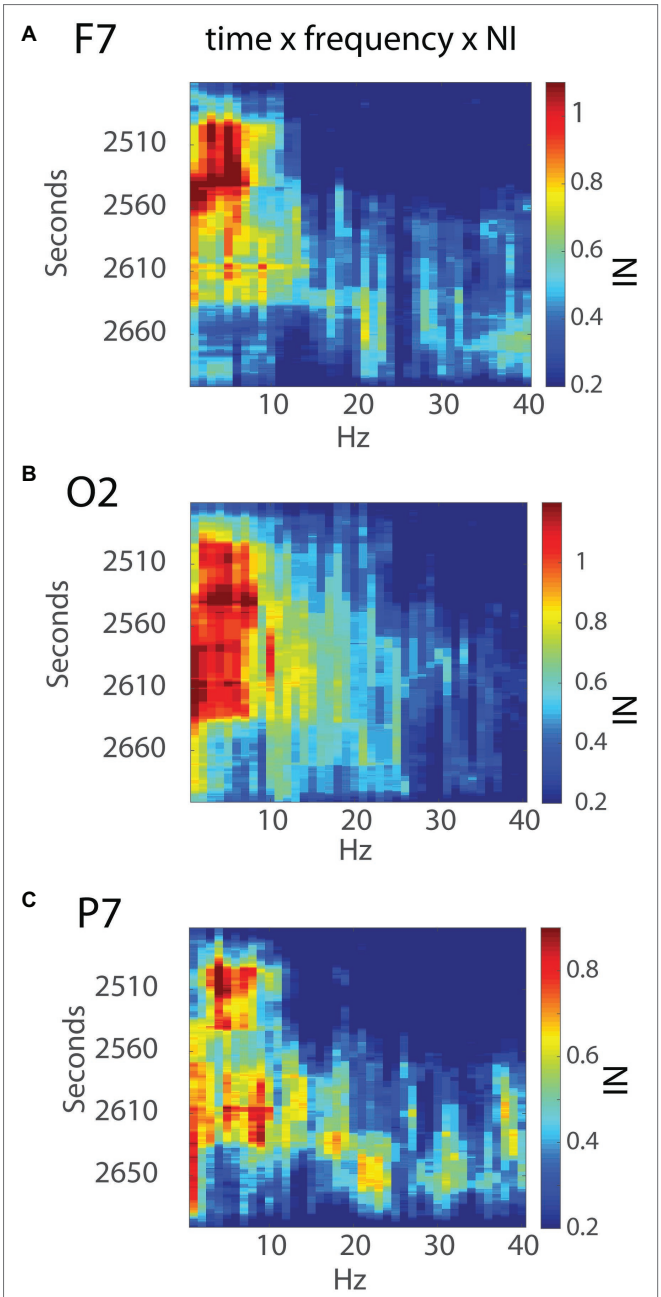

FIGURE 7 | Time x frequency vs. *NI* levels for the **(A)** F7, **(B)** O2, and **(C)** P7 sensors. The NI levels are shown by the color bars to the right.

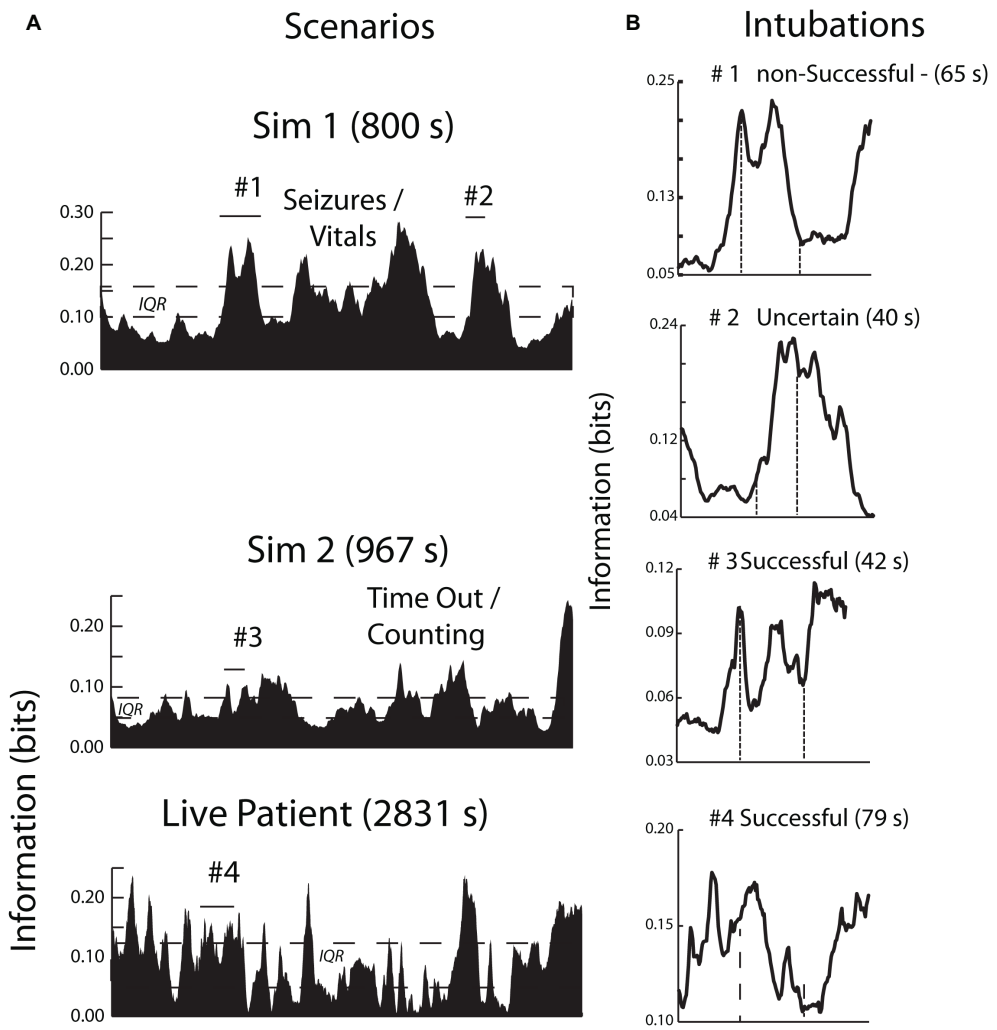

FIGURE 8 | (A) The contexts of the INTB activities are shown by the area plots of the scenario *NI*; the periods of intubation are shown by horizontal lines. **(B)** This figure compares the neurodynamic information profiles of three simulated INTB attempts of varying difficulty with a live patient INTB attempt.

has been associated with memory retrieval (Vergauwe and Cowan, 2014), whereas gamma power suppression has been associated with focused attention and while reading for comprehension (Lachaux et al., 2008; Ossandon et al., 2011; Sato and Mizuhara, 2018).

Analyses were therefore performed using the high, average, or low EEG values (i.e., −1, 1, or 3) rather than *NI* levels. **Figure 11** indicates that the elevated EEG beta-gamma *NI* levels found during the live patient INTB were due to low gamma EEG power values ($H = 137$, df = 3, $p < 0.01$) compared with the above average gamma power values during the simulation.

DISCUSSION

The results indicate that the sensor and frequency-averaged profiles of team and team member neurodynamics were similar in both the simulation and live patient environments. This provides an important validation of previous studies with military and healthcare teams where the team neurodynamics were linked with speech (Gorman et al., 2016), stressful situations (Stevens et al., 2013), and expert performance ratings (Stevens and Galloway, 2017) during high-fidelity simulation training. They further suggest that developing models to track the appearance of these fluctuations or estimate/predict their magnitude and duration could have practical training applications. For instance, providing these neurodynamic profiles to instructors prior to a debriefing following a training exercise could help focus the discussions around periods where the team might have experienced uncertainty. Similarly, the periods of elevated *NI* could serve as triggers for providing feedback in an intelligent tutoring setting for optimizing team health and performance.

While the overall neurodynamic profiles were similar under simulated and live patient conditions, according to the ideas

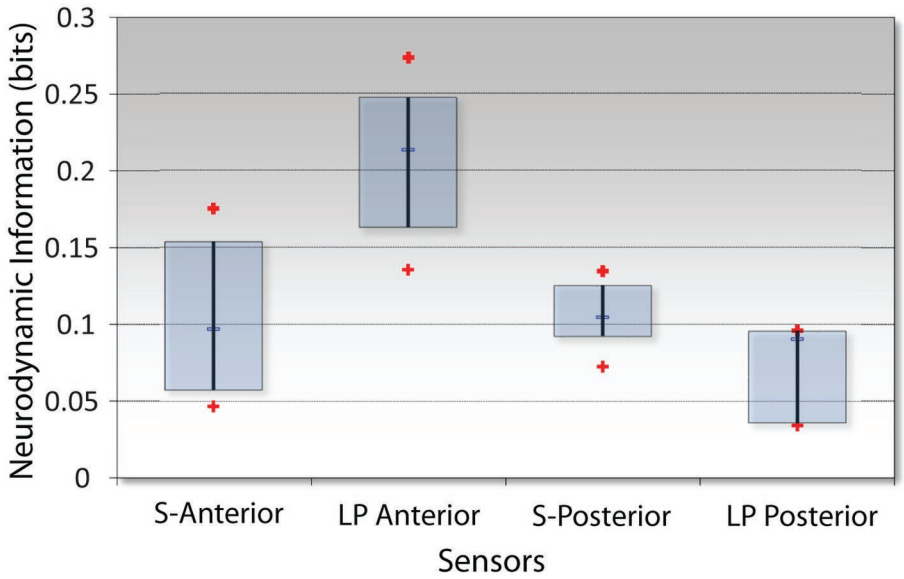

FIGURE 9 | *NI* levels at the anterior vs. posterior channels for the simulation (S) or the live patient (LP) INTB procedures. The frequency-averaged (18–40 Hz) *NI* levels were measured at the anterior (F3, Fz, F4) or posterior (P3, Pz, and P4) sensors for the simulation tasks, and the anterior (Fp1, Fpz, Fp2, F7, and F8) or posterior (P7, O1, Oz, O2, and P8) sensors for the live patient INTB.

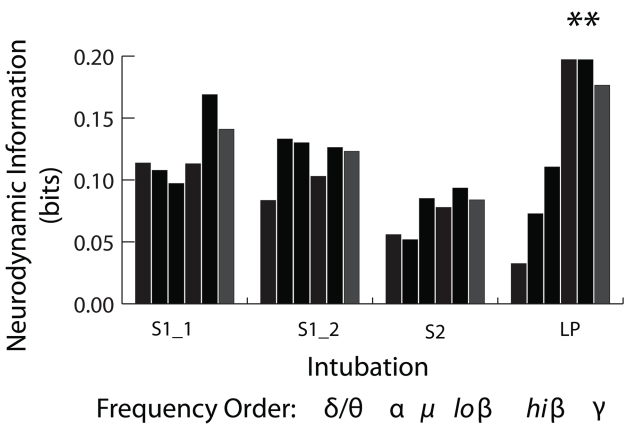

FIGURE 10 | Frequency band distribution of *NI* for the INTB events. The pooled low beta, high beta and gamma frequency bin *NI* levels from the live patient INTB were significantly greater than those from the simulations (Mann Whitney, $Z = 2.4$, $p = 0.01$).

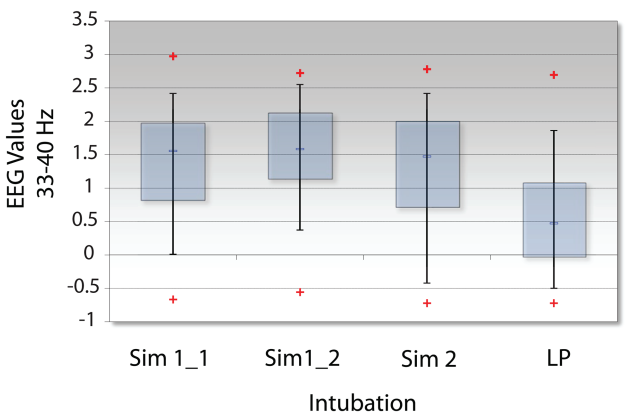

FIGURE 11 | Levels of EEG-gamma power during INTB events. The raw EEG values were determined for each of the intubation events; LP = live patient.

behind hierarchal cognition, each *NI* peak is likely neurodynamically heterogeneous. The appearance of patterns of elevated *NI* with the onset of meaningful events and their decline after the task completion are consistent with the idea they are neurodynamic representations of a set of procedures or subtasks needed to complete a task, i.e., a mental episode. Mental episodes are typically extended periods, with a defined beginning and ending, of focused deliberate behavior during which a sequence of steps are completed (Schneider and Logan, 2015). The execution of episodes is thought to begin by loading a sequence representation of the task into memory, which controls the sequence and identify of the subtasks. Following the ideas of hierarchical cognition, the component sequences are then executed (Schneider and Logan, 2006).

An example of this heterogeneity, and the episodic nature of the final surgical procedure, is shown in **Figures 7, 8** where the neurodynamics revealed a change in the neurosurgeons cognitive state with the onset of the final surgical procedure. The primary focus for this neurodynamic reorganization was the occipital lobe at the 3–11 Hz frequencies.

A second major cognitive state change occurred when the surgery was completed and the occipital lobe neurological organizations were replaced by a more heterogeneous frequency profile at the P7 channel before returning to preoperation levels. A similar neurodynamic analysis of the intubation procedure performed by the anesthesiologist suggests that each *NI* peak might show neurodynamic complexity at the sensor and frequency level.

The *NI* levels during the live patient INTB were unequally distributed between the anterior sensors where the levels were significantly greater than those from the posterior sensors. The anterior and posterior sensors' *NI* levels from simulation attempts were not statistically different, but were intermediate to those at the anterior and posterior levels during the surgery.

The finding of elevated neurodynamic organization in the frontal regions during INTB may be significant as frontal regions have been implicated in the detection of unfavorable outcomes, error correction, and resolution of uncertainty, all of which might be expected to play a role during this critical procedure (Ridderinkhof et al., 2004; Murray and Rudebeck, 2017). The EEG frequencies associated with the elevated frontal sensor *NI* were in the low beta – low gamma frequency range. Gamma EEG rhythms, or "gamma oscillations" emerge from neuronal structures at rates from 30 to up to 300 Hz. Their rhythms are driven by balances of inhibitory GABAergic interneurons and excitatory glutamatergic neurons (Whittington et al., 1995). Gamma oscillations occur alongside and in proportion to perceptual processes/salience (Sedley and Cunningham, 2013) and are thought to be pivotal in: (1) the search for information, or the refreshing of information within the brain, and (2) the communication of this information across regions of the brain.

The suggestion of gamma rhythm involvement in the search for information to populate short-term memory is based on repeated observations showing decreased response speed with the number of items in short-term memory, reaching a processing rate limit of 25–30 items per second (Vergauwe and Cowan, 2014). These authors have proposed that information for features of one item are represented by groups of neurons that fire within a gamma cycle and this gamma-band synchronization facilitates neural communication and synaptic plasticity.

Gamma rhythms do not act in isolation during this neural communication, but become phase locked and nested within theta rhythms (~ 5–7 gamma per theta wave) or alpha oscillations which serve to segment neuronal representations in time, and perhaps support their coordinated action across neuronal assemblies (Bonnefond and Jensen, 2015). In these two instances, gamma activity increases.

It is also becoming clear that attention-demanding tasks like reading for comprehension not only activate specific cortical regions, but also deactivate others that might interfere with the task either at local (Klimesch, 2012) or more distant cortical regions (Farooqi and Manly, 2018). Studies using intracerebral electrodes have suggested that focused interaction with the external world is associated with gamma rhythm suppression in the default mode network (Ossandon et al., 2011). This is a series of brain regions linked with introspective thoughts (Raichle et al., 2001).

Possible linkages between the reduced gamma rhythm levels we have observed during the INTB event of the live patient and previously reported spatially localized network and short-lived gamma suppression are difficult to speculate on from a single sample. The possibility exists however that the INTB with the live patient induced a more attentive state in the AN than that provided by the simulations, suggesting a fundamental difference in the two environments.

As expressed by the AN: "I was aware that the OR was a real patient and the lab case was just a simulation. I felt the usual urgency in the real case to perform well as opposed to the lab simulation where it's more relaxed because you know there isn't anything important at stake." As measures of individual and team performance become more micro-scale and dynamic, and simulations become extended into virtual environments, these results argue for the (at least limited) need for parallel studies in live environments to maximize the benefits from these emerging technologies.

ETHICS STATEMENT

The study and the informed consent protocols were reviewed and approved by the Biomedical IRB, San Diego, CA (Protocol EEG01), and the Order of Saint Francis Healthcare Institutional Review Board, Peoria IL. All participating subjects gave written and informed consent to participate in the EEG data collections and have their data (including images and speech) anonymously analyzed per approved applicable protocols. To maintain confidentiality, each subject was assigned a unique number known only to the investigators of the study, and subject identities were not shared. This design complies with DHHS: protected human subject 45 CFR 46; FDA: informed consent 21 CFR 50.

AUTHOR CONTRIBUTIONS

RS and TG acquired and processed the EEG data for the simulation and live patient performances then performed the neurodyamic modeling and generated and conducted the data analysis. AW-D oversaw the development and implementation of the team simulation activities. All authors participated in preparing the paper.

FUNDING

The studies were supported in part by the Jump Foundation for Simulation Research and the Defense Advanced Research Projects Agency under contract W31P4QC0166 and the Illinois Neurological Institute.

REFERENCES

Aebersold, M. (2018). Simulation-based learning: no longer a novelty in undergraduate education. *Online J. Issues Nurs.* 23. doi: 10.3912/OJIN.Vol23No02PPT39

Bonnefond, M., and Jensen, O. (2015). Gamma activity coupled to alpha phase as a mechanism for top-down controlled gating. *PLoS One* 10:e012866. doi: 10.1371/journal.pone.0128667

Buzaki, G. (2006). *Rhythms of the brain*. New York, NY: Oxford University Press.

Caetano, G., Jousmaki, V., and Hari, R. (2007). Actor's and observers primary motor cortices stabilize similarly after seen or heard motor actions. *Proc. Natl. Acad. Sci. USA* 104, 9058–9062. doi: 10.1073/pnas.0702453104

Cooper, R., and Shallice, T. (2000). Contention scheduling and the control of routine activities. *Cogn. Neuropsychol.* 17, 297–338. doi: 10.1080/026432900380427

Delorme, A., Palmer, J., Onton, J., Oostenveld, R., and Makeig, S. (2012). Independent EEG sources are dipolar. *PLoS One* 7:e30135. doi: 10.1371/journal.pone.0030135

Farooqi, A. A., and Manly, T. (2018). Hierarchical cognition causes task related deactivations but not just in the default mode regions. *eNeuro*. 5. doi: 10.1523/ENEURO.0008-18.2018

Gorman, J. C., Martin, M. J., Dunbar, T. A., Stevens, R. H., Galloway, T. L., Amazeen, P. G., et al. (2016). Cross-level effects between neurophysiology and communication during team training. *Hum. Factors* 58, 181–199. doi: 10.1177/0018720815602575

Guastello, S. J., and Peressini, A. F. (2018). Development of a synchronization coefficient for biosocial interactions in groups and teams. *Nonlinear Dynamics Psychol. Life Sci.* 48, 3–33. doi: 10.1177/1046496416675225

Guastello, S. J., Pincus, D., and Gunderson, P. R. (2006). Electrodermal arousal between participants in a conversation: nonlinear dynamics for linkage effects. *Nonlinear Dynamics Psychol. Life Sci.* 10, 365–399.

James, R. G., Ellison, C. J., and Crutchfield, J. P. (2011). Anatomy of a bit: Information in a time series observation. Santa Fe Institute Working Paper 11-05. arXiv:1105.2988v1 [cs.IT] [Preprint]. doi: 10.1063/1.3637494

Klimesch, W. (2012). Alpha-band oscillations, attention and controlled access to stored information. *Trends Cogn. Sci.* 16, 606–617. doi: 10.1016/j.tics.2012.10.007

Lachaux, J. P., Jung, J., Dreher, J. C., Bertrand, O., Minotti, L., Hoffman, D., et al. (2008). Silence is golden: transient neural deactivation in the prefrontal cortex during attentive reading. *Cereb. Cortex* 18, 443–450. doi: 10.1093/cercor/bhm085

Magee, J. H. (2003). Validation of medical modeling & simulation training devices and systems. *Stud. Health Technol. Inform.* 94, 196–198. doi: 10.3233/978-1-60750-938-7-196

Mullen, T. (2012). NITRC: CleanLine: Tool/Resource Info. Retrieved from: http://www.nitrc.org/projects/cleanline

Murray, E. A., and Rudebeck, P. H. (2017). Specializations for reward-guided decision-making in the primate ventral prefrontal cortex. *Nat. Rev. Neurosci.* 19, 404–417. doi: 10.1038/s41583-018-0013-4

Oostenveld, R., Fries, P., Maris, E., and Schoffelen, M. (2011). FieldTrip: open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Comput. Intell. Neurosci.* 2011:156869. doi: 10.1155/2011/156869

Ossandon, T., Jerbi, K., Vidal, J. R., Bayle, D. J., Henaff, M.-A., Jung, J., et al. (2011). Transient suppression of broadband gamma power in the default mode network is correlated with task complexity and subject performance. *J. Neurosci.* 31, 14521–14530. doi: 10.1523/JNEUROSCI.2483-11.2011

Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., and Shulman, G. L. (2001). A default mode of brain function. *Proc. Natl. Acad. Sci. USA* 98, 676–682. doi: 10.1073/pnas.98.2.676

Ridderinkhof, K. R., Ullsperger, M., Crone, E. A., and Nieuwenhuis, S. (2004). The role of the medial frontal cortex in cognitive control. *Science* 306, 443–447. doi: 10.1126/science.1100301

Salas, E., Stevens, R., Gorman, J., Cooke, N. J., Guastello, S., and von Davier, A. (2015). What will quantitative measures of teamwork look like in 10 years? *Proc. Hum. Factors Ergon. Soc. Annu. Meet.* 59, 235–239. doi: 10.1177/1541931215591048

Sanger, J., Muller, V., and Lindenberger, U. (2012). Intra-and interbrain synchronization and network properties when playing guitar in duets. *Front. Hum. Neurosci.* 6:312. doi: 10.3389/fnhum.2012.00312

Sato, N., and Mizuhara, H. (2018). Successful encoding during natural reading is associated with fixation related potential and large-scale network activation. *eNeuro.* 5. doi: 10.1523/ENEURO.0122-18.2018

Schmidt, E., Goldhaber-Fiebert, S. M., Ho, L. A., and McDonald, D. (2013). Simulation exercises as a patient safety strategy: a systematic review. *Ann. Intern. Med.* 158, 426–432. doi: 10.7326/0003-4819-158-5-201303051-00010

Schneider, D. W., and Logan, G. D. (2006). Hierarchical control of cognitive processes: switching tasks in sequences. *J. Exp. Psychol. Gen.* 135, 623–640. doi: 10.1037/0096-3445.135.4.623

Schneider, D. W., and Logan, D. (2015). Chunking away task-switch costs: a test of the chunk-point hypothesis. *Psychon. Bull. Rev.* 22, 884–889. doi: 10.3758/s13423-014-0721-3

Sedley, W., and Cunningham, M. O. (2013). Do cortical gamma oscillations promote or suppress perception? An under-asked question with an over-assumed answer. *Front. Hum. Neurosci.* 7:595. doi: 10.3389/fnhum.2013.00595

Shannon, C. E. (1948). A mathematical theory of communication. *Bell Syst. Tech. J.* 27, 379–423, 623–656. doi: 10.1002/j.1538-7305.1948.tb01338.x

Shannon, C. E. (1951). Prediction and entropy of printed English. *Bell Syst. Tech. J.* 30, 50–64. doi: 10.1002/j.1538-7305.1951.tb01366.x

Staropoli, P. C., Gregori, N. Z., Junk, A. K., Galor, A., Goldhardt, R., Goldhagen, B. E., et al. (2018). Surgical simulation training reduces intraoperative cataract surgery complications among residents. *Simul. Healthc.* 13, 11–15. doi: 10.1097/SIH.0000000000000255

Stephens, G., Silbert, L., and Hasson, U. (2010). Speaker-listener neural coupling underlies successful communication. *Proc. Natl. Acad. Sci. USA*. 107, 14425–14430. doi: 10.1073/pnas.1008662107

Stevens, R. H., and Galloway, T. (2014). Toward a quantitative description of the neurodynamic organizations of teams. *Soc. Neurosci.* 9, 160–173. doi: 10.1080/17470919.2014.883324

Stevens, R. H., and Galloway, T. (2015). Modeling the neurodynamic organizations and interactions of teams. *Soc. Neurosci.* 11, 123–139. doi: 10.1080/17470919.2015.1056883

Stevens, R. H., and Galloway, T. (2017). Are neurodynamic organizations a fundamental property of teamwork? *Front. Psychol.* 8. doi: 10.3389/fpsyg.2017.00644

Stevens, R. H., Galloway, T., Gorman, J., Willemsen-Dunlap, A., Halpin, D., and Grimm, D. (2018a). *Human factors & ergonomics national meeting.* Philadelphia, PA. 1, 167–172.

Stevens, R. H., Galloway, T., Halpin, D., and Willemsen-Dunlap, A. (2016). Healthcare teams neurodyamically reorganize when resolving uncertainty. *Entropy* 18:427. doi: 10.3390/e18120427

Stevens, R. H., Galloway, T., Lamb, J., Steed, R., and Lamb, C. (2017a). "Linking team neurodynamic organizations with observational ratings of team performance" in *Innovative assessment of collaboration*. eds. A. von Davier, M. Zhu, and P. Kyllonen (New York, NY: Springer International Publishing).

Stevens, R. H., Galloway, T., and Willemsen-Dunlap, A. (2017b). "Low level predictors of team dynamics: a neurodynamic approach" in *Research in managing groups and teams research series: V. 18 team dynamics over time*. eds. E. Salas, B. Vessey, and L. B. Landon (Emerald Publishing Limited), 71–92.

Stevens, R. H., Galloway, T., and Willemsen-Dunlap, A. (2018b). Quantitative modeling of individual, shared and team neurodynamic information. *Hum. Factors* 60, 1022–1034. doi: 10.1177/0018720818781623

Stevens, R. H., Gorman, J. C., Amazeen, P., Likens, A., and Galloway, T. (2013). The organizational neurodynamics of teams. *Nonlinear Dynamics Psychol. Life Sci.* 17, 67–86.

Thomas, P. A., Kern, D. E., Hughes, M. T., and Chen, B. Y. (2015). *Curriculum development for medical education: A six-step approach*. Baltimore, MD: Johns Hopkins University Press.

Vergauwe, E., and Cowan, N. (2014). A common short-term memory retrieval rate may describe many cognitive procedures. *Front. Hum. Neurosci.* 8. doi: 10.3389/fnhum.2014.00126

Whittington, M. A., Traub, R. D., and Jefferys, J. G. R. (1995). Synchronized oscillations in interneuron networks driven by metabotropic glutamate receptor activation. *Nature* 373, 612–615. doi: 10.1038/373612a0

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Stevens, Galloway and Willemsen-Dunlap. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Communication

ORIGINAL RESEARCH
published: 06 September 2019
doi: 10.3389/fcomm.2019.00050

The Evolution of Human-Autonomy Teams in Remotely Piloted Aircraft Systems Operations

Mustafa Demir[1,2]*, *Nathan J. McNeese*[3] *and Nancy J. Cooke*[1,2]

[1] Human Systems Engineering, Arizona State University, Mesa, AZ, United States, [2] The Cognitive Engineering Research Institute, Mesa, AZ, United States, [3] Human-Centered Computing, Clemson University, Clemson, SC, United States

The focus of this current research is 2-fold: (1) to understand how team interaction in human-autonomy teams (HAT)s evolve in the Remotely Piloted Aircraft Systems (RPAS) task context, and (2) to understand how HATs respond to three types of failures (automation, autonomy, and cyber-attack) over time. We summarize the findings from three of our recent experiments regarding the team interaction within HAT over time in the dynamic context of RPAS. For the first and the second experiments, we summarize general findings related to team member interaction of a three-member team over time, by comparison of HATs with all-human teams. In the third experiment, which extends beyond the first two experiments, we investigate HAT evolution when HATs are faced with three types of failures during the task. For all three of these experiments, measures focus on team interactions and temporal dynamics consistent with the theory of interactive team cognition. We applied Joint Recurrence Quantification Analysis, to communication flow in the three experiments. One of the most interesting and significant findings from our experiments regarding team evolution is the idea of entrainment, that one team member (the pilot in our study, either agent or human) can change the communication behaviors of the other teammates over time, including coordination, and affect team performance. In the first and second studies, behavioral passiveness of the synthetic teams resulted in very stable and rigid coordination in comparison to the all-human teams that were less stable. Experimenter teams demonstrated metastable coordination (not rigid nor unstable) and performed better than rigid and unstable teams during the dynamic task. In the third experiment, metastable behavior helped teams overcome all three types of failures. These summarized findings address three potential future needs for ensuring effective HAT: (1) training of autonomous agents on the principles of teamwork, specifically understanding tasks and roles of teammates, (2) human-centered machine learning design of the synthetic agent so the agents can better understand human behavior and ultimately human needs, and (3) training of human members to communicate and coordinate with agents due to current limitations of Natural Language Processing of the agents.

Keywords: human-autonomy teaming, synthetic agent, team cognition, team dynamics, remotely piloted aircraft systems, unmanned air vehicle, artificial intelligence, recurrence quantification analysis

OPEN ACCESS

Edited by:
Eduardo Salas,
Rice University, United States

Reviewed by:
Gilbert Ernest Franco,
Beacon College, United States
Tara Behrend,
George Washington University,
United States

Correspondence:
Mustafa Demir
mdemir@asu.edu

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Communication

Received: *15 February 2019*
Accepted: *23 August 2019*
Published: *06 September 2019*

Citation:
Demir M, McNeese NJ and Cooke NJ (2019) The Evolution of Human-Autonomy Teams in Remotely Piloted Aircraft Systems Operations. Front. Commun. 4:50. doi: 10.3389/fcomm.2019.00050

INTRODUCTION

In general, teamwork can be defined as the interaction of two or more heterogeneous and interdependent team members working on a common goal or task (Salas et al., 1992). When team members interact dynamically with each other and with their technological assets to complete a common goal, they act as a dynamical system. Therefore, an essential part of a successful team is the ability of its members to effectively coordinate their behaviors over time. In the past, teamwork has been investigated for all-human teams by considering team interactions (i.e., communication and coordination) to understand team cognition (Cooke et al., 2013) and team situation awareness (Gorman et al., 2005, 2006). Presently, advancements in machine learning in the development of autonomous agents are allowing agents to interact more effectively with humans (Dautenhahn, 2007), to make intelligent decisions, and to adapt to their task context over time (Cox, 2013). Therefore, autonomous agents are increasingly considered team members, rather than tools or assets (Fiore and Wiltshire, 2016; McNeese et al., 2018) and this has generated research in team science on Human-Autonomy Teams (HAT)s.

In this paper, we summarize findings from three of our three recent experiments regarding the team interaction within the HAT over time in the dynamic context of a Remotely Piloted Aircraft System (RPAS). In the first and the second experiments, we summarize general findings related to the interaction of a three-member team over time, by comparison of HATs with all-human teams. In the third experiment, which extends beyond the first two experiments, we investigate HAT evolution when HATs are faced with a series of unexpected events (i.e., roadblocks) during the task: automation and autonomy failures and malicious cyber-attacks. For all three of these experiments, measures focus on team interactions (i.e., communication and coordination) and temporal dynamics consistent with the theory of interactive team cognition (Cooke et al., 2013). Therefore, the goal of the current paper is to understand how team interaction in HATs develops over time, across routine and novel conditions, and how this team interaction relates to team effectiveness.

We begin by describing HATs as sociotechnical systems and identify the challenges in capturing this dynamical complexity. Next, we introduce the RPAS synthetic task environment, and three RPAS studies conducted in this environment. Then, we summarize the findings from HATs and compare this evolution to that of all-human teams.

Teaming With Autonomous Agents

A HAT consists of a minimum of one person and one autonomous agent "coordinating and collaborating interdependently over time in order to successfully complete a task" (McNeese et al., 2018). In this case, an autonomous team member is considered to be capable of working alongside human team member(s) by interacting with other team members (Schooley et al., 1993; Krogmann, 1999; Endsley, 2015), making its own decision about its actions during the task, and carrying out taskwork and teamwork (McNeese et al., 2018). In team literature, it is clear that autonomous agents have grown more common in different contexts, e.g., software (Ball et al., 2010) and robotics (Cox, 2013; Goodrich and Yi, 2013; Chen and Barnes, 2014; Bartlett and Cooke, 2015; Zhang et al., 2015; Demir et al., 2018c). However, considering an autonomous agent as a teammate is challenging (Klein et al., 2004) and requires effective teamwork functions (McNeese et al., 2018): understanding its own task, being aware of others' tasks (Salas et al., 2005), and effective interaction (namely communication and coordination) with other teammates (Gorman et al., 2010; Cooke et al., 2013). Especially in dynamic task environments, team interaction plays an important role in teamwork and it requires some amount of pushing and pulling of information in a timely manner. However, the central issue to be addressed is more complex than just pushing and pulling information; time is also a factor. This behavioral complexity in dynamic task environments can be better understood from a dynamical systems perspective (Haken, 2003; Thelen and Smith, 2007).

The Temporal Patterning of Team Interaction

Robotics science (Bristol, 2008) posits that complex behavior of an autonomous agent does not necessarily require complex internal mechanisms in order to interact in the environment over time (Barrett, 2015). That is, the behavioral flexibility of a simple autonomous agent is contingent on the mechanics and wiring of its sensors rather than its brain or other components (for an example see Braitenberg and Arbib, 1984). However, in order to produce complex behaviors, there are other elements than hardware, specifically interaction with the environment which it is subject to. The behavioral complexity of an autonomous agent is actually more than parts appear to be individually. This complexity is a real challenge for robotics and cognitive scientists seeking to understand autonomous agents and their dynamic interactions with both humans and the agent's environment (Klein et al., 2004; Fiore and Wiltshire, 2016). Humans have a similar dynamical complexity, as summarized by Simon (1969), who stated, "viewed as behaving systems, [humans] are quite simple. The apparent complexity of our behavior over time is largely a reflection of the complexity of the environment in which we find ourselves" (p. 53).

In order to better understand the complexity of autonomous agents and their interactions with humans in their task environment, we can consider the interactions as happening within a dynamical system where an agent synchronizes with human team members in a dynamic task environment. In this case, a dynamical system is a system which demonstrates a continuous state-dependent change (i.e., hysteresis: future state causally depends on the current state of the system). Thus, interactions are considered a state of the system whole rather than the individual components. A dynamical system can behave in many and different ways over time which move around within a multidimensional "state space." Dynamical systems may favor a particular region of the state space—i.e., move into a reliable pattern of behavior—and, in such cases is considered to have transitioned to an "attractor state." When the system moves beyond this state, it generally reverts to it in the future. The system then becomes more resilient (i.e., the attractor states get

stronger) to adapt to dynamic unexpected changes in the task environment as it develops experience. However, if given a strong enough perturbation from the environment's external forces, the system may move into new patterns of behavior (Kelso, 1997; Demir et al., 2018a).

With that in mind, HAT is a sociotechnical system in which behaviors emerge via interactions between interdependent autonomous and human team members over time. These emerging behaviors are an example of entrainment, the effect of time on team behavioral processes, and in turn team performance (McGrath, 1990). Replacing one human team role with an autonomous agent can change the behavior of other teammates and affect team performance over time. In the sociotechnical system, human and autonomous team members must synchronize and rhythmize their roles with the other team members to achieve a team task over time. In order to do so, it is necessary for the team to develop an emergent complexity which is resilient, adaptable, and includes fault-tolerant systems-level behavior in response to the dynamic task environment (Amazeen, 2018; Demir et al., 2018a).

Adaptive complex behavior of a team (as sociotechnical system) is considered within the realm of dynamical systems (either linear or non-linear) and dynamical changes of the sociotechnical systems behavior can be measured via Non-linear Dynamical Systems (NDS) methods. One commonly used NDS method in team research is Recurrence Plots (RPs) and its extension Recurrence Quantification Analysis (RQA; Eckmann et al., 1987). The bivariate extension of RQA is Cross RQA and multivariate extension is Joint RQA (JRQA; Marwan et al., 2002; Coco and Dale, 2014; Webber and Marwan, 2014). In general, RPs visualize the behavior trajectories of dynamical systems in phase space and RQA evaluates how many recurrences there are which use a phase space trajectory within a dynamical system. The experimental design of the RPAS team is conceptually in line with JRQA and it is thus the method used for HAT research in this exploratory paper.

RPAS SYNTHETIC TASK ENVIRONMENT

The synthetic teammate project (Ball et al., 2010) is a longtitudinal project which aims to replace a ground station team member with a fully-fledged autonomous agent. From a methodological perspective, all three of the experiments were conducted in the context of CERTT RPAS-STE (Cognitive Engineering Research on Team Tasks RPAS—Synthetic Task Environment; Cooke and Shope, 2004, 2005). CERTT RPAS-STE has various features and provides new hardware infrastructure to support this study: (1) text chat capability for communications between the human and synthetic participants, and (2) new hardware consoles for three team members and two consoles for two experimenters who oversee the simulation, inject roadblocks, make observations, and code the observations.

Task and Roles

The RPAS-STE task requires three different, interdependent teammates working together to take good photos of the targets (see **Figure 1**): (1) the *navigator* provides the flight plan to the synthetic pilot (called *Information*) and navigates it to each waypoint, (2) the *pilot* controls the Remotely Piloted Aircraft (RPA) and adjusts altitude and airspeed based on the photographer's requests (called *Negotiation*), and (3) the *photographer* photographs the target waypoints, adjusts the camera settings, and also shares information relating to photo quality—i.e., whether or not the photo was "good"—to the other two team members (called *Feedback*). Taking good photographs of designated target waypoints is the main goal for all the teams, and it requires timely and effective information sharing among teammates. The photographer determines if a photo is good based on the photograph folder which shows examples of good photographs (in regard to camera settings, i.e., camera type, shutter speed, focus, aperture, and zoom). This timely effective coordination sequence for this task is called *Information-Negotiation-Feedback* (INF; Gorman et al., 2010). All interactions occur within a text-based communications system (Cooke et al., 2007).

In the simulated RPAS task environment, the target waypoints were within areas referred to as Restricted Operating Zones (ROZ boxes) which have entry and exit waypoints that teams must pass through to access the target waypoints. All studies had missions that could either be low workload (11–13 target waypoints within five ROZ) or high workload (20 target waypoints within seven ROZ). The number and length of missions varied as follows: In the first and the second experiments, all teams went through five 40 min missions with 15 min breaks in between missions. Missions 1–4 were low workload, but Mission 5 was high workload in order to determine the teams' performance strength. During the last study, teams went through ten 40 min missions which were divided into two sessions with 1 or 2 weeks in between. However, while in the first and second studies, the first four missions had identical workloads, in the third study, the first nine missions had identical workloads and the 10th mission was high workload.

Measures

In the RPAS STE, we collected performance and process measures and then analyzed them with statistical and non-linear dynamical methods. In this way, we could first understand the nature of all-human teams to prepare for the development of HATs. In general, we collected the following measures for the following three RPAS experiments (see **Table 1**; Cooke et al., 2007). Each of these measures was designed during a series of experiments which were part of the synthetic teammate project.

In RPAS studies, we considered *team communication flow* to look at HAT patterns of interaction and their variation over time by using Joint Recurrence Plots (JRPs). JRPs are instances when two or more individual dynamical components show a simultaneous recurrence (pointwise product of reperesentative univariate RPs) and JRQA provides the quantity (and length) of recurrences in a dynamical system using phase space trajectory (Marwan et al., 2007). In this perspective, JRQA can be utilized for the purpose of examining variations between multiple teams in regard to how and why they, specifically how frequently team members synchronize their activities while communicating by text message. That is, JRQA basically evaluates synchronization

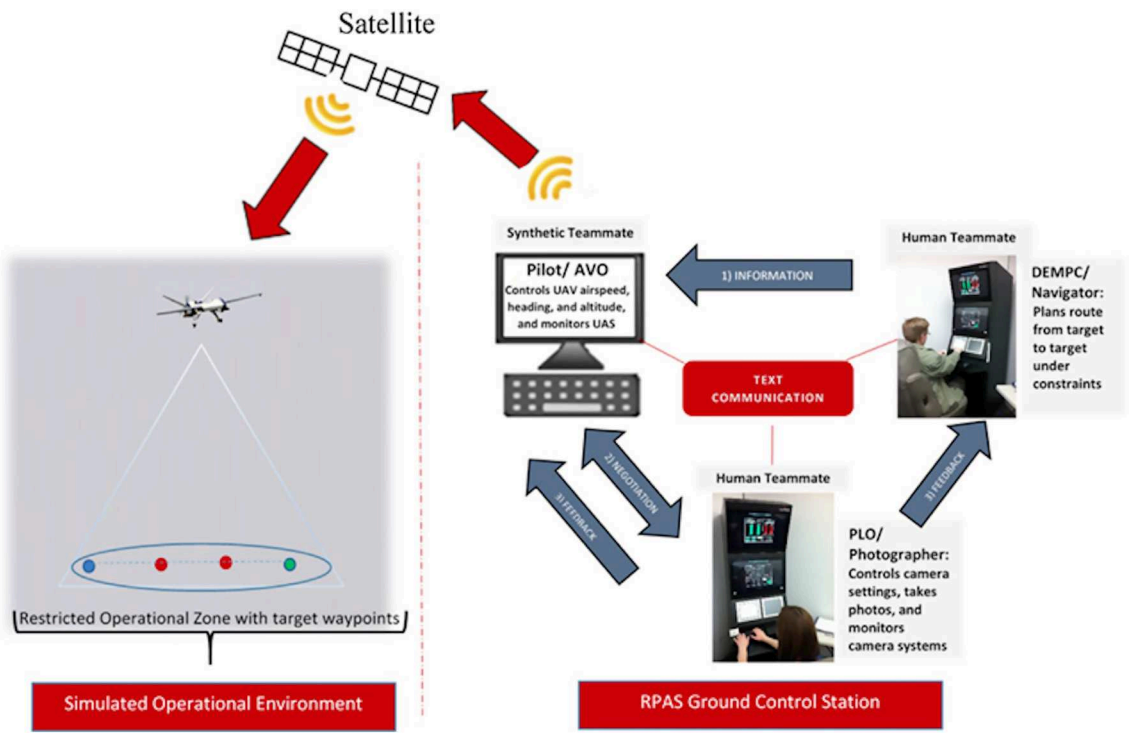

FIGURE 1 | Simulated RPAS task environment for each role, and task coordination (information-negotiation-feedback). The dashed line separates ground control station and simulated operational environment (from Demir et al., 2017; reprinted with permission).

TABLE 1 | The RPAS measures.

Measures	Description
Team performance	A weighted combined score of team-level mission parameters, including time spent in warning and alarm states, number of missed targets, and rate of good target photographs per minute (which was weighted most heavily among the parameters). Teams began each mission with a score of 1,000, and points were deducted based on the final values of the mission sub-scores
Target Processing Efficiency (TPE)	TPE takes into account time spent inside a target waypoint to get a good photo. Each team started with a maximum of 1,000 points then deducted the number of seconds spent in the target radius and 200 penalty points (for bad or missed photos)
Team process rating	The rating comprises: (1) coordination—interacting with the right team member about the appropriate information in the right order; (2) timeliness—represents the ability of the team to sort through relevant data and interact expeditiously enough to effectively deal with the target (to do this, interactions are evaluated in accordance to the relative position of the RPA to the target at that moment); and (3) communication quality—related to the clarity and uniqueness of the interactions since those two qualities are seen to minimize need for repetition
Team Situation Awareness (TSA)	TSA is the degree to which the team members took action and overcame roadblocks (i.e., perturbation). If the team overcame the roadblock, it was coded as "1," otherwise it was "0." This measure indicates how a team can adapt to dynamic unexpected changes in the task environment as it develops experience
Team communication behaviors	The behaviors are classified into two groups: pushing or pulling of information among the team members
Team communication flow	It consists of each team member's message sent time (by seconds)
Workload	NASA Task Load Index (TLX; Hart and Staveland, 1988)
Post experiment question	It includes a series of questions about the backgrounds of team members (e.g., age, sex, automated system experience) and their impressions of the experiment

Cooke et al. (2007).

and influence by means of looking at system interactions (Demir et al., 2018b).

In RPAS studies, the time stamp for each message (as seconds) is used to evaluate the flow of communication between team members, resulting in multivariate binary data. We chose an ideal window size based on the following order: (1) Determinism (DET) was estimated based on windows which increased by 1 s for each mission, and (2) DET variance was evaluated for each size of window and a 1 min window that was chosen according to the average period in which DET no longer increased was

selected. This information was useful in order to visually and quantitatively represent any repeating structural elements within communication of the teams.

For all three experiments, we extracted seven measures from JRQA: recurrence rate, percent determinism (DET), longest diagonal line, entropy, laminarity, trapping time, and longest vertical line. The measure which all three RPAS studies were interested in was DET, represented by formula (1) (Marwan et al., 2007), which we defined as the "ratio of recurrence points forming diagonal lines to all recurrence points in the upper triangle" (Marwan et al., 2007). Time periods during which the system repeated a sequence of states were represented in the RP by diagonal lines. DET is able to characterize the level of organization present in the communications of a system by examining the dispersion of repeating points on the RP; systems which were highly deterministic repeated sequences of states many times (i.e., many diagonal lines on the RP) while systems that were mildly deterministic would only repeat a sequence of states rarely (i.e., few diagonal lines). In Formula (1), l is the length of the diagonal line when its value is l_{min} and $P(l)$ is the probability distribution of line lengths (Webber and Marwan, 2014). A 0% Determinism rate indicated that the time series never repeated, whereas a 100% Determinism rate indicated a perfectly repeating time series.

$$DET = \frac{\sum_{l=l_{\min}}^{N} lP(l)}{\sum_{l=1}^{N} lP(l)} \quad (1)$$

THE RPAS EXPERIMENTS

In the first experiment, human team members collaborate with a "synthetic teammate" [a randomly selected human team member, Wizard of Oz Paradigm; WoZ (Riek, 2012)] that communicates based on natural language. In the second experiment, a synthetic agent with limited communication behavior, the Adaptive, Control of Thought-Rationale (ACT-R; Anderson, 2007), worked with human team members. In the last experiment, similar to the first experiment, human team members communicated and coordinated with a "synthetic teammate" (played this time by a highly trained experimenter who mimicked a synthetic agent with a limited vocabulary; WoZ) in order to overcome automation and autonomy failures, and malicious cyber-attack. Participants in all three experiments were undergraduate and graduate students recruited from Arizona State University and were compensated $10/hour. In order to participate, students were required to have normal or corrected-to-normal vision and be fluent in English. The following table indicates the experimental design and situation awareness index for each of the conditions (see **Table 2**). This study was carried out in accordance with the recommendations of The Cognitive Engineering Research Institute Institutional Review Board under The Cognitive Engineering Research Institute (CERI, 2007). The protocol was approved by The Cognitive Engineering Research Institute Institutional Review Board. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

TABLE 2 | Experimental design for three RPAS studies.

Experiment	Condition *x* Mission	Design
1	2 (condition) × 5(40 min mission)	Control: pilot was randomly selected participant Synthetic: pilot was randomly selected participant
2	3 (condition) × 5(40 min mission)	Control: pilot was randomly selected participant Synthetic: pilot was ACT-R based model Experimenter: pilot was highly trained confederate researcher
3	No condition with 10 (40 min mission)	Automation and Autonomy Failures, and Cyber Attack

RPAS I: Human-Autonomy Teaming When the Synthetic Agent Had Natural Language Capability

For the first experiment, the main question is whether the manipulation of team members' beliefs about their pilot can be associated with team interactions and, ultimately, team performance for overcoming the roadblocks (Demir and Cooke, 2014; Demir et al., 2018c). Thus, there are two conditions in this experiment: synthetic and control, with 10 teams in each condition (total 20 teams). Sixty randomly selected participants completed the experiment ($M_{age} = 23$, $SD_{age} = 6.39$). In the synthetic condition, we simulated a "synthetic agent" using a WoZ paradigm: one participant was chosen to be the pilot, and in therefore automatically and unknowingly became the synthetic agent. The other two team members were randomly assigned to navigator and photographer roles and were informed that there was a synthetic agent serving as the pilot. In this case, the navigator and photographer could not see the pilot when entering or leaving the room, nor during the breaks. Since the pilot in the control condition was a randomly assigned participant and the other two team members knew this (all three roles signed the consent forms together, and they all saw each other during that time), communication developed naturally among the team members (again, the navigator and photographer roles were randomly assigned).

In this study, we manipulated the beliefs of the navigator and the photographer in that they were led to believe that the third team member was not human, but a synthetic agent. This was done in order to answer the question of whether the manipulation of that belief could affect team interactions and ultimately team effectiveness (Demir and Cooke, 2014; Cooke et al., 2016; Demir et al., 2018c). The key aspects of two articles of this study use several quantitative methods to understand team interaction and its relationship with team effectiveness across the conditions. In this specific experiment, the teams went through five 40 min missions (with a 15 min break after each) and we

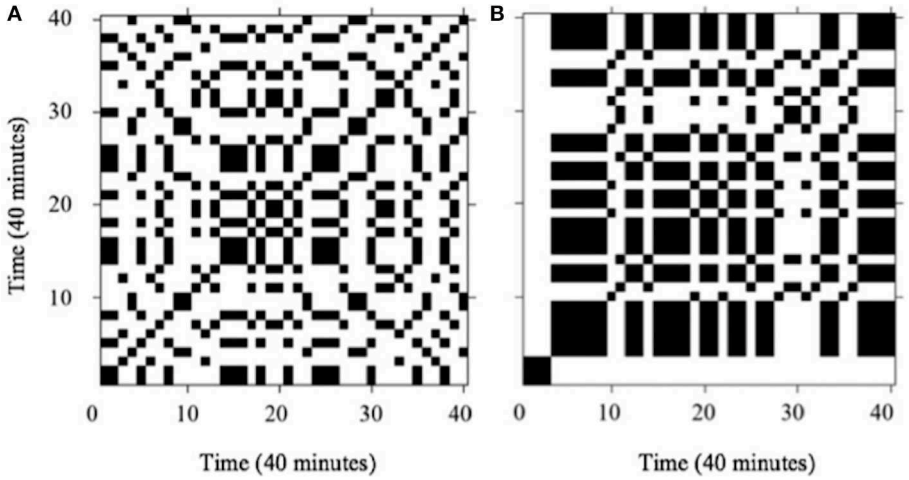

FIGURE 2 | Example JRP for two high performing UAV teams' interactions (length 40 min): **(A)** control (Determinism: 46%) and **(B)** synthetic teams (Determinism: 77.6%) (from Demir et al., 2018c; reprinted with permission).

collected the measures described in **Table 1**. We comprehensively discussed the key findings in previous papers (Demir and Cooke, 2014; Demir et al., 2018c).

As a dynamical analysis, we applied JRQA to binary communication flow time series data for 40 min missions in order to visually and quantitatively represent any repeating structural elements within communication of the teams. In the following figure, we give two example JRP (one control and one synthetic team) for two RPAS teams' interactions; these consist of three binary sequences (one for each team member) that are each 40 min in length. The three binary sequences were created based on whether navigator, pilot, or photographer sent a message in any given minute. If a message was sent or no message was sent, they was coded as "1" and "0," respectively. Based on the JRP and DET, the very short diagonals indicated that the control teams showed less predictable team communication (Determinism: 46%) while the longer diagonals mean that the synthetic teams demonstrated more predictable communication (Determinism: 77.6%; see **Figure 2**). Also, we found that the predictability in synthetic teams had more negative relationship with their performance on target processing (TPE), whereas this relationship was less negative in the control teams (Demir et al., 2018c).

Overall findings from this first experiment (see **Table 3**) indicate that the teams which had been informed that their pilot was actually a synthetic agent not only liked the pilot more, but also perceived lower workload, and assisted the pilot by giving it more suggestions (Demir and Cooke, 2014). Based on the two goals of current paper, our findings indicate that (Demir et al., 2018c) the control teams processed and coordinated more effectively at the targets to get good photographs (i.e., target processing efficiency) than the synthetic teams and displayed a higher level of interaction while planning the task. Team interaction was related to improved team effectiveness, suggesting that the synthetic teams did not demonstrate enough of the adaptive complex behaviors that were present in control teams, even though they could interact via natural language. The implication here is that merely believing that the pilot was a not human resulted in more difficult planning for the synthetic teams, thus making it more difficult to effectively anticipate their teammates' needs.

RPAS II: Human-Autonomy Teaming When Humans Collaborate With ACT-R Based Synthetic Teammate

In the second experiment, the focal manipulation was of the pilot position resulting in three conditions: synthetic, control, and experimenter (10 teams for each condition). As indicated by the name, the synthetic condition had a synthetic team member in the role of, which had been developed using ACT-R cognitive modeling architecture (Anderson, 2007); participants in this condition had to communicate with the synthetic agent in a manner void of ambiguous or cryptic elements due to its limited language capability (Demir et al., 2015). In the control condition, since the pilot was human, communication among team members developed naturally. Finally, in the experimenter condition, the pilot was limited to using a coordination script specific to the role. Using the script, the experimenter pilot interacted with the other roles by asking questions at appropriate times in order to promote adaptive and timely sharing of information regarding critical waypoints. In all three conditions, the roles of navigator and photographer were randomly assigned. Therefore, 70 randomly selected participants completed the second experiment ($M_{age} = 23.7$, $SD_{age} = 3.3$).

In the synthetic condition, the ACT-R based synthetic pilot was designed based on interaction with team members and interaction in the task environment, including adaptation of various of English constructions, selection of apropos utterances, discernment of whether or not communication was necessary, and awareness of the current situation of the RPA, i.e., flying the RPA between waypoints on the simulated task environment

TABLE 3 | Key findings from three RPAS experiments.

Experiment	Measures	Results
RPAS I (WoZ based Synthetic)	Target processing efficiency	Synthetic teams had poorer target processing efficiency than the control teams
	Team communication behaviors	Control teams conducted more planning than the synthetic teams. Synthetic teams made more suggestions than the control teams
	Team communication flow	Synthetic teams demonstrated more stable coordination dynamics
	Workload	Synthetic teams had less workload
RPAS II (ACT-R based Synthetic)	Team performance	Synthetic and control teams demonstrated same performance but were poorer than the experimenter teams
	Target processing efficiency	Synthetic teams had poorer target processing efficiency than the control and experimenter teams. Experimenter teams were more efficient than the control teams
	Team situation awareness	Synthetic and control teams performed equally to overcome the roadblocks, but poorer than the experimenter teams
	Team communication behaviors	Synthetic teams pulled more information than they pushed, and pushing information was not as effective for their performance as the all-human teams. control and the experimenter teams did more pushing than pulling, and the pushing information which was effective with their performance
	Team communication flow	Synthetic teams demonstrated stable coordination dynamics, while experimenter teams were moderately stable and the control teams were unstable
RPAS III (WoZ based Synthetic)	Team performance	Team performance increased across the missions
	Target processing efficiency	Target processing efficiency increased across the missions
	Team process rating	Target process rating increased across the missions
	Team situation awareness	Teams demonstrated better performance on overcoming automation and autonomy failures than the malicious attacks. Teams overcame an increasing number of automation failures across the missions, but a decreasing number of autonomy failures. Teams poorly performed to overcome malicious cyber-attacks
	Team communication behaviors	Pushing information increased across the missions, while pulling decreased
	Team communication flow	Teams demonstrated better performance when they become more flexible during the failures

All results use the $\alpha = 0.05$ significance level.
RPAS I: (Demir and Cooke, 2014; Demir et al., 2018c).
RPAS II: (Demir et al., 2016, 2017, 2018b; McNeese et al., 2018).
RPAS III: (Cooke et al., 2018; Grimm et al., 2018a,b).

(Ball et al., 2010). However, since the synthetic pilot still had limited interaction capability, it was crucial that the navigator and photographer made certain that their messages to the non-human teammate were void of ambiguous or cryptic elements. If not, their synthetic teammate was unable to understand and, in some cases, malfunctioned (Demir et al., 2015).

In the second experiment, we explore and discuss team interaction and effectiveness by comparing HATs with all-human teams (i.e., control and experimenter teams). Here, we give a conceptual summary of findings from previous papers that compared human-autonomy and all-human teams on dynamics (Demir et al., 2018a,b) and also their relationship with team situation awareness and team performance, via interaction (Demir et al., 2016, 2017; McNeese et al., 2018).

In **Figure 3**, three example JRPs from this study are depicted for three teams' communication for each condition (same as in the first RPAS study: three 40 min binary sequences) along with their calculated DET: **Figure 3A**—synthetic (DET = 52%), **Figure 3B**—control (DET = 34%), and **Figure 3C**—experimenter (DET = 47%). Visible on the y-axis, instances of any messages sent by any of the three roles (navigator, pilot, or photographer) in any minute were coded as "1," and if no message was sent in any minute, it was coded as "0." The synthetic team in this example exhibited rigid communication (higher determinism), whereas the control team demonstrated an unstable communication pattern compared to the other two teams. Taking into account the goals of this paper, in the synthetic team, higher determinism tended to correspond to instances when all three team members were silent (see **Figure 3A** between 30 and 35 min). For control teams, such varied communication patterns were not unanticipated since the pilot role was randomly assigned. On the other hand, coordination behaviors of control teams, experimenter teams, and synthetic teams were unstable, metastable, and rigid, respectively, as indexed by the percent DET from JRQA. Extreme team coordination dynamics (overly flexible or overly rigid) in the control and synthetic teams resulted in low team performance. Experimenter teams performed better in the simulated RPAS task environment due to metastability (Demir, 2017; Demir et al., 2018a,b). In addition to the dynamic findings, overall findings for this study showed positive correlations between pushing information and both team situation awareness and team performance. Additionally, the all-human teams had higher levels than the synthetic teams in regard to both pushing and pulling. By means of this study, we

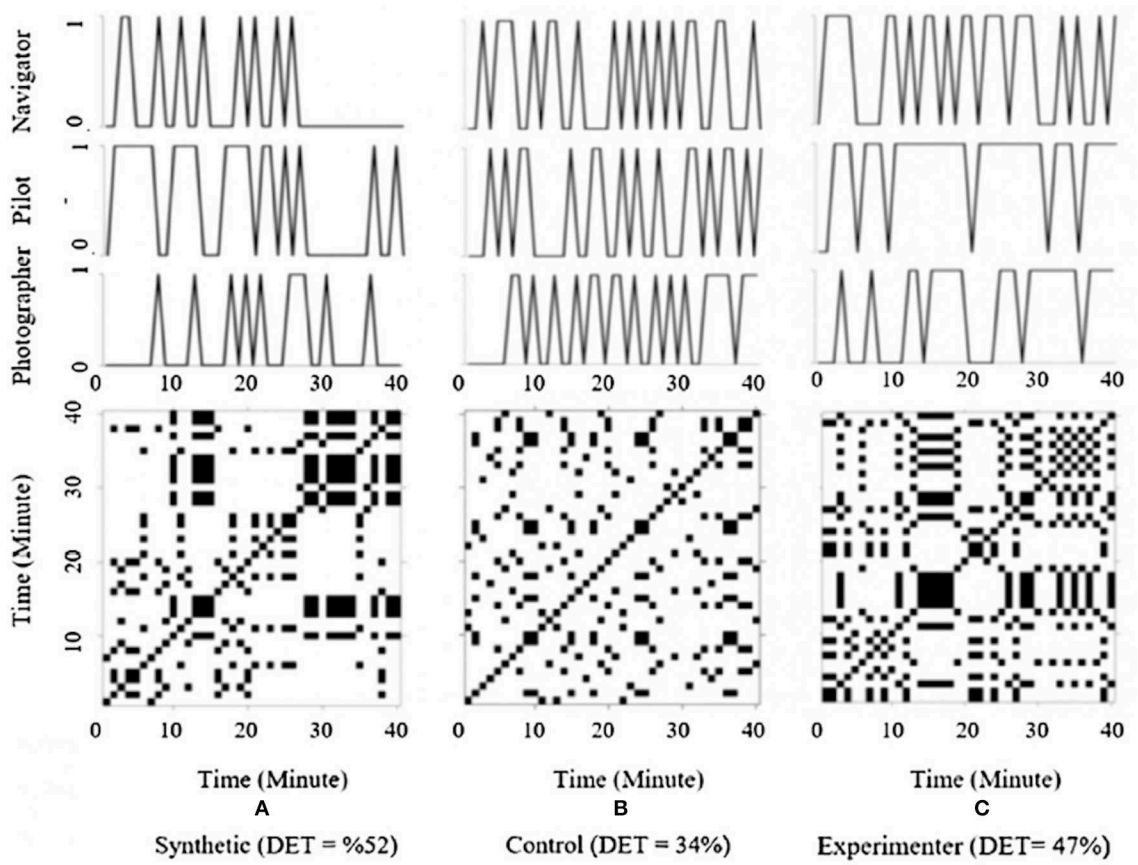

FIGURE 3 | Example joint recurrence plots for three RPAS teams' interactions in three conditions—length 40 min: **(A)** synthetic, **(B)** control, and **(C)** experimenter teams (from Demir et al., 2018b; reprinted with permission).

saw that anticipation of other team members' behaviors as well as information requirements are important for effective Team Situation Awareness (TSA) and team performance in HATs. Developing mechanisms to enhance the pushing of information with HATs is necessary in order to increase the efficacy of teamwork in such teams.

RPAS III: Human-Autonomy Teaming When a Human Collaborates With a Synthetic Teammate Under Degraded Conditions

In the third experiment, the "synthetic" pilot position was filled by a well-trained experimenter (in a separate room—WoZ paradigm) who mimicked the communication and coordination of a synthetic agent from the previous experiment (Demir et al., 2015). In the third experiment, 40 randomly selected participants (20 teams) completed the experiment ($M_{age} = 23.3$, $SD_{age} = 4.04$). In order to facilitate their effective communication with the synthetic pilot, both the navigator and the photographer had a cheat sheet to use during the training and the task. The main manipulation and consideration of this study was team resilience, so at selected target waypoints teams faced one of three kinds of roadblocks—automation failure, autonomy failure, or malicious cyber-attack—and had to overcome it within a set time limit. Automation failures were implemented as loss of displayed information for one of the agents for a set period. Autonomy failures were implemented as comprehension or anticipation failures on the part of the synthetic pilot. The malicious cyber-attack was implemented near the end of the final mission as an attack on the synthetic pilot wherein it flew the RPA to a site known to be a threat but claimed otherwise (Cooke et al., 2018; Grimm et al., 2018a,b).

The teams encountered three types of automation failures present on either the pilot's shared information data display, or the photographer's, e.g., there was an error in the current and next waypoint information or in the distance and time from the current target waypoint. In order to overcome each failure, team members were required to effectively communicate and coordinate with each other. Each of the automation failures were inserted individually at specific target waypoints from Missions 2 through 10 (Mission 1 was the baseline mission and didn't include any failures). Malicious cyber-attack was only applied on Mission 10. Therefore, Mission 10 was the most challenging.

Within the concept of dynamical systems analysis, two sample JRP are shown for the communication of high and low performing RPAS teams, which were indicated based on

their target processing efficiency (TPE) scores during Mission 10 (three 40 min binary sequences). Additionally, the plots show the calculated DET for both teams; the first one performed well (DET = 48%) and the second performed poorly (DET = 54%). Accordingly, as shown in **Figure 4A**, although the percentages of the DET scores were not too far apart, the communication of the high performing team was more rigid than that of the low performing team. Interestingly each of the team members in the high performing team communicated more frequently during each one of the failures, than those of the other teams, and they overcame all of the failures they encountered, including the malicious cyber-attack. As for the low performing team (see **Figure 4B**), the members communicated more during the automation failure and they successfully overcame that roadblock. Unfortunately, the same team did not communicate to the same degree and with the same efficacy during the remaining two roadblocks (autonomy failure and malicious cyber-attack). In fact, the navigator did not even participate during the autonomy failure, and the photographer either failed to anticipate the needs of his teammates during the malicious cyber-attack, the photographer was simply unaware of the failure. This lack of team situation awareness resulted in poor TPE scores.

Based on the goals of current paper, when the HATs interact effectively, they improve in their performance and process over time and tend to push information or anticipate the information needs of others more as they gain experience. In addition, dynamics of HATs differ in how they respond to failures. When the HAT teams demonstrated more flexible behavior, they became more adaptive to the chaotic environment, and in turn overcame more failures in the RPAS task environment.

CONCLUSION

The goal of this current paper is 2-fold: first, to understand how team interaction in HATs evolves in the dynamic RPAS task context and second, to observe how HATs respond to a variety of failures (automation, autonomy, and malicious cyber-attack) over time. One of the most significant findings from our experiments regarding team evolution is the idea of entrainment, that one team member (the pilot in our study, either synthetic or human) can change the communication behaviors of the other teammates over time, including coordination, and affect team performance. In the communication context of this task, we know that pushing information between the team members is important and we know that, in general, the synthetic teammate was capable of communication and knew its own needs, but it did not know the needs of its counterparts in a timely manner, especially during novel conditions. In the first experiment, synthetic teams did not effectively plan during the task and, in turn, did not anticipate each others' needs. Similarly, in the second experiment synthetic teams more often relied on pulling information instead of anticipating each other's needs in a timely manner. Behavioral passiveness of the synthetic teams addresses team coordination dynamics which is a fundamental concept of the ITC theory. Therefore, we applied one of the NDS methods, JRQA, on communication flow from the three experiments and the findings from dynamical systems contributed more insights to explain the dynamic complex behavior of HATs.

In the first and second studies, behavioral passiveness of the synthetic teams resulted in very stable and rigid coordination in comparison to the all-human teams, which were less stable. We know that some degree of stability and instability is needed for team effectiveness, but teams with too much of either performed poorly. In the second experiment, this issue is clearly seen across three conditions: synthetic, control, and experimenter teams. Experimenter teams demonstrated metastable coordination (not rigid nor unstable) and performed better, whereas the control and synthetic teams demonstrated unstable and rigid coordination, respectively, and performed worse. Metastable coordination behavior of the experimenter teams may have helped them adapt to the unexpected changes in the dynamic task environment. In addition to metastable coordination behavior, the experimenter teams also demonstrated effective team communication, pushing and pulling information in a timely and constructive way. This type of metastable pattern was also discovered in different contexts using the entropy measure. For instance, a system functions better if there is a trade-off between its level of complexity and health functionality (Guastello, 2017). Another sample entropy analysis on neurophysiology shows that teams at the optimum level of organization exhibit metastable behavior in order to overcome unexpected changes in the task environment (Stevens et al., 2012). Sample entropy analysis also revealed that a moderate amount of stability resulted in high team performance. This finding also resembles the third experiment, moderately stable behavior and timely anticipation of team members' needs helped teams to overcome the three types of failures. However, one of the most important findings from these experiments is entrainment. That is, one team member (in our case was the pilot).

Through these studies it is clearly possibly to have successful HATs, but a more important question moving forward is how to achieve high levels of HAT performance. How can we ensure effective levels of communication, coordination, and situation awareness between humans and agents? In response to this question, the authors propose three potential future needs for ensuring effective HATs: (1) training humans how to communicate and coordinate with agents, (2) training agents on the principles of teamwork, and (3) human-centered machine learning design of the synthetic agent. In other words, for humans and agents to interact with one other as team members, all participants must understand teamwork and be able to effectively communicate and coordinate with the others; it's not just one or the other.

First, before participating in HATs, humans should be specifically trained on how to interact with the agent. In the future this training will be fundamentally important as the types of available agents with which a person might team up vary greatly, with many variants in both cognitive modeling and machine learning. Understanding how to interact with these agents is step one in ensuring effective HATs, because without meaningful communication, effective teamwork is impossible. In our studies, we specifically trained participants in how to properly interact with the synthetic agents in

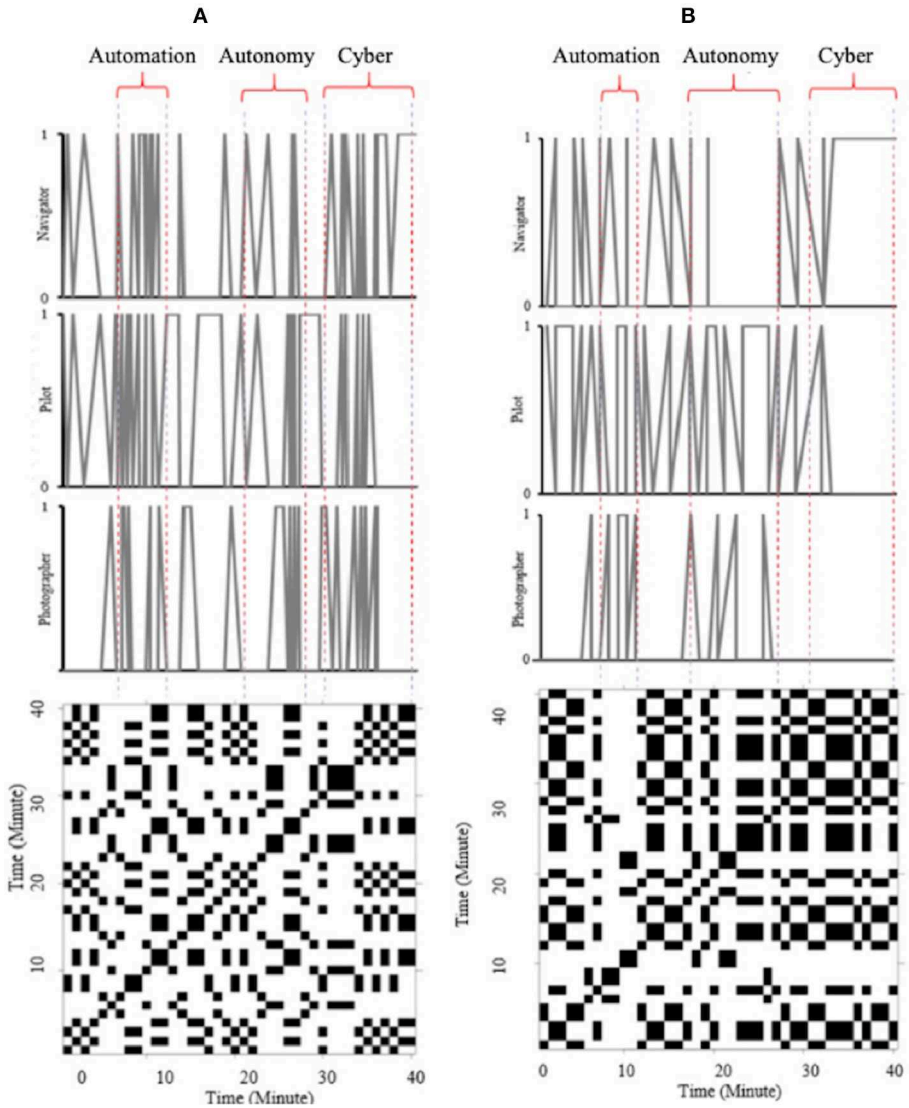

FIGURE 4 | Example Joint Recurrence Plots for two RPAS teams' interactions: **(A)** high performing team (Mission 10—DET: 48%) overcame all three failures (automation, autonomy, and malicious cyber-attack); and **(B)** low performing team (Mission—DET: 54%) only overcame automation failure—Mission 10: length 40 min (from Grimm et al., 2018b; reprinted with permission).

their teams. If we had not trained them how to interact, the interaction would have been significantly hindered due to the participants not understanding the communication and coordination limitations of the synthetic agent. The training allowed them to successfully interact with the agent due to an understanding of the agent's capabilities. In the future, the need for training humans to interact with agents will hopefully decrease due to the increased availability and experience of interacting with agents and advancements in natural language processing. However, in the immediate future it will be necessary to develop appropriate training specific to this type of interaction.

Second, agents as team members must be programmed and trained with a fundamental conceptualization of what teamwork is and what the important principles of teamwork are. If you dig into the fundamentals of the synthetic agent in our studies, they did not understand the concept of teaming. Instead, it was capable of communication and understood its own task with very little understanding of other team members' tasks, let alone the team task. Moving forward, computer scientists and cognitive scientists need to work together to harness the power of machine learning to train agents to know what teamwork is (communication, coordination, awareness, etc.). An agent will never be able to adapt and adjust to dynamical characteristics such as coordination if it is not trained to conceptualize and taught how to apply that knowledge first.

Finally, there is a significant need to have serious discussions on how the broader community should be developing these agents technically. Our agent was built on the ACT-R cognitive

architecture which has certain advantages, but as advancements in machine learning continue, it is valuable to debate the technical foundation of these agents. The major advantage and promise of using machine learning is that the agent can be trained and can learn many facets of teamwork. Reinforcement and deep learning provide promise that an agent will develop human-centered capabilities by recalibrating its technical infrastructure based on more and more interactions with a human team member. We are not arguing for one side or the other (cognitive architectures or machine learning), but rather that the community carefully should weigh the pros and cons of each and then choose the technical methodology that is most efficient and leads to developing an effective agent as a team member.

We are still in the early stages of the evolution of HAT. Our current work extends team coordination metrics to assess coordination quality and ultimately, team effectiveness in terms of adaptation and resilience; and also, explores the kinds of training, technological design, or team composition interventions that can improve HAT under degraded conditions. A great deal of ongoing work is needed in many areas. We strongly encourage the broader team science community to conduct interdisciplinary work to advance HAT.

AUTHOR CONTRIBUTIONS

MD helped with the specific decisions on the experimental design, applied dynamical systems methods, and led the writing of this manuscript. NM and NC contributed to crafting the general idea of the research, provided input to make the ideas of this study concrete, designed the experiment, the paradigm and the experimental protocol, and contributed to writing up this manuscript.

FUNDING

RPAS I and II research were partially supported by ONR Award N000141110844 (Program Managers: Marc Steinberg, Paul Bello) and ONR Award N000141712382 (Program Managers: Marc Steinberg, Micah Clark). RPAS III research was supported by ONR Award N000141712382 (Program Managers: Marc Steinberg, Micah Clark).

ACKNOWLEDGMENTS

The authors acknowledge Steven M. Shope from Sandia Research Corporation who updated RPAS-STE testbed and integrated the synthetic teammate into the RPAS STE testbed.

REFERENCES

Amazeen, P. G. (2018). From physics to social interactions: scientific unification via dynamics. *Cogn. Syst. Res.* 52, 640–657. doi: 10.1016/j.cogsys.2018.07.033

Anderson, J. R. (2007). *How Can the Human Mind Occur in the Physical Universe?* Oxford; New York, NY: Oxford University Press.

Ball, J., Myers, C., Heiberg, A., Cooke, N. J., Matessa, M., Freiman, M., et al. (2010). The synthetic teammate project. *Comput. Math. Org. Theory* 16, 271–299. doi: 10.1007/s10588-010-9065-3

Barrett, L. (2015). *Beyond the Brain: How Body and Environment Shape Animal and Human Minds, 1st Edn.* Princeton, NJ; Oxford: Princeton University Press.

Bartlett, C. E., and Cooke, N. J. (2015). Human-robot teaming in urban search and rescue. *Proc. Hum. Fact. Ergon. Soc. Ann. Meet.* 59, 250–254. doi: 10.1177/1541931215591051

Braitenberg, V., and Arbib, M. A. (1984). *Vehicles: Experiments in Synthetic Psychology, 1st Edn.* Cambridge, MA: The MIT Press.

Bristol, U. (2008). *Grey Walter and His Tortoises | News | University of Bristol.* Available online at: http://www.bristol.ac.uk/news/2008/212017945378.html (accessed October 24, 2018).

CERI (2007). Available online at: http://cerici.org/ceri_about.htm (accessed January 16, 2019).

Chen, J. Y. C., and Barnes, M. J. (2014). Human-agent teaming for multirobot control: a review of human factors issues. *IEEE Trans. Hum. Mach. Syst.* 44, 13–29. doi: 10.1109/THMS.2013.2293535

Coco, M. I., and Dale, R. (2014). Cross-recurrence quantification analysis of categorical and continuous time series: an R package. *Front. Psychol.* 5:510. doi: 10.3389/fpsyg.2014.00510

Cooke, N. J., Demir, M., and McNeese, N. J. (2016). *Synthetic Teammates as Team Players: Coordination of Human and Synthetic Teammates* (Technical Report No. N000141110844). Mesa, AZ: Cognitive Engineering Research Institute.

Cooke, N. J., Demir, M., McNeese, N. J., and Gorman, J. (2018). *Human-Autonomy Teaming in Remotely Piloted Aircraft Systems Operations Under Degraded Conditions*. Mesa, AZ: Arizona State University.

Cooke, N. J., Gorman, J., Pedersen, H., Winner, J., Duran, J., Taylor, A., et al. (2007). *Acquisition and Retention of Team Coordination in Command-and-Control.* Available online at: http://www.dtic.mil/docs/citations/ADA475567 (accessed November 10, 2018).

Cooke, N. J., Gorman, J. C., Myers, C. W., and Duran, J. L. (2013). Interactive team cognition. *Cogn. Sci.* 37, 255–285. doi: 10.1111/cogs.12009

Cooke, N. J., and Shope, S. M. (2004). "Designing a synthetic task environment," in *Scaled Worlds: Development, Validation, and Application,* eds L. R. E. Schiflett, E. Salas, and M. D. Coovert, 263–278. Available online at: http://www.cerici.org/documents/Publications/scaled%20worlds%20paper3.pdf (accessed November 10, 2018).

Cooke, N. J., and Shope, S. M. (2005). "Synthetic task environments for teams: CERTT's UAV-STE," in *Handbook of Human Factors and Ergonomics Methods,* eds N. Stanton, A. Hedge, K. Brookhuis, E. Salas, and H. Hendrick, 41–46. Available online at: http://cerici.org/documents/Publications/Synthetic%20Task%20Environments%20for%20Teams.pdf (accessed November 10, 2018).

Cox, M. T. (2013). "Goal-driven autonomy and question-based problem recognition," in *Poster Collection*. Presented at the Second Annual Conference on Advances in Cognitive Systems (Palo Alto, CA). Available online at: http://mcox.org/

Dautenhahn, K. (2007). "A paradigm shift in artificial intelligence: why social intelligence matters in the design and development of robots with human-like intelligence," in *50 Years of Artificial Intelligence,* eds M. Lungarella, F. Iida, J. Bongard, and R. Pfeifer (Berlin; Heidelberg: Springer-Verlag), 288–302.

Demir, M. (2017). *The impact of coordination quality on coordination dynamics and team performance: when humans team with autonomy* (Unpublished Dissertation). Arizona State University. Available online at: http://hdl.handle.net/2286/R.I.44223 (accessed November 10, 2018).

Demir, M., and Cooke, N. J. (2014). Human teaming changes driven by expectations of a synthetic teammate. *Proc. Hum. Fact. Ergonom. Soc. Ann. Meet.* 58, 16–20. doi: 10.1177/1541931214581004

Demir, M., Cooke, N. J., and Amazeen, P. G. (2018a). A conceptual model of team dynamical behaviors and performance in human-autonomy teaming. *Cogn. Syst. Res.* 52, 497–507. doi: 10.1016/j.cogsys.2018.07.029

Demir, M., Likens, A. D., Cooke, N. J., Amazeen, P. G., and McNeese, N. J. (2018b). Team coordination and effectiveness in human-autonomy teaming. *IEEE Trans. Hum. Mach. Syst.* 49, 150–159. doi: 10.1109/THMS.2018.2877482

Demir, M., McNeese, N. J., and Cooke, N. J. (2016). "Team communication behaviors of the human-automation teaming," *2016 IEEE International Multi-disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support (CogSIMA)* (San Diego, CA), 28–34.

Demir, M., McNeese, N. J., and Cooke, N. J. (2017). Team situation awareness within the context of human-autonomy teaming. *Cogn. Syst. Res.* 46, 3–12. doi: 10.1016/j.cogsys.2016.11.003

Demir, M., McNeese, N. J., and Cooke, N. J. (2018c). The impact of a perceived autonomous agent on dynamic team behaviors. *IEEE Transac. Emerg. Top. Comput. Intell.* 2, 258–267. doi: 10.1109/TETCI.2018.2829985

Demir, M., McNeese, N. J., Cooke, N. J., Ball, J. T., Myers, C., and Freiman, M. (2015). Synthetic teammate communication and coordination with humans. *Proc. Hum. Fact. Ergonom. Soc. Ann. Meet.* 59, 951–955. doi: 10.1177/1541931215591275

Demir, M., McNeese, N. J., Cooke, N. J., Bradbury, A., Martinez, J., Nichel, M., et al. (2018d). "Dyadic team interaction and shared cognition to inform human-robot teaming," in *Proceedings of the Human Factors and Ergonomics Society*. Presented at the Human Factors and Ergonomics Society Annual Meeting 62 (Philadelphia, PA).

Eckmann, J.-P., Kamphorst, S. O., and Ruelle, D. (1987). Recurrence plots of dynamical systems. *Europhy. Lett.* 4:973. doi: 10.1209/0295-5075/4/9/004

Endsley, M. R. (2015). *Autonomous Horizons: System Autonomy in the Air Forceâ?"A Path to the Future* (Autonomous Horizons No. AF/ST TR 15-01). Department of the Air Force Headquarters of the Air Force. Available online at: http://www.af.mil/Portals/1/documents/SECAF/AutonomousHorizons.pdf?timestamp=1435068339702

Fiore, S. M., and Wiltshire, T. J. (2016). Technology as teammate: examining the role of external cognition in support of team cognitive processes. *Front. Psychol.* 7:1531. doi: 10.3389/fpsyg.2016.01531

Goodrich, M. A., and Yi, D. (2013). "Toward task-based mental models of human-robot teaming: a Bayesian approach," in *Virtual Augmented and Mixed Reality. Designing and Developing Augmented and Virtual Environments*, ed R. Shumaker (Las Vegas, NV: Springer), 267–276.

Gorman, J. C., Amazeen, P. G., and Cooke, N. J. (2010). Team coordination dynamics. *Nonlin. Dyn. Psychol. Life Sci.* 14, 265–289.

Gorman, J. C., Cooke, N. J., Pederson, H. K., Connor, O. O., and DeJoode, J. A. (2005). Coordinated Awareness of Situation by Teams (CAST): measuring team situation awareness of a communication glitch. *Proc. Hum. Fact. Ergon. Soc. Ann. Meet.* 49, 274–277. doi: 10.1177/154193120504900313

Gorman, J. C., Cooke, N. J., and Winner, J. L. (2006). Measuring team situation awareness in decentralized command and control environments. *Ergonomics* 49, 1312–1325. doi: 10.1080/00140130600612788

Grimm, D., Demir, M., Gorman, J. C., and Cooke, N. J. (2018a). "Systems level evaluation of resilience in human-autonomy teaming under degraded conditions," in *2018 Resilience Week*. Presented at the Resilience Week 2018 (Denver, CO).

Grimm, D., Demir, M., Gorman, J. C., and Cooke, N. J. (2018b). "The complex dynamics of team situation awareness in human-autonomy teaming," in *Cognitive and Computational Aspects of Situation Management (CogSIMA)*. Presented at the 2018 IEEE Conference on Cognitive and Computational Aspects of Situation Management (CogSIMA) (Boston, MA).

Guastello, S. J. (2017). Nonlinear dynamical systems for theory and research in ergonomics. *Ergonomics* 60, 167–193. doi: 10.1080/00140139.2016.1162851

Haken, H. (2003). "Intelligent behavior: a synergetic view," in *Studies of Nonlinear Phenomena in Life Science*, *Vol. 10. The Dynamical Systems Approach to Cognition,* eds W. Tschacher and J.-P. Dauwalder (World Scientific Publisher Co. Inc.), 3–16.

Hart, S. G., and Staveland, L. E. (1988). "Development of NASA-TLX (Task Load Index): results of empirical and theoretical research," in *Human Mental Workload,* eds P. A. Hancock and N. Mashkati (Amsterdam: North Holland Press), 139–183.

Kelso, J. A. S. (1997). *Dynamic Patterns: The Self-organization of Brain* and *Behavior*. Cambridge, MA; London: MIT Press.

Klein, G., Woods, D. D., Bradshaw, J. M., Hoffman, R. R., and Feltovich, P. J. (2004). Ten challenges for making automation a "team player" in joint human-agent activity. *IEEE Intell. Syst.* 19, 91–95. doi: 10.1109/MIS.2004.74

Krogmann, U. (1999). *From Automation to Autonomy-Trends Towards Autonomous Combat Systems* (Unclassified No. RTO MP-44). Science and Technology Organization. Available online at: NATO http://www.dtic.mil/dtic/tr/fulltext/u2/p010300.pdf

Marwan, N., Carmen Romano, M., Thiel, M., and Kurths, J. (2007). Recurrence plots for the analysis of complex systems. *Phys. Rep.* 438, 237–329. doi: 10.1016/j.physrep.2006.11.001

Marwan, N., Wessel, N., Meyerfeldt, U., Schirdewan, A., and Kurths, J. (2002). Recurrence plot based measures of complexity and its application to heart rate variability data. *Phys. Rev. E* 66:026702. doi: 10.1103/PhysRevE.66.026702

McGrath, J. E. (1990). "Time matters in groups," in *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work,* eds J. Galegher, R. E. Kraut, and C. Egido (Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.), 23–61.

McNeese, N. J., Demir, M., Cooke, N. J., and Myers, C. (2018). Teaming with a synthetic teammate: insights into human-autonomy teaming. *Hum. Fact.* 60, 262–273. doi: 10.1177/0018720817743223

Riek, L. D. (2012). Wizard of Oz studies in HRI: a systematic review and new reporting guidelines. *J. Hum. Robot Interact.* 1, 119–136. doi: 10.5898/JHRI.1.1.Riek

Salas, E., Dickinson, T. L., Converse, S. A., and Tannenbaum, S. I. (1992). "Toward an understanding of team performance and training: Robert W. Swezey, Eduardo Salas: Books," in *Teams: Their Training and Performance,* eds R. W. Swezey and E. Salas, 3–29. Available online at: http://www.amazon.com/Teams-Training-Performance-Robert-Swezey/dp/089391942X (accessed November 10, 2018).

Salas, E., Sims, D. E., and Burke, C. S. (2005). Is there a "Big Five" in teamwork? *Small Group Res.* 36, 555–599. doi: 10.1177/1046496405277134

Schooley, L. C., Zeigler, B. P., Cellier, F. E., and Wang, F. Y. (1993). High-autonomy control of space resource processing plants. *IEEE Cont. Syst.* 13, 29–39. doi: 10.1109/37.214942

Simon, H. A. (1969). *The Sciences of the Artificial*. Cambridge, MA; London: MIT Press.

Stevens, R. H., Galloway, T. L., Wang, P., and Berka, C. (2012). Cognitive neurophysiologic synchronies: what can they contribute to the study of teamwork? *Hum. Fact.* 54, 489–502. doi: 10.1177/0018720811427296

Thelen, E., and Smith, L. B. (2007). "Dynamic systems theories," in *Handbook of Child Psychology, Vol. 1: Theoretical Models of Human Development, 6th Edn.,* eds W. Damon and R. M. Lerner (Hoboken, NJ: Wiley), 258–312.

Webber, C. L., and Marwan, N. (eds.). (2014). *Recurrence Quantification Analysis: Theory and Best Practices, 2015 Edn.* New York, NY: Springer.

Zhang, Y., Narayanan, V., Chakraborti, T., and Kambhampati, S. (2015). "A human factors analysis of proactive support in human-robot teaming," in *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (Hamburg), 3586–3593.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Demir, McNeese and Cooke. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

ORIGINAL RESEARCH
published: 09 October 2019
doi: 10.3389/fpsyg.2019.02266

Adaptive Team Performance: The Influence of Membership Fluidity on Shared Team Cognition

*Wendy L. Bedwell**

Fogelman College of Business and Economics, University of Memphis, Memphis, TN, United States

Team membership change literature has traditionally focused on performance effects of newcomers to teams. Yet, in practice, teams frequently experience membership loss *without* replacement (e.g., downsizing) or membership exchanges—replacing a member who has left the organization with a current, experienced employee. Despite the prevalence of these practices, little is known about the impact of such changes on team performance. Drawing upon two complementary team adaptation theories, the influence of both membership loss without replacement and loss with replacement by experienced personnel on the cognitive processes underlying adaptation (operationalized as development of effective team mental models – TMMs) was examined. Results suggested that Teammate TMMs (i.e., shared knowledge of member preferences/tendencies) and Team Interaction TMMs (i.e., shared knowledge of roles/responsibilities) are differentially influenced by the movement of members in and out of teams and differentially predict adaptive team performance. Further, TMM measurement choice (i.e., the use of similarity versus distance scores) matters as relationships differed depending on which metric was used. These results are discussed in the context of team adaptation theory, with implications for strategic human resource management.

Keywords: team adaptation, adaptive team performance, team composition, dynamic team, team membership change, membership fluidity, team mental models, team cognition

OPEN ACCESS

Edited by:
Michael Rosen,
Johns Hopkins Medicine,
United States

Reviewed by:
M. Travis Maynard,
Colorado State University,
United States
Roni Reiter-Palmon,
University of Nebraska Omaha,
United States

Correspondence:
Wendy L. Bedwell
wldbwell@memphis.edu

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *26 October 2018*
Accepted: *23 September 2019*
Published: *09 October 2019*

Citation:
Bedwell WL (2019) Adaptive Team Performance: The Influence of Membership Fluidity on Shared Team Cognition. Front. Psychol. 10:2266. doi: 10.3389/fpsyg.2019.02266

INTRODUCTION

Downsizing has become common for organizational survival, as evidenced by the 2009 economic recession, when mass layoffs (i.e., ≥50 employees) increased dramatically (US Department of Labor Bureau of Labor Statistics, 2011). In work teams, downsizing creates membership loss without replacement *or* requires job rotation of current employees into new teams; here these "new members" are not novices but have task experience. Despite the prevalence of such practices, little is known about their impact, as research has rarely compared dynamic to stable team configurations, let alone membership loss to membership replacement (Tannenbaum et al., 2012).

With the exception of work on team downsizing (DeRue et al., 2008), research on membership fluidity—the dynamic flow of members in and out of teams (e.g., Edmondson et al., 2001; Edmondson, 2003; Tannenbaum et al., 2012)—has historically focused on newcomer socialization (see Moreland and Levine, 2001 for a comprehensive review). However, organizational performance outcomes largely depend on the ability of teams to quickly adapt their processes to rapidly changing demands (Burke et al., 2006), such as varying membership (e.g., Bedwell et al., 2012). Thus, such research is important.

Surprisingly, the underlying *cognitive processes* of adaptation in teams experiencing membership change have also received little attention in the team adaptation research, despite the prevalence of "learning" and "team cognition" constructs in prominent theories focusing on how teams adapt to change. One particular cognitive process often associated with effective team adaptation is the development and/or change of team mental models (TMMs), which are organized knowledge structures shared among members of a team (Cannon-Bowers et al., 1993; Mathieu et al., 2000). The two prevailing models of adaptation in the literature, Kozlowski et al. (1999) and Burke et al. (2006), highlight the importance of these cognitive structures. Burke and colleagues include TMMs within the learning phase of their multiphasic model of team adaptation. Kozlowski et al. (1999) did not specifically mention TMMs in their theory of adaptive teams; yet, they did argue for the importance of developing *shared knowledge* regarding tasks, team roles, role boundaries, and other team members—which is the definition of the various TMMs originally outlined by Cannon-Bowers et al. (1993). Both theories suggest that increasing sharedness of TMMs regarding both task and team members *should* enable teams to adapt to any number of situations (Kozlowski et al., 1999; Burke et al., 2006).

Thus, this effort seeks to advance the team adaptation literature by testing the effects of membership change on performance via development of shared TMMs. The contribution is twofold: (1) integrating two complementary models of team adaptation (Kozlowski et al., 1999; Burke et al., 2006) and (2) offering the first empirical test of multiple membership change types (i.e., loss and exchange) against stable teams, thereby addressing the call by Tannenbaum et al. (2012) for simultaneous investigations into various member change configurations.

Membership Change

Membership change has two main schools of thought. On one hand, some defend membership change, suggesting it can increase the available cognitive resources of a team (Kane et al., 2005) and fuel reflection on team processes (Sutton and Louis, 1987; Feldman, 1994). Researchers argue that such activities enable members to draw from a broader knowledge base, develop greater shared thinking regarding how the team should continue to operate and, ultimately, improve performance outcomes (Ancona, 1990; Gersick and Hackman, 1990; Waller, 1999).

A second school of thought, however, suggests that membership change is detrimental to team performance. Members take knowledge with them when they leave (Cascio, 1999), which eliminates access to that individually held knowledge (Argote, 1999). In tasks where performance hinges on the ability of members to pool relevant knowledge, loss of a member (and thereby, loss of knowledge) can lead to performance decrements. With regard to membership replacement or loss, research has found that after a member change, attention is temporarily diverted from the task because teams are in a state of flux (i.e., dynamic, unstable interaction pattern; Summers et al., 2012). Essentially, when teams take time away from a task (e.g., for socialization of a new member), they face potential process loss (Steiner, 1972).

Additionally, stable membership leads to teammate familiarity, which has been linked to positive outcomes such as cohesion, coordination, low anxiety, willingness to express disagreement, and performance, in both lab and field studies (e.g., Levine and Moreland, 1991; Gruenfeld et al., 1996; Kim, 1997; Moreland et al., 1998). Although some studies have found familiarity to have negative or curvilinear effects (e.g., Katz, 1982; Berman et al., 2002; Sieweke and Zhao, 2015), any positive benefits are certainly not afforded to teams with new members (i.e., membership replacement). As the task in the present study required effective pooling of distributed information, in accordance with the second school of thought, it is hypothesized that teams experiencing membership loss or replacement would experience performance decrements as compared to teams with stable membership.

> *Hypothesis 1a and b: (a) Membership loss and (b) membership loss w/replacement teams will experience performance decrements as compared to intact teams.*

TMMs and Adaptive Performance

As noted above, current team adaptation theory has noted that effective adaptive processes are predicated on successful team learning, including development of shared knowledge structures (Kozlowski et al., 1999; Burke et al., 2006, 2008). Cannon-Bowers et al. (1993) have argued for the existence of several types of TMM when teams are engaged in complex tasks. They specifically addressed four types. Team members must have a shared understanding of the *technology/equipment* required for task completion. Members must also share knowledge structures regarding the *task*, specifically procedures, task strategies, constraints and resources. Third, teams share knowledge regarding *team interaction*, which is comprised of the roles/responsibilities, interaction patterns, interdependencies, and information flow. Finally, teams can have shared knowledge regarding members of the *team* itself, including knowing other members' skills, attitudes, preferences and tendencies.

Mathieu et al. (2000) considered the difficulty in operationalizing these four types within a single study and suggested all four types essentially depict two major content domains: team relevant information and task relevant information. Arguably, collapsing the Task TMMs does make sense in this effort as it is difficult to separate the components of those two dimensions (e.g., there is no specialized equipment therefore knowing the operating procedures naturally involve knowing the task procedures). However, maintaining distinction among the Team Interaction and Team TMMs is important in this particular study, as members can have a shared understanding of the roles/responsibilities and interaction patterns (i.e., Team Interaction TMMs) without having a shared understanding of members preferences (i.e., Team TMMs).

Task TMMs

When teams experience replacement of a member with a task-experienced one, task knowledge (e.g., task procedures, strategies, resources, and operating procedures) can remain highly shared when information is standardized. However, even

in the most standardized tasks, team members bring their own task conceptualizations and views regarding appropriate task strategies (Burtscher and Manser, 2012). Thus, in teams with membership replacement, new members may have different task conceptualizations. Alternatively, when there is membership loss without replacement, teams must reconfigure. This can require changes in task conceptualizations, which can negatively influence sharedness when teams are under time pressures and unable to articulate new views (Rico et al., 2008). Also, if there are different ways to achieve effectiveness (as is the case in this study), this can further inhibit sharedness, as evidenced in the difficulty of short-lived (Rico et al., 2008) and *ad hoc* fluid (Kolbe et al., 2009) teams in developing shared cognition.

Team mental models sharedness is positively related to performance (DeChurch and Mesmer-Magnus, 2010a,b) and it is anticipated that these findings will also extend to adaptive performance. Indeed, research on Task TMMs and adaptive performance suggests that Task TMMs aid adaptive performance in novel environments (Waller et al., 2004). However, TMMs are only one aspect of teamwork (e.g., attitudes, behaviors, and cognitions; Salas et al., 2009), and therefore, a team's composition can influence team performance through a variety of mediators beyond shared cognition (see Mathieu et al., 2008). Given this complex relationship, partial mediation is hypothesized:

> *Hypothesis 2: Task TMMs will partially mediate the relationship between membership fluidity and performance, with intact teams developing more similar Task TMMs than membership loss and replacement teams.*

Team Interaction TMMs are comprised of team-relevant knowledge, such as individual roles and interdependencies, interaction patterns, and information flow. It may seem as though teams experiencing member replacement with a role-experienced member will have little (or no) disruptions in development of Team Interaction TMMs (similar to intact teams) since interdependencies associated with roles/responsibilities are dictated by the task (and not specific team members). However, teams rapidly develop stable patterns of working (e.g., Gersick and Hackman, 1990; Zijlstra et al., 2012) and given that there was no "one correct" way to interact in this task for effectiveness, each team could have developed different, yet effective, interaction patterns. Thus, a member coming to a new team may have had different interaction norms than the new team and membership loss with replacement teams may show decrements in sharedness of their Team Interaction TMMs. Similarly, yet more pronounced, teams experiencing membership loss *must* redefine roles by redistributing task requirements, which can affect interdependencies. Teams failing to develop a new shared understanding of these redistributions will show decrements in Team Interaction TMMs as compared to intact teams.

Just as Task TMMs are important for team performance, it is suggested that Team Interaction TMM will also be positively related to adaptive performance. Although there is a lack of studies examining TMMs in adaptive contexts, Marks et al. (2000) found that such TMMs were stronger predictors of performance in novel, as compared to routine, environments. This supports the notion that teams with highly shared Team Interaction TMMs adapt better than teams without highly shared TMMs. This effort sought to replicate those findings in the adaptive performance context, again, arguing for partial mediation.

> *Hypothesis 3: Team Interaction TMMs will partially mediate the relationship between membership fluidity and performance gains, with intact teams developing more similar Team Interaction TMMs than membership loss or replacement teams.*

Team mental model theory posits that team members who work together gain knowledge about each other and, thus, develop shared knowledge regarding each other's working preferences (i.e., specific Teammate TMMs; Cannon-Bowers et al., 1993). Only a few studies have empirically investigated relationships between shared Teammate TMMs and performance (e.g., Smith-Jentsch et al., 2009). One study considered task changes and team familiarity, finding an interaction between diverse experiences and team familiarity that led to performance improvements (Huckman and Staats, 2011). This suggests that teams who know each other's expertise and ways of working are able to overcome task changes. Such findings should also hold true for membership loss because the content of the team-specific knowledge regarding member preferences should remain relatively constant. In other words, remaining members should maintain shared understanding of other's preferences, knowledge, attitudes, regardless of who remains on the team as membership does not dictate how people approach their work. In contrast, membership replacement teams must integrate an unknown member, which should negatively influence shared knowledge of member preferences, because such learning takes time (Akgün and Lynn, 2002)—time that teams required to rapidly adapt to new members rarely have.

Teammate TMMs should be important for performance, just like Task and Team Interaction TMMs. Indeed, research has found that teammates with prior working experience showed greater agreement with respect to their Teammate TMMs, which partially explained the relationship between familiarity and the willingness to ask for/accept assistance (Smith-Jentsch et al., 2009). These findings suggest that a team's ability to adapt (e.g., by compensating for one another) is undermined by a lack of shared Teammate TMMs. Furthermore, research has demonstrated that teams who train together perform better because they have greater knowledge of one another (Liang et al., 1995). It follows that more highly shared Teammate TMMs should enable teams to realize performance gains as compared to teams without such sharedness.

> *Hypothesis 4: Teammate TMMs will partially mediate the relationship between membership fluidity and performance, with intact teams developing more similar Teammate TMMs than membership replacement teams.*

Essentially, the proposed model argues that shared TMMs partially enables performance and mitigates the negative

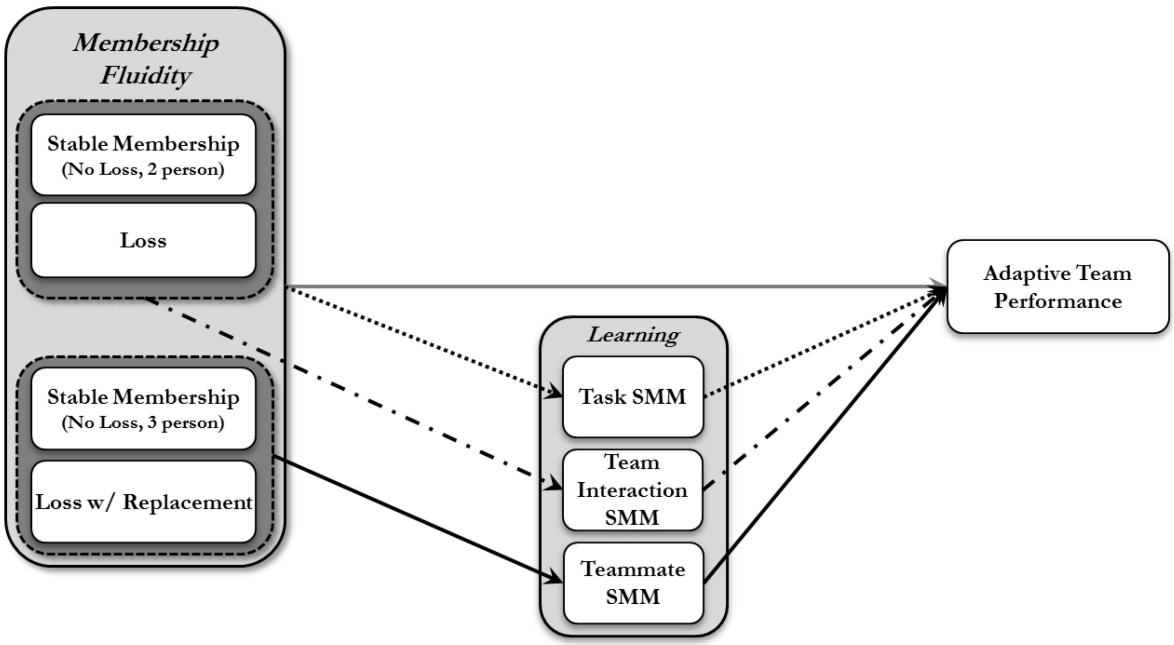

FIGURE 1 | Hypothesized relationship among study variables.

influence of membership replacement/loss on performance (see **Figure 1**).

MATERIALS AND METHODS

Participants

Hundred and sixty five undergraduate and graduate students (71 males, 93 females, one declined to state gender) from a university in the southeastern U.S. were randomly assigned to 60 teams in four conditions: (a) a *two-member control* condition (15 teams, N = 30); (b) a *three-member control* condition (15 total teams, N = 45); (c) a *membership replacement* condition (i.e., where a lost team member was replaced with an experienced participant from another team; 15 teams, N = 45) and (d) a *membership loss* condition (i.e., loss of participant without replacement; 15 teams, N = 45). Two control conditions were used to avoid the confound of team size accounting for performance outcomes. Thus, membership loss teams were always compared to the two-person control team and membership exchange teams were always compared to the three-person control condition.

Participants received a cash stipend ($10/h, $25 total). To ensure high levels of motivation and encourage keeping manipulations confidential, participants were eligible to win a performance reward ($25/participant for top teams; $20 and $15/participant for 2nd and 3rd place teams, respectively). Treatment of participants was in accordance with APA ethical guidelines and federal regulations, and the study had been reviewed and approved by the university's Institutional Review Board (IRB). Written consent was waived by the IRB as that would be the only identifiable information tying participants to the study. Consent was indicated by completion of the study as all participants were informed of their right to withdrawal at any time. No participants withdrew.

Procedure

Teams engaged in an interactive, computer-based simulation set in an emergency room waiting area, filmed from a first-person view. Actors portrayed the role of doctors, volunteers, and patients. Participants "interacted" with the characters in the video verbally, simulating a real conversations even though it was recorded video (see Smith-Jentsch, 2007). The simulation was similar across performance periods and identical across conditions. There were three roles: *Waiting Room Staffer*, *Records Staffer,* and *Claims Staffer* (the Claims and Records roles were combined in two-person teams). The Waiting Room Staffer interacted directly with the simulation, answering patient/staff questions and responding to voicemails. The Records Staffer maintained: (a) an employee tracking form and (b) a patient log form. The Claims Staffer completed: (i) a patient insurance claim form and (ii) a complaint form for formal complaints made against employees, and received patient details from the "admittance department."

Upon arrival, participants were told their purpose and that another team was working on the same simulation simultaneously. Then all members watched a training video and completed a demographic measure (e.g., age, gender, GPA, major, etc.). Using a worksheet tailored for team size, teams engaged in a 15-min planning period, performed Part I of the simulation, and then completed Time I performance measure. This was followed by the membership change event (or no change for

control teams). As noted previously, there were four conditions: two-person intact teams (*Team Foxtrot*: control group with two members), three-person intact teams (*Team Delta*: control group with three members), membership loss teams (*Team Bravo:* three-person membership loss team, resulting in two remaining members), and membership replacement teams (*Team Echo:* three-person team who lost one yet gained another member, resulting in three members). After Performance Cycle I, remaining members of *Team Bravo* were told their Claims Staffer was needed elsewhere and there were no replacement personnel available (see **Figure 2** for a visual representation of members across all four conditions at Time 1 and Time 2).

All teams were then told to take no more than 5 min to plan for the next phase. When finished, members completed the TMM measures; performed Part II of the simulation; completed the Time II performance measure; were debriefed, paid, and released.

Measures

Demographic Information

The demographic survey included customary data such as age, gender, GPA, year in school, and major (among other data). GPA, specifically used as a covariate in this study across all analyses, was calculated as an average for the team. The mean across conditions was 2.85 (SD = 0.61). Skewness (−0.97) and kurtosis (0.96) levels across conditions were within acceptable ranges. The means within conditions were as follows: two-person intact teams (M = 3.14, SD = 0.45), three-person intact teams (M = 3.20, SD = 0.30), three-person membership loss teams (M = 3.33, SD = 0.42), and three-person membership loss with replacement teams (M = 3.23, SD = 0.39).

Familiarity

Familiarity was defined in this study as the degree to which participants knew one another. This was measured using a scale developed for use with the simulation task by Smith-Jentsch and colleagues. Familiarity was calculated as a team-level variable, averaging the level of familiarity among each dyadic pair within a team using one item – the number of months members had known one another. This was used as a control variable in analyses that considered Teammate SMMs, since greater familiarity could increase the amount of information known regarding a person's personality characteristics. Across conditions, the mean was 4.44 (SD = 8.46). Within conditions, means were as follows: two-person intact teams (M = 1.00, SD = 2.36), three-person intact teams (M = 4.47, SD = 6.96), three-person membership loss teams (M = 4.83, SD = 9.04), and three-person membership loss with replacement teams (M = 7.45, SD = 11.96).

Role Comprehension

This original scale was designed to determine the degree to which the task training was effective. This is the only control variable measured after the initial transition phase and was used in all analyses as it directly influences Task as well as Team Interaction SMMs. Specifically, the more clarity members have regarding the roles, the better able they would be to determine what tasks are critical and how to coordinate to accomplish those tasks. The scale was either 2-items or 3-items, depending on the number of team members (2-item for two-person intact teams, 3-items for all other conditions). The items asked whether members understood the requirements of their own roles as well as the roles of the other team members. The mean across conditions was 3.73 (SD = 0.43). Skewness (0.31) and kurtosis (1.46) levels across conditions were within acceptable ranges. Means within conditions were as follows: two-person intact teams (M = 3.63, SD = 0.52), three-person intact teams (M = 3.67, SD = 0.41), three-person membership loss teams (M = 3.84, SD = 0.43), and three-person membership loss with replacement teams (M = 3.78, SD = 0.36).

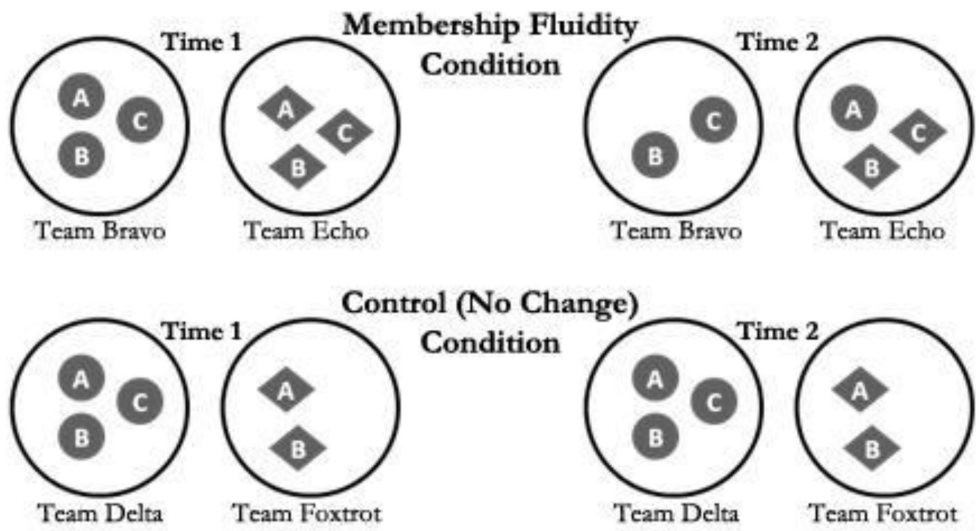

FIGURE 2 | Team member configurations at Time 1 and Time 2.

Team Mental Models

Research has suggested two approaches to studying TMMs: (a) sharedness in TMMS among members, and (b) accuracy of the TMMs (i.e., the degree to which TMMs reflect an expert model). Although prior research is helpful in selecting metrics, the task often dictates their appropriateness for the measurement (Mohammed et al., 2010). In this experiment, there was no one correct way to work; therefore, interest lay in sharedness rather than accuracy. TMM sharedness was calculated as an average correlation between team members, as outlined by Smith-Jentsch et al. (2005), who argued such an approach was warranted because the indices are correlational and thus, parallel to Pathfinder C (e.g., Stout et al., 1999; Marks et al., 2002), UCFNET QAP coefficients (e.g., Mathieu et al., 2000), or coefficient alphas (e.g., Webber et al., 2000). More similar TMMs have an index closer to 1. However, sharedness indices only represent similarities in the *patterns* of responses, not the actual *closeness* of the scores. To capture this latter metric, a Euclidean distance was also calculated, where lower distance scores are indicative of closer ratings (i.e., more similar the TMMs, based on a range of 0 – 13.86).

Data for the team interaction and taskwork TMMs were captured using a structured network approach (e.g., paired comparisons), because prior research suggested it is most predictive of adaptive performance (Resick et al., 2010). Participants were given a matrix of all tasks (or relevant teamwork attributes) and instructed to rate each attribute in relation to all other attributes for that model using a scale ranging from "−4" *(= high degree of one requires low degree of the other)* through "0" (= *unrelated)* to "4" *(= high degree of one requires high degree of the other)*. The ratings were completed before Performance Cycle II, yet after the membership change event (Task similarity: $M = 0.38$, $SD = 0.24$, Task distance: $M = 12.00$, $SD = 3.92$, Team Interaction similarity: $M = 0.13$, $SD = 0.23$, and Team Interaction distance: $M = 9.48$, $SD = 3.21$). Means within conditions for Task MM similarity are as follows: two-person intact teams ($M = 0.46$, $SD = 0.25$), three-person intact teams ($M = 0.32$, $SD = 0.20$), membership loss teams ($M = 0.32$, $SD = 0.28$), and membership loss with replacement teams ($M = 0.42$, $SD = 0.23$). Means within conditions for Team Interaction MM similarity are as follows: two-person intact teams ($M = 0.16$, $SD = 0.28$), three-person intact teams ($M = 0.14$, $SD = 0.19$), membership loss teams ($M = 0.14$, $SD = 0.26$), and membership loss with replacement teams ($M = 0.09$, $SD = 0.17$). Means within conditions for Task MM distance are as follows: two-person intact teams ($M = 11.45$, $SD = 4.91$), three-person intact teams ($M = 11.89$, $SD = 2.07$), membership loss teams ($M = 13.15$, $SD = 4.21$), and membership loss with replacement teams ($M = 11.50$, $SD = 4.08$). Finally, means within conditions for Team Interaction MM distance are as follows: two-person intact teams ($M = 8.61$, $SD = 3.28$), three-person intact teams ($M = 10.17$, $SD = 3.49$), membership loss teams ($M = 10.34$, $SD = 3.61$), and membership loss with replacement teams ($M = 8.82$, $SD = 2.18$).

Teammate TMMs were calculated using mini-IPIP, a 20-item short form of the International Personality Item Pool-Five-Factor Model measure (Donnellan et al., 2006). Recall that Teammate TMMs include general preferences for working (based on personality), as well as levels of expertise. This particular study was focused on *ad hoc* teams engaging in customer service-related tasks; therefore, the personality dimension of Teammate TMMs was the most appropriate measure, as members would have more opportunity to observe personality characteristics than prior expertise. Prior research on TMMs has included personality identification and similarity as evidence of the Teammate TMMs (e.g., Lim and Klein, 2006). Each member was required to complete this measure about themselves and about every other member of the team. To compute similarity and distance indices, a mean was calculated for each subscale (i.e., openness to experience, conscientiousness, extroversion, agreeableness, and neuroticism) per person. These means were then compared for each dyadic pair within the team (self to other rating of self). These dyadic comparisons were then averaged to create a "team member" average and all team member averages were aggregated, using the mean, to create a teammate similarity SMM index or distance SMM index. These team level variables were used in all analyses. Overall means and standard deviations across conditions for each index are as follows: similarity ($M = 0.47$, $SD = 0.27$) and distance ($M = 2.25$, $SD = 0.45$). Within conditions, means were as follows for the similarity index: two-person intact teams ($M = 0.56$, $SD = 0.32$), three-person intact teams ($M = 0.50$, $SD = 0.26$), three-person membership loss teams ($M = 0.37$, $SD = 0.26$), and three-person membership loss with replacement teams ($M = 0.44$, $SD = 0.23$). For the distance index, means within conditions were as follows: two-person intact teams ($M = 2.08$, $SD = 0.49$), three-person intact teams ($M = 2.22$, $SD = 0.41$), three-person membership loss teams ($M = 2.31$, $SD = 0.47$), and three-person membership loss with replacement teams ($M = 2.39$, $SD = 0.42$).

Adaptive Performance

Performance was measured using a card-sorting task. At Time I, participants were given 5 min to place cards listing each patient into the correct triage level. As knowledge about patient problems was distributed among team members (e.g., not all patients needing care were seen in the simulation or listed in patient files), all members needed to work together to successfully categorize all patients. A similar card-sorting task was given for Time II. Adaptive performance was calculated as the difference between Time I and Time II (Time II – Time I). Means for Adaptive Performance within conditions were as follows: two-person intact teams ($M = 0.67$, $SD = 1.95$), three-person intact teams ($M = 1.87$, $SD = 2.50$), three-person membership loss teams ($M = 1.40$, $SD = 3.23$), and three-person membership loss with replacement teams ($M = 0.13$, $SD = 3.50$).

RESULTS

As expected, there was no significant difference in Time I Performance across the four experimental conditions, $F(3,56) = 0.68$, $p = 0.57$, $\eta^2 = 0.04$, suggesting no spurious differences from random assignment. Descriptive statistics

and Pearson product-moment correlations are reported in **Table 1**. **Table 2** contains condition intercorrelations among performance variables.

Hypotheses H2 through H4 tested the mediating effects of learning. Although such tests have traditionally been guided by a multistep process proposed by Baron and Kenny (1986), more recent work suggested methodological shortcomings of this approach (e.g., MacKinnon et al., 2002; Edwards and Lambert, 2007). Preacher and Hayes (2004) suggested a different, more powerful, approach called bootstrapping, which can be applied using an SPSS macro (Kolbe et al., 2009). Adaptive performance was regressed onto membership condition, as well as the various TMM measures. Models were tested using correlations and Euclidean distances, run separately, as (a) results can differ based on metrics (Smith-Jentsch, 2009) and (b) there is currently no theory guiding metric selection for adaptive performance.

Two-Person Intact vs. Membership Loss Teams

Similarity Index

H1 suggested that condition would predict performance and H2 suggested that Task TMMs would partially mediate the relationship between membership fluidity (two-person intact teams and membership loss teams) and adaptive team performance. Results did not support mediation for membership loss teams and two-person intact teams when Task TMMs were operationalized using the similarity index (see **Table 3**) as Task TMMs were not significantly related to condition, $\beta = -0.01$, $t(28) = -0.14$, $p = 0.89$, nor were they significant predictors of Performance, $\beta = -0.50$, $t(28) = -0.19$, $p = 0.85$. The indirect effect of condition on performance was not in the hypothesized direction ($\beta = 1.05$), nor was it significant ($p = 0.38$).

TABLE 2 | Intercorrelations, means, and standard deviations for performance variables by condition.

	1	2	3
2-person Intact Teams			
Performance Time I	–		
Performance Time II	0.62*	–	
Adaptive Performance	−0.62*	0.23	–
M	4.40	5.01	0.67
SD	2.41	1.95	1.95
3-person Intact Teams			
Performance Time I	–		
Performance Time II	0.41	–	
Adaptive Performance	−0.38	0.69**	–
M	3.93	5.80	1.87
SD	1.98	2.54	2.50
Membership Loss Teams (3 → 2 members)			
Performance Time I	–		
Performance Time II	0.15	–	
Adaptive Performance	−0.64**	0.66**	–
M	3.47	4.87	1.40
SD	2.45	2.50	3.23
Membership Replacement Teams (3 → 3 members)			
Performance Time I	–		
Performance Time II	0.18	–	
Adaptive Performance	−0.61*	0.67**	–
M	4.60	4.73	0.13
SD	2.64	2.82	3.50

*$p \leq 0.05$; **$p \leq 0.01$.

H3 suggested Team Interaction TMMs would partially mediate the relationship between membership fluidity (two-person intact teams and membership loss teams) and adaptive team performance. These results did not suggest mediation either (**Table 3**). Team Interaction TMMs were not significantly related

TABLE 1 | Intercorrelations, means, and standard deviations for study variables.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Task TMM Corr.	–														
Team Interaction TMM Corr.	−0.01	–													
Teammate TMM Corr.	0.12	−0.01	–												
Task TMM Euc. Dist.	−0.51**	−0.14	−0.34**	–											
Team Interaction TMM Euc. Dist.	−0.11	−0.18	−0.28*	0.32	–										
Teammate TMM Euc. Dist.	−0.14	0.07	−0.54**	0.17	0.08	–									
Total Info Sharing	−0.01	−0.07	−0.08	−0.02	−0.01	0.30*	–								
GPA (Average for Team)	−0.05	−0.20	0.22	−0.23	−0.26	−0.05	0.13	–							
APGO (Team)	−0.08	0.04	0.08	0.10	−0.02	0.03	0.08	0.05	–						
Team Tolerance for Ambiguity	−0.25	0.10	0.02	−0.01	−0.17	0.003	0.15	0.09	−0.49**	–					
Team Familiarity	−0.09	0.09	0.06	−0.03	0.18	0.08	0.09	0.15	0.01	0.12	–				
Role Comprehension	−0.06	0.08	−0.07	−0.04	0.07	0.03	−0.03	−0.08	−0.08	0.09	−0.10	–			
Performance Time I	0.04	0.16	0.19	0.06	−0.17	−0.04	0.12	0.09	−0.001	0.26*	−0.05	−0.11	–		
Performance Time II	−0.002	0.14	0.16	−0.06	−0.16	−0.05	0.000	0.12	0.06	0.18	−0.13	0.07	0.29*	–	
Adaptive Performance	−0.03	−0.01	−0.02	−0.10	0.01	−0.01	−0.10	0.03	0.05	−0.07	−0.07	0.15	−0.58**	0.61**	–
M	0.38	0.13	0.47	12.00	9.48	2.25	9.23	3.23	2.60	3.50	4.44	3.73	4.10	5.12	1.02
SD	0.14	0.23	0.27	3.92	3.21	0.45	6.04	0.39	0.53	0.33	8.46	0.43	2.36	2.44	2.87

*$p \leq 0.05$; **$p \leq 0.01$.

TABLE 3 | Mediation: TMMs, 2-person intact and membership loss teams.

Variable	β	*SE*	*t*	*p*	Confidence Interval	
					LL 95% CI	UL 95% CI
Direct and Total Effects – CORRELATION						
Adaptive Performance Regressed on Condition[a]	0.33	1.49	0.22	0.83	−2.77	3.42
Task TMMs Regressed on Condition[a]	−0.01	0.10	−0.14	0.89	−0.23	0.20
Team Interaction TMMs Regressed on Condition[a]	−0.09	0.11	−0.78	0.44	−0.31	0.14
Teammate TMMs Regressed on Condition[a]	**−0.32**	**0.11**	**−2.86**	**0.01***	**−0.55**	**−0.09**
Adaptive Performance Regressed on Task TMMs, controlling for Condition[a]	−0.50	2.64	−0.19	0.85	−6.00	5.00
Adaptive Performance Regressed on Team Interaction TMMs, controlling for Condition[a]	−2.29	2.34	−0.98	0.34	−7.16	2.59
Adaptive Performance Regressed on Teammate TMMs, controlling for Condition[a]	−1.65	2.50	−0.66	0.52	−6.84	3.54
Adaptive Performance Regressed on Condition[a], including TMMs as Mediator (Total Effects Model[b])	1.05	1.18	0.89	0.38	−1.38	3.49
Direct and Total Effects – EUCLIDEAN DISTANCE						
Adaptive Performance Regressed on Condition[a]	1.34	1.52	0.88	0.39	−1.83	4.51
Task TMMs Regressed on Condition[a]	**3.21**	**1.89**	**1.70**	**0.10*[1]**	**−0.69**	**7.11**
Team Interaction TMMs Regressed on Condition[a]	**3.86**	**1.19**	**3.24**	**0.004****	**1.40**	**6.31**
Teammate TMMs Regressed on Condition[a]	0.23	0.22	1.09	0.29	−0.21	0.68
Adaptive Performance Regressed on Task TMMs, controlling for Condition[a]	−0.01	0.15	−0.05	0.97	−0.31	0.30
Adaptive Performance Regressed on Team Interaction TMMs, controlling for Condition[a]	−0.09	0.23	−0.37	0.71	−0.56	0.39
Adaptive Performance Regressed on Teammate TMMs, controlling for Condition[a]	0.27	1.29	0.21	0.84	−2.41	2.95
Adaptive Performance Regressed on Condition[a], including TMMs as Mediator (Total Effects Model[b])	1.05	1.18	0.89	0.38	−1.38	3.49

*n = 30 teams. Bootstrap sample size = 5,000. LL, lower limit; CI, confidence interval; UL, upper limit. Condition[a] = Conditions 2 (2-Person Intact Teams) and 4 (Membership Loss Teams). Total Effects Model[b] = Direct Effects + Indirect Effects. Controlling for Average GPA, APGO, Tolerance for Ambiguity, and Role Comprehension. *[1]p = 0.05, one-tailed, **p ≤ 0.01.*

to condition, β = −0.09, $t(28) = -0.78$, $p = 0.44$. Furthermore, Team Interaction TMMs were not significant predictors of Performance, β = −2.29, $t(28) = -0.98$, $p = 0.34$.

Euclidian Distance Index

However, when using the relative distance metric, the degree of Euclidean distance for Task TMMs was significantly predicted by condition, β = 3.21, $t(28) = 1.70$, $p = 0.05$. Essentially, membership loss teams had greater distance among Task TMMs ratings than two-person intact teams. Similarly, Team Interaction TMMs were significantly predicted by condition, β = 3.86, $t(28) = 3.24$, $p = 0.004$.

Three-Person Intact vs. Membership Replacement Teams

Similarity Index

As reported in **Table 4**, analyses were conducted to test the mediation hypotheses for three-person intact teams compared to membership replacement teams. When operationalized using the similarity index, neither Task TMMs [β = 0.11, $t(28) = 1.23$, $p = 0.23$] nor Teammate TMMs [β = −0.08, $t(28) = -0.88$, $p = 0.39$] were predicted by condition. However, condition did predict adaptive performance in the hypothesized direction, β = −2.06, $t(28) = -1.79$, $p = 0.04$.

Euclidian Distance Index

Results for the relative distance TMM metric also did not support mediation for Task or Teammate TMMs. Task TMMs, operationalized as Euclidean distance, were not significantly predicted by condition, β = −0.39, $t(28) = -0.31$, $p = 0.76$. Condition also did not predict Teammate TMMs, β = 0.17, $t(28) = 1.04$, $p = 0.14$ with the distance metric. Further, neither of the TMMs distance indices predicted Adaptive Team Performance [Task:β = −0.23, $t(28) = -1.23$, $p = 0.23$; Teammate:β = −0.12, $t(28) = -0.08$, $p = 0.93$].

Exploratory Analyses

Upon reflection, the task likely determined the extent to which members were able to gain information regarding member preferences/tendencies. The task in this study was social in nature, comprised of *ad hoc* teams. So, skewness and kurtosis analyses were conducted across conditions. Results suggest that familiarity data were not normally distributed. Specifically, the positive skewness value (2.57) suggests that the majority of the responses were less than the mean while the kurtosis level (6.79) suggests that the data are more closely clustered around the mean (i.e., low lower levels of data fluctuation than what is seen in normal distributions). Together, this suggests that participants generally had low levels of familiarity with one another. As such, members could only develop similar views of easily observed characteristics, which could have led to spurious ratings of unobserved personality traits (e.g., without any demonstration of cues for openness to experience, members would have little insight into that personality factor). The use of an aggregated Teammate TMM (i.e., aggregation of all five personality factors) could have, therefore, led to attenuated correlations or inflated Euclidean distances, limiting explanatory power. Thus, teammate TMM was re-operationalized at the factor level (separate personality constructs) and additional analyses were then conducted using these separate variables.

The *Agreeableness* factor was predicted by condition, β = −0.14, $t(28) = -2.23$, $p = 0.04$ (see **Table 5**). Essentially,

TABLE 4 | Mediation: TMMs, 3-person intact and membership loss w/replacement teams.

Variable	β	*SE*	*t*	*P*	Confidence Interval	
					LL 95% CI	UL 95% CI
Direct and Total Effects – CORRELATION						
Adaptive Performance Regressed on Condition[a]	−1.77	1.26	−1.41	0.17	−4.37	0.83
Task TMMs Regressed on Condition[a]	0.11	0.09	1.23	0.23	−0.07	0.28
Team Interaction TMMs Regressed on Condition[a]	0.30	0.51	0.51	0.62	−0.19	0.10
Teammate TMMs Regressed on Condition[a]	−0.08	0.09	−0.88	0.39	−0.27	0.11
Adaptive Performance Regressed on Task TMMs, controlling for Condition[a]	−0.55	2.90	−0.19	0.85	−6.56	5.46
Adaptive Performance Regressed on Team Interaction TMMs, controlling for Condition[a]	4.50	3.59	1.25	0.22	−2.95	11.94
Adaptive Performance Regressed on Teammate TMMs, controlling for Condition[a]	0.29	2.62	0.11	0.91	−5.15	5.72
Adaptive Performance Regressed on Condition[a], including TMMs as Mediator (Total Effects Model)[b]	**−2.06**	**1.15**	**−1.79**	**0.09***	**−4.43**	**0.32**
Direct and Total Effects – EUCLIDEAN DISTANCE						
Adaptive Performance Regressed on Condition[a]	−1.77	1.26	−1.41	0.17	−4.37	0.83
Task TMMs Regressed on Condition[a]	−0.39	1.27	−0.31	0.76	−3.02	2.23
Team Interaction TMMs Regressed on Condition[a]	−1.66	1.08	−1.53	0.14	−3.88	0.57
Teammate TMMs Regressed on Condition[a]	0.17	0.16	1.04	0.31	−0.17	0.51
Adaptive Performance Regressed on Task TMMs, controlling for Condition[a]	−0.23	0.19	−1.23	0.23	−0.61	0.16
Adaptive Performance Regressed on Team Interaction TMMs, controlling for Condition[a]	−0.15	0.23	−0.688	0.50	−0.62	0.31
Adaptive Performance Regressed on Teammate TMMs, controlling for Condition[a]	−0.12	1.48	−0.08	0.93	−3.19	2.94
Adaptive Performance Regressed on Condition[a], including TMMs as Mediator (Total Effects Model)	**−2.06**	**1.15**	**−1.79**	**0.09***	**−4.43**	**0.32**

*n = 30 teams. Bootstrap sample size = 5,000. LL, lower limit; CI, confidence interval; UL, upper limit. Condition[a] = Conditions 3 (3-Person Intact Teams) and 5 (Membership Loss w/Replacement Teams), Total Effects Model[b] = Direct Effects + Indirect Effects. Controlling for Average GPA, Team Familiarity, and Role Comprehension. *p = 0.04 level, one-tailed.*

intact teams had more similar Teammate TMMs regarding members' levels of agreeableness than did membership loss with replacement teams. Also, the *Neuroticism* factor significantly predict adaptive performance, $\beta = 4.49$, $t(28) = 1.96$, $p = 0.03$. Teams that correctly identified fellow members' levels of neuroticism performed better at Time II than Time I. The Neuroticism factor (Euclidean distance) was predicted by condition [$\beta = -0.43$, $t(28) = -1.69$, $p = 0.05$]. Additionally, the Agreeableness factor, operationalized as Euclidean distance [$\beta = -3.57$, $t(28) = -2.90$, $p = 0.01$], significantly predicted adaptive team performance. Teams who had more similar TMMs regarding members' levels of agreeableness performed better at Time II than at Time I. Interestingly, when considered along with the factors of Teammate TMMs, Task TMMs significantly predicted adaptive team performance [$\beta = -0.30$, $t(28) = -1.72$, $p = 0.05$].

DISCUSSION

The hypotheses in this study essentially described a mediation model, derived from theory, to explain one possible mechanism that enables teams to adapt: TMMs. It was hypothesized that teams in the experimental conditions would not develop the same level of sharedness in mental models as teams who did not experience any membership changes. Membership fluidity was expected to negatively influence adaptive performance but that relationship was predicted to be partially mediated by the lack of sharedness in mental models. Although results did not support partial mediation, three-person intact teams demonstrated greater adaptive performance than teams who experienced membership loss with replacement. Furthermore, two-person intact teams developed more similar task and team interaction TMMs than teams who lost a member when TMMs were indexed as a Euclidean distance score. Contrary to predictions, there were no differences in the level of sharedness regarding Task or Teammate TMMs for three-person intact teams as compared to membership loss with replacement teams.

When Teammate TMMs were operationalized as individual personality factors (i.e., the Big 5 – openness to experience, conscientiousness, extroversion, agreeableness, and neuroticism), three-person intact teams did develop more similar TMMs regarding the agreeableness factor (similarity index) and the neuroticism factor (distance index) than membership loss with replacement teams. Additionally, when operationalized as Euclidean distance, the Agreeableness factor significantly predicted adaptive team performance—specifically, the smaller the distance (i.e., more similar the TMMs), the greater the adaptive performance in teams. When operationalized as the similarity index, the neuroticism factor significantly predicted adaptive team performance as well, such that the more similar the TMMs, the greater the adaptive performance in teams. Finally, when factors were included in the analyses, Task TMMs significantly predicted adaptive team performance (distance index). **Figure 3** shows a model of the supported relationships.

Theoretical and Practical Implications

Theoretically, this research extends our current understanding of team adaptation by moving beyond a change in task complexity or one type of change in team configuration to investigate team member loss as well as team member loss with replacement. This may more accurately represent the dynamic flow of individuals among teams that is common in organizations today. Team

TABLE 5 | Mediation: teammate TMM dimensions—correlations, exploratory analyses.

Variable	β	*SE*	*T*	*P*	Confidence Interval	
					LL 95% CI	UL 95% CI
Direct and Total Effects – CORRELATION						
Adaptive Performance Regressed on Condition[a]	−1.76	1.47	−1.20	0.25	−4.82	1.30
Task TMMs Regressed on Condition[a]	0.05	0.08	0.60	0.55	−0.12	0.23
Team Inter. TMMs Regressed on Condition[a]	−0.07	0.07	−0.99	0.33	−0.22	0.08
Teammate O TMMs Regressed on Condition[a]	0.01	0.06	−0.09	0.93	−0.13	0.12
Teammate C TMMs Regressed on Condition[a]	**0.19**	**0.09**	**2.08**	**0.05**	**0.002**	**0.38**
Teammate E TMMs Regressed on Condition[a]	−0.07	0.11	−0.60	0.55	−0.30	0.17
Teammate A TMMs Regressed on Condition[a]	**−0.14**	**0.06**	**−2.23**	**0.04**	**−0.27**	**−0.01**
Teammate N TMMs Regressed on Condition[a]	0.09	0.11	0.83	0.42	−0.14	0.32
Adaptive Performance Regressed on Task TMMs, controlling for Condition[a]	1.56	2.95	0.53	0.60	−4.57	7.69
Adaptive Performance Regressed on Team Interaction TMMs, controlling for Condition[a]	2.39	3.95	0.61	0.55	−5.82	10.61
Adaptive Performance Regressed on Teammate O TMMs, controlling for Condition[a]	−3.95	4.20	−0.94	0.36	−12.69	4.78
Adaptive Performance Regressed on Teammate C TMMs, controlling for Condition[a]	−4.35	3.20	−1.36	0.19	−11.01	2.31
Adaptive Performance Regressed on Teammate E TMMs, controlling for Condition[a]	−2.02	2.11	−0.96	0.35	−6.41	2.37
Adaptive Performance Regressed on Teammate A TMMs, controlling for Condition[a]	−3.38	4.38	−0.77	0.45	−12.49	5.73
Adaptive Performance Regressed on Teammate N TMMs, controlling for Condition[a]	**4.49**	**2.29**	**1.96**	**0.06***	**−0.27**	**9.26**
Adaptive Performance Regressed on Condition[a], including TMMs as Mediator (Total Effects Model)[b]	−1.73	1.11	−1.56	0.13	−4.01	0.54
Direct and Total Effects – EUCLIDEAN DISTANCE						
Adaptive Performance Regressed on Condition[a]	−1.05	1.17	−0.90	0.38	−3.49	1.39
Task TMMs Regressed on Condition[a]	0.48	1.24	0.39	0.70	−2.07	3.03
Team Inter. TMMs Regressed on Condition[a]	−1.71	1.13	−1.51	0.14	−4.05	0.63
Teammate O TMMs Regressed on Condition[a]	−0.29	0.20	−1.48	0.15	−0.70	0.11
Teammate C TMMs Regressed on Condition[a]	0.20	0.19	1.06	0.30	−0.19	0.60
Teammate E TMMs Regressed on Condition[a]	0.01	0.20	0.03	0.98	−0.40	0.41
Teammate A TMMs Regressed on Condition[a]	0.08	0.24	0.35	0.73	−0.40	0.57
Teammate N TMMs Regressed on Condition[a]	**−0.43**	**0.26**	**−1.69**	**0.10***	**−0.96**	**0.09**
Adaptive Performance Regressed on Task TMMs, controlling for Condition[a]	**−0.30**	**0.18**	**−1.72**	**0.10***	**−0.67**	**0.06**
Adaptive Performance Regressed on Team Interaction TMMs, controlling for Condition[a]	−0.19	0.18	−1.08	0.30	−0.57	0.18
Adaptive Performance Regressed on Teammate O TMMs, controlling for Condition[a]	**3.94**	**1.46**	**2.69**	**0.01**	**0.89**	**6.98**
Adaptive Performance Regressed on Teammate C TMMs, controlling for Condition[a]	0.37	1.33	0.28	0.79	−2.40	3.13
Adaptive Performance Regressed on Teammate E TMMs, controlling for Condition[a]	−0.90	1.26	−0.72	0.48	−3.51	1.71
Adaptive Performance Regressed on Teammate A TMMs, controlling for Condition[a]	**−3.57**	**1.23**	**−2.90**	**0.01**	**−6.14**	**−1.01**
Adaptive Performance Regressed on Teammate N TMMs, controlling for Condition[a]	−1.04	0.91	−1.14	0.27	−2.93	0.86
Adaptive Performance Regressed on Condition[a], including TMMs as Mediator (Total Effects Model)[b]	−1.73	1.11	−1.56	0.13	−4.01	0.54

*n = 30 teams. Bootstrap sample size = 5,000. LL, lower limit; CI, confidence interval; UL, upper limit. Condition[a] = Conditions 3 (3-Person Intact Teams) and 5 (Membership Loss w/Replacement). Total Effects Model[b] = Direct Effects + Indirect Effects. Controlling for Average GPA, APGO, and Team Familiarity. *p = 0.03, one-tailed (finding is in hypothesized direction).*

research is just beginning to consider membership fluidity as a potential issue in process loss as early work on team adaptation with regard to membership change has largely been theoretical (Summers et al., 2012). Providing empirical evidence regarding the influence of fluidity on TMM sharedness helps move the field forward in terms of synthesizing existing assumptions into meaningful theory.

Results support a direct negative influence of membership loss with replacement on adaptive team performance, which is consistent with previous research on team familiarity (Goodman and Leyden, 1991; Smith-Jentsch et al., 2009). Although results did not support TMMs mediating the relationship between the various condition and performance in this study, membership fluidity did negatively influence the development of task, team interaction, and teammate TMMs, depending on whether teams experienced membership loss or change. However, there were inconsistent findings with regard to the relationship of these variables to adaptive team performance, depending on operationalization and condition. This may be due to the fact that TMMs do not exert a direct effect on adaptive performance, but rather an indirect effect through team process (e.g., Mathieu et al., 2000) or an interaction of TMMs (Smith-Jentsch et al., 2005). Thus, theory must link specific types of TMMs (rather than overall shared cognition constructs) to particular team processes to drive future research (Smith-Jentsch, 2009).

Although none of the hypothesized TMMs influenced adaptive performance, when operationalized at the factor level, teammate (agreeableness, neuroticism) and task TMMs significantly predicted adaptive team performance. Research within the team domain rarely considers multiple types of TMMs within a single study, especially since Mathieu et al. (2000) suggested that the four types of TMMs outlined by

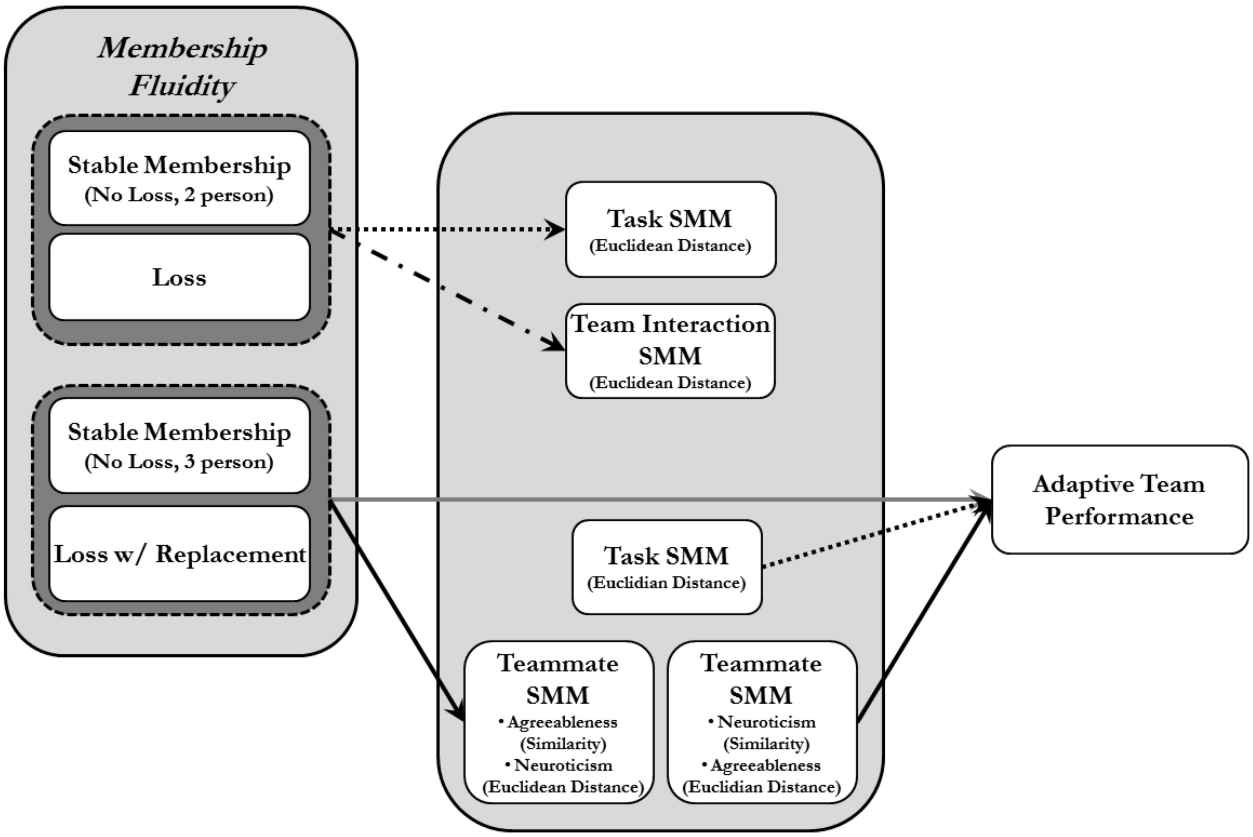

FIGURE 3 | Actual relationship among hypothesized study variables.

Cannon-Bowers et al. (1993) ultimately depict two major content domains. A review of the team literature noted that few studies have conceptualized more than one dimension of TMMs (Mathieu et al., 2008). When more than one dimension has been studied, researchers almost unanimously focus on task and team TMMs, ignoring *teammate* TMMs and instead focusing on *team interaction* TMMs. Other than the work from Smith-Jentsch et al. (2001, 2009), the majority of research that has considered the degree to which team member preferences are known, has typically resided in the transactive memory system literature. Transactive memory systems are considered to be the collection of individually held information and the knowledge regarding the distribution of that information among team members (Wegner, 1986) and some would argue, includes the degree to which members hold knowledge of other member work preferences (e.g., Lewis et al., 2007). In fact, results are consistent (i.e., differences in TMS between intact and reconstituted teams) with such findings. Indeed, in this study, intact teams had significantly higher levels of all three types of TMMs measured (i.e., task, team interaction, and teammate). However, findings differed based on whether teams lost or changed members.

Furthermore, findings from the exploratory analyses suggest that multiple dimensions of TMMs—particularly teammate—differentially influence results. This particular task was a customer service task, and the hospital staff and patients were scripted specifically to be challenging to work with, providing many opportunities for teammates to observe levels of agreeableness. Consider the member who is interacting with the simulation (Waiting Room Staffer) who specifically sees all patients and hospital staffers, some of whom are difficult to deal with. It is very easy to determine one's level of agreeableness when observing someone interacting with the simulation. During the second action phase, members could have leveraged such information to alter how they interacted with that person (be more candid for highly agreeable individuals and be more patient with those lower on agreeableness). This change in how members approach their teammates helps everyone gain additional information and thus, could improve performance.

Additionally, the performance measures were timed and a performance reward was offered for the highest-ranking teams. Therefore, the measures focused on both speed and accuracy. This provides many opportunities to observe levels of neuroticism as well. During the next performance episode, effective team members who noticed more neurotic levels of behavior from a teammate during the timed performance measure at Time 1 could elicit information from that person first, to avoid having him/her get flustered toward the end of the time period or perseverate over the information while waiting to contribute, resulting in a member who had confused the details and thus, could negatively influence team performance.

Thus, adaptation theory should discuss how *specific types* of TMMs (and corresponding dimensions) influence adaptation. The Burke et al. (2006) specifically discusses cognitions, suggesting that adaptive team performance, by definition, requires a change in "cognitive or behavioral goal-directed actions or structures to meet expected or unexpected demands" (p. 1192); however, the discussion is limited to generic TMMs, not specifying which types are most important at any given time. Kozlowski et al. (1999) also suggest adaptive performance is comprised of a series of stages, but do not specifically mention shared mental models. However, when considered closely, the underlying mechanisms required for successfully moving through the phases are cognitively based. For example, socialization—the first phase—is focused on reducing social ambiguity, which is often inherent at team formation by seeking knowledge regarding the team. One particular type of knowledge that the authors suggest aids in the socialization process is *interpersonal knowledge*, which is the information that comprises teammate TMMs. Kozlowski also suggests that team orientation aids adaptive performance. The development of a *team orientation* involves the identification of team goals (i.e., what the team is trying to do), team climate (i.e., what it is like to be part of this particular team), and norms for interaction (i.e., acceptable behavior within the team). This provides the necessary boundary conditions within which the team will operate, enabling members to see how each particular individual role aligns with the overall mission of the team and provides a basis for development of shared perceptions (Nieva et al., 1978). This, essentially, describes team interaction TMMs. If adaptation theory can integrate with team cognition theory, there will be greater specificity with regard to the team level cognitions required for effective adaptation, allowing researchers to target specific dimensions of task, team interaction, and teammate TMMs when conducting team adaptation research. Such integration can streamline research efforts, which facilitates translation of science to practice.

As researchers continue to call for more complex investigations into team adaptation phenomena (e.g., Baard et al., 2014; Waller et al., 2016) more theory is needed to guide such efforts. Zajac et al. (2014) attempted to add some clarity to the cognitive domain of adaptive team performance with their theory, integrating TMS and TMMs specifically with adaptive performance, resulting in a model that highlights how TMS and TMMs evolve over time. Indeed researchers (Uitdewilligen et al., 2013) found that mental model updating is positively related to postchange team performance. Thus, future research should incorporate multiple measures of TMMs and include in regression analyses that look at sequential mediators as the timing of the TMM measurement may influence results if only measured once. Further, theory must begin to incorporate time into models of adaptation (Cronin et al., 2011; Kozlowski and Chao, 2012; Waller et al., 2016). Rosen et al. (2011) have outlined a number of principles that should be considered when studying team adaptation with suggested measurement strategies for each principle. Such work can aid researchers in identifying variables and measurement strategies for more complex investigations.

On a more practical level, organizations trying to recover from economic hardships are tightening control over expenditures by redistributing workload among existing employees rather than hiring additional help. Thus, experienced workers are often removed from one team and placed on another team. Although much adaptive team performance research has focused on integration of a new member (e.g., Moreland and Levine, 2001), research has not adequately considered fluid team configurations (Summers et al., 2012; Tannenbaum et al., 2012).

This research provides a necessary first step toward understanding the implications of both membership loss and membership loss with replacement on adaptive team performance. Various membership fluidity conditions differentially influenced the sharedness of TMMs. Essentially, removing members without replacement in decision-making tasks requiring pooled, uniquely held knowledge caused decrements to the sharedness of TMMs (task and team interaction). Replacing lost teammates with members who were familiar with the task did not result in decrements to task TMMs; however, it did influence the sharedness of teammate TMMs. Ultimately, task and teammate TMMs directly influenced adaptive performance when operationalized as personality factors. These findings suggest organizations relying upon such teams cannot engage in downsizing or team reconfigurations without incurring some degree of process loss—and potentially, performance decrements. Thus, organizations should focus on knowledge management to store task-relevant information so it remains easily accessible to teams. Organizations should also encourage teams to take time to engage in interpersonal knowledge sharing and role specification discussions (Kozlowski et al., 1999; Burke et al., 2006) to provide mechanisms for developing a shared understanding of the task(s) and the team.

Limitations and Future Research

Hypothesis testing did not fully support the supposition that high shared task, team interaction and teammate TMMs would alleviate the negative effects of membership fluidity on performance. The team mental model literature emphasizes overlapping knowledge of team members as a critical predictor of team effectiveness (Cannon-Bowers et al., 1993; Mathieu et al., 2000). However, researchers have suggested that shared knowledge encompasses perspectives that are both shared and complementary and further argue that complementary perspectives are most appropriate for heterogeneous teams with distinct roles where performance relies on uniquely held knowledge (Cooke et al., 2000, 2003)—similar to the notion of transactive memory. In fact, Cooke et al. (2000) have suggested that in such teams, researchers should use knowledge distribution metrics to identify where specific knowledge lies as gaps can be compensated for if that knowledge is held by other members. In teams requiring pooling of uniquely held knowledge, measuring overlapping knowledge may not be predictive of what is truly required for successful performance (Mohammed and Dumville, 2001), particularly adaptation. Adaptation theory should, thus, incorporate such knowledge to spur future research.

The decision to remove the Claims Staffer could have influenced results. It was speculated that this particular role required uniquely held knowledge required for effective performance (critical updates provided by the experimenter). Removal of the Waiting Room Staffer, who interacted directly with the simulation, may have led to different results. Team members had much greater opportunities to observe personality factors based on tasks requirements of this role. Perhaps through removal of this member, condition would have more strongly predicted overall Teammate TMMs and such TMMs would have been related to adaptive performance because the Waiting Room Staffer had more detailed patient knowledge. Removal of this member would have necessitated reconfiguration, as someone would have been required to change roles to engage with the simulation, thus, impacting team interaction TMMs. Finally, this particular role was qualitatively different from the Claims or Records Staffer. Removal of the Waiting Room Staffer would have required remaining members in the loss condition to develop an understanding of a different task, perhaps influencing sharedness of task mental models. Future research should investigate results based on different role removals.

As noted previously, Euclidean distance scores were found to be significant more often than correlation scores. Finally, some SMM findings were associated with the similarity index, while others were based on the Euclidean distance. Practically speaking, it is important to consider measurement indices and this study adds additional support to the notion that measurement matters. Smith-Jentsch (2009) articulated these issues in her chapter on team cognitions. She noted that different metrics produce different results and careful consideration should be placed on the specific research questions to select the most appropriate metric. Resick et al. (2010) added additional support to Smith-Jentsch's argument by empirically demonstrating that different SMM elicitation methods result in varied relationships with outcomes of interest, such as adaptive team performance. This study is yet another indicator of the importance of measurement. SMM correlations (i.e., similarity indices) were more predictive at times, however, the Euclidian distance scores provided more overall support for hypothesis (and exploratory analysis) testing. This is possibly due to the fact that correlations can be attenuated when members completely agree (restriction of range), either through item or aggregate team-level analyses (i.e., an average self-rating of 4 across items compared to an average other rating of 4 results in lack of a correlation or a correlation of 0.0). However, if the pattern of responses were different such that one rating was 4-5-3 and the other rating was 3-5-4, the distance score would reflect an actual Euclidean distance score of 1.0, which indicates high levels of agreement. Similarly, correlation ratings can also be inflated, in the case of a "perfect" correlation based on the same pattern of responses, but different actual ratings. Consider one person rating 4-5-4-4 and another rating 2-3-2-2. This would be considered a perfect correlation of 1.0. Yet, when calculated as the distance score, it is 4.0, which is considerably less "agreement" than indicated by a perfect correlation. Essentially, the correlations measure the how similar members were able to rate patterns of responses, whereas Euclidean distances measure absolute distance among ratings (whether members figure out that others were either high or low, but just were slightly off regarding the specific pattern of responses). In cases with restriction of range (as discussed above), the Euclidean distance score would more accurately capture the true nature of relatedness. Yet caution must be taken when considering results using distance score metrics. Although it is true that distance scores may yield attenuated relationships, some argue that they are problematic as they are generally unreliable and polynomial regression should be used instead (which generally requires a large sample size); thus, future research should consider collecting more samples and running analyses with polynomial regression (Edwards, 2001).

The nature of the tasks within this study forced members to engage in independent taskwork, and then suddenly shift to interdependent teamwork. Research should consider how such transitions influences the development of TMMs and adaptive performance as previous research suggests that teams have more performance problems when shifting from a functional structure to a divisional structure (Moon et al., 2004). Thus, there could be different performance implications when shifting from interdependent to independent as compared to the independent-interdependent entrainment shifts experienced by teams in this effort.

CONCLUSION

To provide practitioners with evidence-based guidelines for training teams to be adaptive to changing conditions (e.g., membership changes), conceptual direction is required and, more importantly, empirical evidence stemming from rigorous theoretical tests. Based upon these results, it is argued that team adaptation theory, which includes cognitive components, must go deeper than suggesting that overall cognition—or even the general construct of TMMs—is necessary. In particular, there must be integration of empirical findings regarding specific aspects of cognition to begin to theorize relationships among key constructs, especially in teams with fluid membership as they are more and more common in environments across work domains. Research that considers membership fluidity, such as this effort, can help shed light into the nature of such required theoretical changes necessary to effectively guide future research efforts. Such work is critical to move the field forward in a meaningful manner and really explore how the cognitive component of teamwork influences team performance in fluid teams.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the University of Central Florida Institutional Review Board (UCF IRB). Given that a signed informed consent would be the only identifying information tied to participation, signed informed consent was waived. The protocol was approved by the UCF IRB.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

FUNDING

This work was partially supported by NASA grant (NNX09AK48G), awarded to the University of Central Florida. The views expressed in this work are those of the author and do not necessarily reflect the organizations with which the author is affiliated or the sponsoring institution or agency.

ACKNOWLEDGMENTS

The author would like to thank Drs. Eduardo Salas, Stephen M. Fiore, Kimberly Smith-Jentsch, and Ramón Rico for comments on previous versions of this work.

REFERENCES

Akgün, A. E., and Lynn, G. S. (2002). Antecedents and consequences of team stability on new product development performance. *J. Eng. Techn. Manag.* 19, 263–286. doi: 10.1016/s0923-4748(02)00021-8

Ancona, D. G. (1990). Outward bound: strategies for team survival in an organization. *Acad. Manag. J.* 33, 334–365. doi: 10.5465/256328

Argote, L. (1999). *Organizational Learning: Creating, Retaining, and Transferring Knowledge*. Norwell, MA: Kluwer.

Baard, S. K., Rench, T. A., and Kozlowski, S. W. J. (2014). Performance adaptation: a theoretical integration and review. *J. Manag.* 40, 48–99. doi: 10.1177/0149206313488210

Baron, R. M., and Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *J. Pers. Soc. Psychol.* 51, 1173–1182. doi: 10.1037/0022-3514.51.6.1173

Bedwell, W. L., Ramsay, P. S., and Salas, E. (2012). Helping fluid teams work: a research agenda for effective team adaptation in healthcare. *Transl. Behav. Med.* 2, 504–509. doi: 10.1007/s13142-012-0177-9

Berman, S. L., Down, J., and Hill, C. W. L. (2002). Tacit knowledge as a source of competitive advantage in the National Basketball Association. *Acad. Manag. J.* 45, 13–31. doi: 10.2307/3069282

Burke, C. S., Salas, E., DiazGranados, D., Sessa, V. I., and London, M. (2008). *The Role of Team Learning in Facilitating Team Adaptation within Complex Environments: Tools and Strategies Work Group Learning: Understanding, Improving and Assessing How Groups Learn in Organizations*. New York, NY: Taylor & Francis Group, 217–241.

Burke, C. S., Stagl, K. C., Salas, E., Pierce, L., and Kendall, D. (2006). Understanding team adaptation: a conceptual analysis and model. *J. Appl. Psychol.* 91, 1189–1207. doi: 10.1037/0021-9010.91.6.1189

Burtscher, M. J., and Manser, T. (2012). Team mental models and their potential to improve teamwork and safety: a review and implications for future research in healthcare. [Review Article]. *Saf. Sci.* 50, 1344–1354. doi: 10.1016/j.ssci.2011.12.033

Cannon-Bowers, J. A., Salas, E., and Converse, S. (1993). *Shared Mental Models in Expert Team Decision Making Individual and Group Decision Making: Current Issues*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc., 221–246.

Cascio, W. F. (1999). *Costing Human Resources*, 4th Edn. Dallas, TX: Southwestern College Publishing.

Cooke, N. J., Kiekel, P. A., Salas, E., Stout, R., Bowers, C., and Cannon-Bowers, J. (2003). Measuring team knowledge: a window to the cognitive underpinnings of team performance. *Group Dyn.* 7, 179–199. doi: 10.1037/1089-2699.7.3.179

Cooke, N. J., Salas, E., Cannon-Bowers, J. A., and Stout, R. J. (2000). Measuring team knowledge. *Hum. Fact.* 42, 151–173. doi: 10.1518/001872000779656561

Cronin, M. A., Weingart, L. R., and Todorova, G. (2011). Dynamics in groups: are we there yet? *Acad. Manag. Ann.* 5, 571–612. doi: 10.5465/19416520.2011.590297

DeChurch, L. A., and Mesmer-Magnus, J. R. (2010a). Measuring shared team mental models: a meta-analysis. *Group Dyn. Theory Res. Pract.* 14, 1–14. doi: 10.1037/a0017455

DeChurch, L. A., and Mesmer-Magnus, J. R. (2010b). The cognitive underpinnings of effective teamwork: a meta-analysis. *J. Appl. Psychol.* 95, 32–53. doi: 10.1037/a0017328

DeRue, D. S., Hollenbeck, J. R., Johnson, M. D., Ilgen, D. R., and Jundt, D. K. (2008). How different team downsizing approaches influence team-level adaptation and performance. *Acad. Manag. J.* 51, 182–196. doi: 10.5465/amj.2008.30776769

Donnellan, M. B., Oswald, F. L., Baird, B. M., and Lucas, R. E. (2006). The Mini-IPIP scales: tiny-yet-effective measures of the Big Five factors of personality. *Psychol. Assess.* 18, 192–203. doi: 10.1037/1040-3590.18.2.192

Edmondson, A. C. (2003). Speaking up in the operating room: how team leaders promote learning in interdisciplinary action teams. *J. Manag. Stud.* 40, 1419–1452. doi: 10.1111/1467-6486.00386

Edmondson, A. C., Bohmer, R. M., and Pisano, G. P. (2001). Disrupted routines: team learning and new technology implementation in hospitals. *Adm. Sci. Q.* 46, 685–716.

Edwards, J. R. (2001). Ten difference score myths. *Organ. Res. Methods* 4, 265–287. doi: 10.1177/109442810143005

Edwards, J. R., and Lambert, L. S. (2007). Methods for integrating moderation and mediation: a general analytical framework using moderated path analysis. *Psychol. Methods* 12, 1–22. doi: 10.1037/1082-989x.12.1.1

Feldman, D. C. (1994). Who's socializing whom? The impact of socializing newcomers on insiders, work groups, and organizations. *Hum. Resour. Manag. Rev.* 4, 213–233. doi: 10.1016/1053-4822(94)90013-2

Gersick, C. J. G., and Hackman, J. R. (1990). Habitual routines in task-performing groups. *Organ. Behav. Hum. Decis. Process.* 47, 65–97. doi: 10.1016/0749-5978(90)90047-d

Goodman, P. S., and Leyden, D. P. (1991). Familiarity and group productivity. *J. Appl. Psychol.* 76, 578–586. doi: 10.1037/0021-9010.76.4.578

Gruenfeld, D. H., Mannix, E. A., Williams, K. Y., and Neale, M. A. (1996). Group composition and decision making: how member familiarity and information distribution affect process and performance. *Organ. Behav. Hum. Decis. Process.* 67, 1–15. doi: 10.1006/obhd.1996.0061

Huckman, R. S., and Staats, B. R. (2011). Fluid tasks and fluid teams: the impact of diversity in experience and team familiarity on team performance. *Manuf. Serv. Oper. Manag.* 13, 310–328. doi: 10.1287/msom.1100.0321

Kane, A. A., Argote, L., and Levine, J. M. (2005). Knowledge transfer between groups via personnel rotation: effects of social identity and knowledge quality. *Organ. Behav. Hum. Decis. Process.* 96, 56–71. doi: 10.1016/j.obhdp.2004.09.002

Katz, R. (1982). The effects of group longevity on project communication and performance. *Adm. Sci. Q.* 27, 81–104.

Kim, P. H. (1997). When what you know can hurt you: a study of experiential effects on group discussion and performance. *Organ. Behav. Hum. Decis. Process.* 69, 165–177. doi: 10.1006/obhd.1997.2680

Kolbe, M., Künzle, B., Manser, T., Zala-Mezö, E., Wacker, J., and Grote, G. (2009). "Measuring coordination behavior in anaesthesia teams during induction of general anesthetics," in *Safer Surgery: Analysing Behavior in the Operating Theatre*, eds R. Flin, and L. Mitchell, (Aldershot: Ashgate), 202–220.

Kozlowski, S. W., and Chao, G. T. (2012). The dynamics of emergence: cognition and cohesion in work teams. *Manage. Decis. Econ.* 33, 335–354. doi: 10.1002/mde.2552

Kozlowski, S. W. J., Gully, S. M., Nason, E. R., and Smith, E. M. (1999). "Developing adaptive teams: a theory of compilation and performance across levels and time," in *The Changing Nature of Work Performance: Implications for Staffing, Personnel Actions, and Development*, eds D. R. Ilgen, and E. D. Pulakos, (San Francisco, CA: Jossey-Bass), 240–292.

Levine, J. M., and Moreland, R. L. (1991). "Culture and socialization in work groups," in *Perspectives on Socially Shared Cognition*, eds L. B. Resnick, J. M. Levine, and S. D. Teasdale, (Washington, DC: American Psychological. Association), 257–279. doi: 10.1037/10096-011

Lewis, K., Belliveau, M., Herndon, B., and Keller, J. (2007). Group cognition, membership change, and performance: investigating the benefits and detriments of collective knowledge. *Organ. Behav. Hum. Decis. Process.* 103, 159–178. doi: 10.1016/j.obhdp.2007.01.005

Liang, D. W., Moreland, R., and Argote, L. (1995). Group versus individual training and group performance: the mediating role of transactive memory. *Pers. Soc. Psychol. Bull.* 21, 384–393. doi: 10.1177/0146167295214009

Lim, B. C., and Klein, K. J. (2006). Team mental models and team performance: a field study of the effects of team mental model similarity and accuracy. *J. Organ. Behav.* 27, 403–418. doi: 10.1037/a0025148

MacKinnon, D. P., Lockwood, C. M., Hoffman, J. M., West, S. G., and Sheets, V. (2002). A comparison of methods to test mediation and other intervening variable effects. *Psychol. Methods* 7, 83–104. doi: 10.1037/1082-989x.7.1.83

Marks, M. A., Sabella, M. J., Burke, C. S., and Zaccaro, S. J. (2002). The impact of cross-training on team effectiveness. *J. Appl. Psychol.* 87, 3–13. doi: 10.1037/0021-9010.87.1.3

Marks, M. A., Zaccaro, S. J., and Mathieu, J. E. (2000). Performance implications of leader briefings and team-interaction training for team adaptation to novel environments. *J. Appl. Psychol.* 85, 971–986. doi: 10.1037//0021-9010.85.6.971

Mathieu, J. E., Heffner, T. S., Goodwin, G. F., Salas, E., and Cannon-Bowers, J. A. (2000). The influence of shared mental models on team process and performance. *J. Appl. Psychol.* 85, 273–283. doi: 10.1037/0021-9010.85.2.273

Mathieu, J. E., Maynard, M. T., Rapp, T., and Gilson, L. (2008). Team effectiveness 1997-2007: a review of recent advancements and a glimpse into the future. *J. Manag.* 34, 410–476. doi: 10.1177/0149206308316061

Mohammed, S., and Dumville, B. C. (2001). Team mental models in a team knowledge framework: expanding theory and measurement across disciplinary boundaries. *J. Organ. Behav.* 22, 89–106. doi: 10.1002/job.86

Mohammed, S., Ferzandi, L., and Hamilton, K. (2010). Metaphor no more: a 145-year review of the team mental model construct. *J. Manag.* 36, 876–910. doi: 10.1177/0149206309356804

Moon, H., Hollenbeck, J. R., Humphrey, S. E., Ilgen, D. R., West, B., Ellis, A. P. J., et al. (2004). Asymmetric adaptability: dynamic team structures as one-way streets. *Acad. Manage. J.* 47, 681–695. doi: 10.2307/20159611

Moreland, R. L., Argote, L., and Krishnan, R. (1998). "Training people to work in groups," in *Theory and Research on Small Groups*, eds R. S. Tindale, L. Heath, J. Edwards, E. J. Posavac, F. B. Bryant, Y. Suarez-Balcazar, et al. (New York, NY: Plenum Press), 37–60. doi: 10.1007/0-306-47144-2_3

Moreland, R. L., and Levine, J. M. (2001). "Socialization in organizations and work groups," in *Groups at work: Theory and Research*, ed. M. E. Turner, (Mahway, NJ: Lawrence Erlbaum Associates), 69–112.

Nieva, V. F., Fleishman, E. A., and Rieck, A. M. (1978). *Team Dimensions: Their Identity, Their Measurement, and Their Relationships*. Washington, DC: ARRO.

Preacher, K., and Hayes, A. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behav. Res. Methods* 36, 717–731. doi: 10.3758/bf03206553

Resick, C. J., Murase, T., Bedwell, W. L., Sanz, E., Jiménez, M., and DeChurch, L. A. (2010). Mental model metrics and team adaptability: a multi-facet multi-method examination. *Group Dyn. Theory Res. Pract.* 14, 332–349. doi: 10.1037/a0018822

Rico, R., Sánchez-Manzanares, M., Gil, F., and Gibson, C. (2008). Team implicit coordination processes: a team knowledge-based approach. *Acad. Manag. Rev.* 33, 163–184. doi: 10.5465/amr.2008.27751276

Rosen, M. A., Bedwell, W. L., Wildman, J. L., Fritzsche, B. A., Salas, E., and Burke, C. S. (2011). Managing adaptive performance in teams: guiding principles and behavioral markers for measurement. *Hum. Resour. Manag. Rev.* 21, 107–122. doi: 10.1016/j.hrmr.2010.09.003

Salas, E., Rosen, M. A., Burke, C. S., and Goodwin, G. F. (2009). "The wisdom of collectives in organizations: an update of the teamwork competencies," in *Team Effectiveness in Complex Organizations: Cross-Disciplinary Perspectives and Approaches*, eds E. Salas, G. F. Goodwin, and C. S. Burke, (New York, NY: Routledge), 39–79.

Sieweke, J., and Zhao, B. (2015). The impact of team familiarity and team leader experience on team coordination errors: a panel analysis of professional basketball teams. *J. Organ. Behav.* 36, 382–402. doi: 10.1002/job.1993

Smith-Jentsch, K. A. (2007). The impact of making targeted dimensions transparent on relations with typical performance predictors. *Hum. Perform.* 20, 187–203. doi: 10.1080/08959280701332992

Smith-Jentsch, K. A. (2009). "Measuring team-related cognition: the devil is in the details," in *Team Effectiveness in Complex Organizations : Cross-Disciplinary Perspectives and Approaches*, eds E. Salas, G. F. Goodwin, and C. S. Burke, (New York, NY: Routledge), 491–508.

Smith-Jentsch, K. A., Campbell, G. E., Milanovich, D. M., and Reynolds, A. M. (2001). Measuring teamwork mental models to support training needs assessment, development, and evaluation: two empirical studies. *J. Organ. Behav.* 22, 179–194. doi: 10.1002/job.88

Smith-Jentsch, K. A., Kraiger, K., Cannon-Bowers, J. A., and Salas, E. (2009). Do familiar teammates request and accept more backup? Transactive memory in air traffic control. *Hum. Fact.* 51, 181–192. doi: 10.1177/0018720809335367

Smith-Jentsch, K. A., Mathieu, J. E., and Kraiger, K. (2005). Investigating linear and interactive effects of shared mental models on safety and efficiency in a field setting. *J. Appl. Psychol.* 90, 523–535. doi: 10.1037/0021-9010.90.3.523

Steiner, I. (1972). *Group Process and Productivity*. New York, NY: Academic Press.

Stout, R. J., Cannon-Bowers, J. A., Salas, E., and Milanovich, D. M. (1999). Planning, shared mental models, and coordinated performance: an empirical link Is established. *Hum. Fact.* 41, 61–71. doi: 10.1518/001872099779577273

Summers, J. K., Humphrey, S. E., and Ferris, G. R. (2012). Team member change, flux in coordination, and performance: effects of strategic core roles, information transfer, and cognitive ability. *Acad. Manag. J.* 55, 314–338. doi: 10.5465/amj.2010.0175

Sutton, R. I., and Louis, M. R. (1987). How selecting and socializing newcomers influences insiders. *Hum. Resour. Manag.* 26, 347–361. doi: 10.1002/hrm.3930260304

Tannenbaum, S. I., Mathieu, J. E., Salas, E., and Cohen, D. (2012). Teams are changing: are research and practice evolving fast enough? *Ind. Organ. Psychol.* 5, 2–24. doi: 10.1111/j.1754-9434.2011.01396.x

Uitdewilligen, S., Waller, M. J., and Pitariu, A. H. (2013). Mental model updating and team adaptation. *Small Group Res.* 44, 127–158. doi: 10.1177/1046496413478205

US Department of Labor Bureau of Labor Statistics, (2011). *Mass layoffs-October 2011*. Available at: http://www.bls.gov/news.release/archives/mmls_11222011.pdf (accessed December 1, 2011).

Waller, M. J. (1999). The timing of adaptive group responses to nonroutine events. *Acad. Manag. J.* 42, 127–137. doi: 10.5465/257088

Waller, M. J., Gupta, N., and Giambatista, R. C. (2004). Effects of adaptive behaviors and shared mental models on control crew performance. *Manag. Sci.* 50, 1534–1544. doi: 10.1287/mnsc.1040.0210

Waller, M. J., Okhuysen, G. A., and Saghafian, M. (2016). Conceptualizing emergent states: a strategy to advance the study of group dynamics. *Acad. Manag. Ann.* 10, 561–598. doi: 10.5465/19416520.2016.1120958

Webber, S. S., Chen, G., Payne, S. C., Marsh, S. M., and Zaccaro, S. J. (2000). Enhancing team mental model measurement with performance appraisal practices. *Organ. Res. Methods* 3, 307–322. doi: 10.1177/109442810034001

Wegner, D. M. (1986). "Transactive memory: a contemporary analysis of the group mind," in *Theories of Group Behavior*, eds B. Mullen, and G. R. Goethals, (New York, NY: Springer-Verlag), 185–208. doi: 10.1007/978-1-4612-4634-3_9

Zajac, S., Gregory, M. E., Bedwell, W. L., Kramer, W. S., and Salas, E. (2014). The cognitive underpinnings of adaptive team performance in ill-defined task situations: a closer look at team cognition. *Organ. Psychol. Rev.* 4, 49–73.

Zijlstra, F. R., Waller, M. J., and Phillips, S. I. (2012). Setting the tone: early interaction patterns in swift-starting teams as a predictor of effectiveness. *Eur. J. Work Organ. Psychol.* 21, 749–777. doi: 10.1080/1359432X.2012.690399

Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Bedwell. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

REVIEW
published: 21 November 2019
doi: 10.3389/fpsyg.2019.02571

The Behavioral Biology of Teams: Multidisciplinary Contributions to Social Dynamics in Isolated, Confined, and Extreme Environments

*Lauren Blackwell Landon[1], Grace L. Douglas[2], Meghan E. Downs[3], Maya R. Greene[4], Alexandra M. Whitmire[5], Sara R. Zwart[6] and Peter G. Roma[1]**

[1]Behavioral Health & Performance Laboratory, Biomedical Research and Environmental Sciences Division, Human Health and Performance Directorate, KBR/NASA Johnson Space Center, Houston, TX, United States, [2]Advanced Food Technology, Human Systems Engineering and Development Division, Human Health and Performance Directorate, NASA Johnson Space Center, Houston, TX, United States, [3]Human Physiology, Performance, Protection, and Operations Laboratory, Biomedical Research and Environmental Sciences Division, Human Health and Performance Directorate, KBR/NASA Johnson Space Center, Houston, TX, United States, [4]Usability Testing and Analysis Facility, Human Systems Engineering and Development Division, Human Health and Performance Directorate, KBR/NASA Johnson Space Center, Houston, TX, United States, [5]Human Factors and Behavioral Performance Element, Human Research Program, NASA Johnson Space Center, Houston, TX, United States, [6]Nutritional Biochemistry Laboratory, Biomedical Research and Environmental Sciences Division, Human Health and Performance Directorate, University of Texas Medical Branch/NASA Johnson Space Center, Houston, TX, United States

OPEN ACCESS

Edited by:
Richard Eleftherios Boyatzis, Case Western Reserve University, United States

Reviewed by:
Ronald Stevens, University of California, Los Angeles, United States
Michael Rosen, Johns Hopkins Medicine, United States

***Correspondence:**
Peter G. Roma
peteroma@gmail.com;
pete.roma@nasa.gov

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: 12 December 2018
Accepted: 30 October 2019
Published: 21 November 2019

Citation:
Landon LB, Douglas GL, Downs ME, Greene MR, Whitmire AM, Zwart SR and Roma PG (2019) The Behavioral Biology of Teams: Multidisciplinary Contributions to Social Dynamics in Isolated, Confined, and Extreme Environments. Front. Psychol. 10:2571. doi: 10.3389/fpsyg.2019.02571

Teams in isolated, confined, and extreme (ICE) environments face many risks to behavioral health, social dynamics, and team performance. Complex long-duration ICE operational settings such as spaceflight and military deployments are largely closed systems with tightly coupled components, often operating as autonomous microsocieties within isolated ecosystems. As such, all components of the system are presumed to interact and can positively or negatively influence team dynamics through direct or indirect pathways. However, modern team science frameworks rarely consider inputs to the team system from outside the social and behavioral sciences and rarely incorporate biological factors despite the brain and associated neurobiological systems as the nexus of input from the environment and necessary substrate for emergent team dynamics and performance. Here, we provide a high-level overview of several key neurobiological systems relevant to social dynamics. We then describe several key components of ICE systems that can interact with and on neurobiological systems as individual-level inputs influencing social dynamics over the team life cycle—specifically food and nutrition, exercise and physical activity, sleep/wake/work rhythms, and habitat design and layout. Finally, we identify opportunities and strategic considerations for multidisciplinary research and development. Our overarching goal is to encourage multidisciplinary expansion of team science through (1) prospective horizontal integration of variables outside the current bounds of team science as significant inputs to closed ICE team systems and (2) bidirectional vertical integration of biology as the necessary inputs and mediators of individual and team behavioral health and performance. Prospective efforts to account for the behavioral biology of teams in ICE settings through an integrated organizational neuroscience approach will enable the field of team science to better understand and support teams who work, live, serve, and explore in extreme environments.

Keywords: social dynamics, extreme environment, neurobiology, behavioral health, team performance, multidisciplinary

Teams that work, live, and serve in isolated, confined, and extreme (ICE) environments face many threats to behavioral health, social dynamics, and team performance over time (Landon et al., 2018). In the prototypical long-duration ICE environment—space exploration—as well as military deployments, remote work outposts, and other high-risk operational settings, teams must adapt to multiple interacting risks from the surrounding external environment, the constructed operational environment, the social environment, and individual-level vulnerabilities (Goswami et al., 2012; Roma and Bedwell, 2017).

In recognition of the critical and increasing importance of team-based work throughout society, including ICE operations, the field of team science has experienced rapid growth in recent years (DeChurch et al., 2018; Goodwin et al., 2018). Led largely by the Industrial/Organizational (I/O) subfield of Psychology, an appreciation for the complexity of teams in operational environments has enabled the innovative integration of theories, models, methods, and metrics from engineering and computer science, sociology, and other fields within the social sciences to enrich the understanding of social behavior and team performance. One of the major conceptual innovations that has come to define the field of team science is the Input-Mediator-Outcome-Input model of team dynamics (IMOI; Ilgen et al., 2005). Inspired by general systems theory, the IMOI model is a framework of how teams operate and change over time. The model is conceptualized as a flow from inputs (I) to mediators (M) to outputs (O), which then become inputs (I) for subsequent team performance cycles. Individual-level inputs include factors such as the team members' respective personalities, knowledge, skills, abilities, and learning histories. Team-level inputs include group size, composition, roles, and leadership structure. Organizational-level inputs include the industry (e.g., corporate, military, and athletic) and operational context (e.g., office, virtual, and field site). Together, these inputs contribute to and interact with multiple emergent mediating phenomena that influence social dynamics, team performance outputs, and organizational outcomes. Mediators include team affective states (e.g., cohesion, confidence, and trust), behavioral processes (e.g., transition, action, and interpersonal behaviors), and cognitive processes (e.g., team learning, shared mental models, and transactive memory systems; Kozlowski and Ilgen, 2006; Fiore et al., 2015). Outputs include individual- and team-level performance, health and well-being, and organizational outcomes such as mission success, safety, and profitability. As a mission continues over time, the team repeats these performance episodes, with the outputs of each episode feeding back to shape the team's mediating processes and states while becoming a contextual input for the next episode.

Although the structure of the IMOI model is largely agnostic to content, its manifestation within team science quite naturally focuses on input and mediator variables from the social and behavioral sciences from which it originated. However, at its most extreme, ICE operational settings are fully closed systems with tightly coupled, or highly interconnected, components (Perrow, 1984), i.e., fully autonomous microsocieties within isolated ecosystems involving far more than just the psychological processes of the inhabitants (Brady, 1990, 2005; Gitelson et al., 2003; Anker, 2005; Emurian et al., 2009; Checinska et al., 2015). Tightly coupled systems are those in which an unexpected occurrence can have an immediate and pervasive impact on the other parts of the system (Perrow, 1984). Systems with redundancy and flexibility between components, including input from outside the system, allow the system to be more resilient to disruptions; however, complexity of the system can also increase risk. A fully closed system with no outside input has even less flexibility than tightly coupled systems and potentially greater ripple effects of a disruption throughout the system. Insofar as ICE mission environments are closed systems, they are inherently "multidisciplinary" in that all components of the system—regardless of their scientific origins—can interact and potentially influence team dynamics through direct or indirect pathways. Thus, a primary goal of this article is to highlight several critical components of ICE mission environments that are outside the traditional bounds of team research, and how they may impact social dynamics and team performance over time as individual inputs in the IMOI model. Specifically, we discuss food and nutrition, exercise and physical activity, sleep/wake/work rhythms, and habitat design and layout. The purpose of this review is to encourage multidisciplinary horizontal integration of team science with fields relevant to ICE environments whose primary focus is not behavior, cognition, and social dynamics, but whose topics of focus can indirectly and directly impact team performance as individual-level inputs.

Our discussion of multidisciplinary contributions to social dynamics in ICE environments is firmly rooted in biology, on the premise that the brain is the nexus of individual-level inputs in the IMOI or any model of human functioning and thus worthy of systematic consideration in the science of teams. However, this emphasis on biological mechanisms is explicitly on inclusion and integration, not radical reductionism attempting to define behavioral, cognitive, and social phenomena as exclusively neurobiological (Ashkanasy et al., 2014). That said, even if the brain and associated neurobehavioral systems are not sufficient to define team phenomena, they are the necessary substrate from which team processes and social dynamics emerge (Krakauer et al., 2017; Killeen, 2018). Despite this, the proximal biological mechanisms of team performance and adaptation to extreme environments have received relatively little attention within team science (Golden et al., 2018; Maynard et al., 2018; Salas et al., 2018). This may be an artifact of I/O Psychology's extension to "higher" levels of analysis, building off Psychology's focus on behavior and cognition in individuals and small groups to incorporate multi-level frameworks including multi-team systems, organizations, cultures, societies, and related constructs (Kozlowski and Klein, 2000; Ilgen et al., 2005). By contrast, the subfield of Biological Psychology (including Social Neuroscience) shares I/O's core interest in behavior and cognition in individuals and small groups but extends into "lower" levels of analysis, drawing from the natural sciences in the biomedical tradition to incorporate factors such as physiological systems, brain circuits, neurochemicals, and genetics. Consequently, another goal of this article is to not only encourage expanding team science through horizontal integration across disciplines but also encourage bidirectional vertical integration of multiple levels of analysis from the molecular through the societal in support of further

development of an "organizational neuroscience" (cf. Becker and Cropanzano, 2010; Lee et al., 2012; Foxall, 2014a,b; Murray and Antonakis, 2019; **Figure 1**). Such an integrated approach is especially relevant for the application of team science to the tightly coupled closed systems of long-duration ICE settings, where the behavioral biology of teams is effectively defined by both horizontal and vertical factors continuously interacting and converging on the brain to influence individual and team behavioral health and performance over time (**Figure 2**).

The following sections first provide a selective overview of several core neurobiological systems relevant to individual and team behavioral health and performance within the closed systems of isolated, confined, and extreme operational environments. We then describe several key components of ICE systems that can interact with and on individual neurobiological systems to affect social dynamics—specifically food and nutrition, exercise and physical activity, sleep/wake/work rhythms, and habitat design and layout. Using long-duration space exploration missions as a prototypical ICE team setting, we consider how each of these disciplines may inform team researchers to understand ICE teams from a systemic, biological perspective, particularly as social dynamics develop over the life cycle of a team. Finally, we discuss opportunities and strategic considerations for prospective integrated multidisciplinary team research for ICE environments.

CORE NEUROBEHAVIORAL MECHANISMS FOR ISOLATED, CONFINED, AND EXTREME TEAMS

Humans are demonstrably capable of thriving in a wide variety of environments, so it comes as no surprise that we have evolved complex neurobehavioral systems for perceiving, responding, and adapting to the physical and social contexts in which we live, work, and explore. However, by their very nature, ICE environments are only extreme because they diverge in many ways from environments in which humans naturally thrive, and indeed, the brain provides an extraordinarily rich target for all components of ICE environments to profoundly affect individual and team behavioral health, performance, and social dynamics. To this end, we provide a brief and simplified overview of selected neurobiological systems underlying individual and team adaptation to ICE environments. These systems serve not only as both direct and indirect targets of the various input variables described in subsequent sections of this article but also as potential targets for countermeasure development to monitor, maintain, and enhance team dynamics in ICE mission settings.

To help guide the discussion, we refer to the National Institute of Mental Health's (NIMH) Research Domain Criteria (RDoC) framework (Cuthbert and Kozak, 2013)[1]. Although the primary goal of RDoC is to elucidate the nature of mental health and illness, it does so not through a traditional symptom/category-based clinical diagnostic approach but rather by defining the degree of (dys) function of core overlapping neurobehavioral systems ("domains") applicable to all individuals, teams, and situations (Clark et al., 2017). The six domains include the

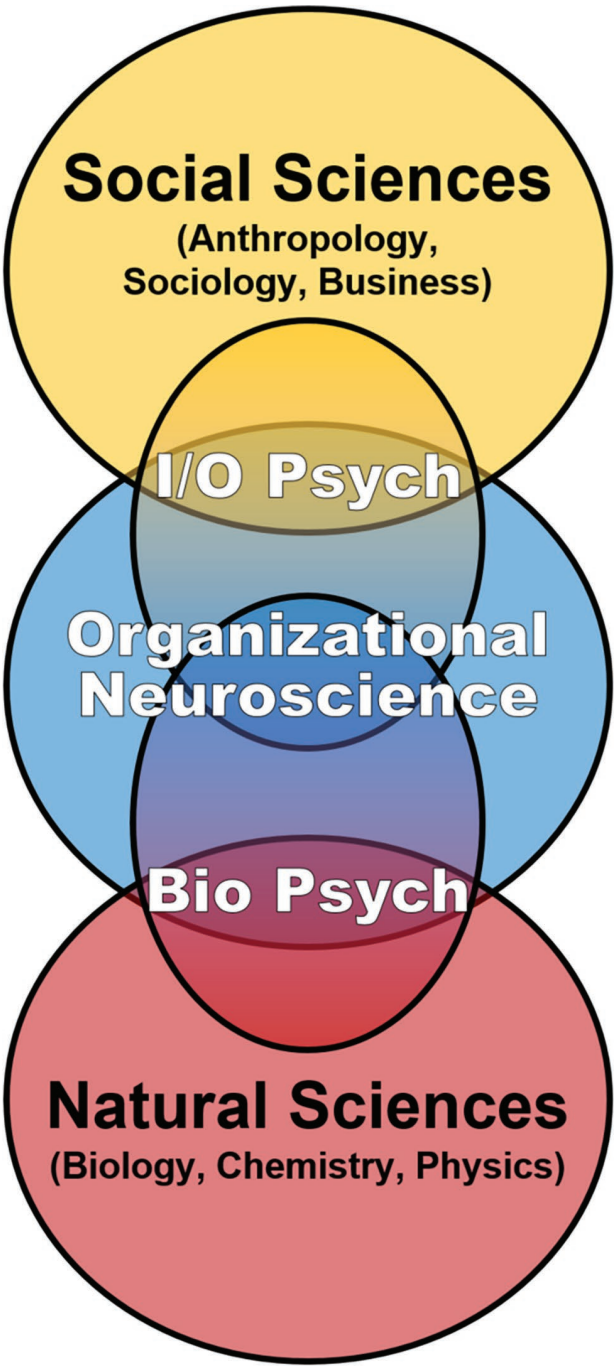

FIGURE 1 | Team science is currently dominated by the Industrial/Organizational subfield of Psychology, which skillfully integrates multi-level frameworks, concepts, and methods from the social sciences. We support bidirectional vertical expansion of team science toward further development of organizational neuroscience that includes multiple biological levels of analysis to more fully understand individual and team functioning over time in the inherently integrated setting of isolated, confined, and extreme environments.

[1]https://www.nimh.nih.gov/research-priorities/rdoc/index.shtml

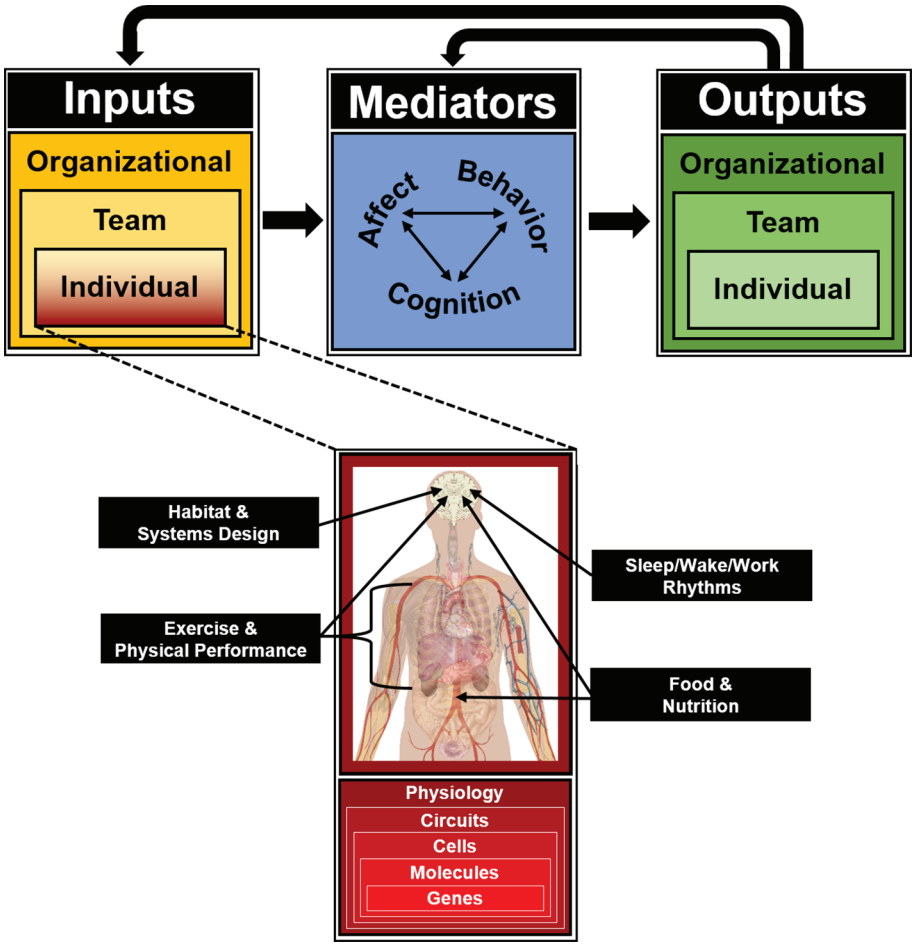

FIGURE 2 | Input-Mediator-Output-Input (IMOI) model of team function for isolated, confined, and extreme operational environments, adapted to reflect "horizontal" integration of individual input variables inherent to ICE settings but outside the founding disciplines of team science, and "vertical" integration of multiple biological levels of analysis as targets and substrates for all individual inputs to the team system as an integrated approach toward the behavioral biology of teams.

physical functions of the *Arousal and Regulatory Systems* (including sleep-wakefulness and circadian rhythms) and *Sensorimotor* (including action initiation and inhibition) domains, as well as the psychological and social domains of *Negative Valence* (including fear, anxiety, and loss), *Positive Valence* (including reward responsiveness and reinforcement), *Cognitive* (including memory and cognitive control), and *Social Processes* (including affiliation and communication). Although RDoC is an evolving framework continuously undergoing review and revision as the underlying science advances, a defining feature is that each domain's function is characterized through multiple levels of influence from genes, molecules, cells, circuits, and physiological systems through to observable behaviors. For the sake of brevity, we focus our discussion on behavioral and physiological outputs, primary brain circuits and structures, and associated neurochemicals underlying key constructs within and across domains, and how they may relate to IMOI team systems in extreme environments. Subsequent sections describing team implications of food and nutrition, exercise and activity, sleep/wake/work rhythms, and habitat design include relevant biological mechanisms, and we consider potential pathways by which those factors may impact core neurobehavioral systems as individual-level inputs affecting team behavioral health and performance in ICE environments.

Arousal/Regulatory and Sensorimotor Systems

The systems of the arousal/regulatory and sensorimotor domains serve essential biobehavioral functions, most notably sleep-wakefulness rhythms and physical movement. In a team mission context, wakefulness and sufficient attentional and physical capacity are required for functional presence and participation in any team processes and activities. Beyond presence vs. absence, individual differences in sleep-wake rhythms and interactions with mission schedules and features of the constructed environment can impact team dynamics as individual- or team-level inputs to the IMOI model. Biologically, perhaps the most critical brain structure regulating sleep/wake rhythms is the suprachiasmatic nucleus (SCN) within the hypothalamus. Light-sensitive cells in the retina project the

excitatory neurotransmitter glutamate directly to the SCN, which help entrain the SCN's rhythm as the brain's "master clock" governing release of melatonin from the pineal gland to promote sleep (Ebling, 1996; Altun and Ugur-Altun, 2007; Dubocovich, 2007). The SCN also receives input of the neurotransmitter serotonin from the dorsal raphe nucleus in the brainstem, which attenuates light-induced shifts in circadian phase (Rosenwasser, 2009). On the opposite end of the sleep-wake spectrum, sustained attention is critically dependent on the neurotransmitter acetylcholine projected from the basal forebrain to multiple areas of the cortex involved in sensorimotor and cognitive processing (Sarter et al., 2001). Although these mechanisms are often associated with the basic functions of sleep-wake rhythms, many hormones relevant to team behavioral health and performance (as described in subsequent sections) also exhibit natural circadian rhythms, including cortisol, testosterone, and oxytocin (Amico et al., 1983; Haus, 2007), which could systematically impact team dynamics based on scheduling as an organizational-level input to an IMOI team system. At the extreme end, circadian rhythm disturbances in sleep-wake patterns, hormones, and mood states are associated with, if not diagnostic of, psychiatric disorders including major depression, bipolar disorder, and schizophrenia (Cohrs, 2008; Vadnie and McClung, 2017; Pilz et al., 2018), which could profoundly impair team functioning and mission success in closed system ICE environments.

Under more conscious control are the sensorimotor systems largely responsible for the control, execution, and inhibition of motor behaviors. In a team mission context, this manifests in the overt physical performance of individual and team tasks and activities, and within the IMOI model could serve as an individual-level ability input potentially affecting mediating behaviors and team performance outcomes. These largely neuromuscular processes are regulated in the brain by the motor cortex, which projects to the basal ganglia in the midbrain, the brainstem, and spinal cord, terminating on motoneurons innervating muscles to execute movement (Lemon, 2008). Neural projections from the motor cortex largely discharge the excitatory neurotransmitter glutamate, with the basal ganglia and brainstem regions projecting the inhibitory neurotransmitter gamma-amino butyric acid (GABA), which disinhibits motoneurons, thereby allowing the release of acetylcholine to stimulate muscle activity (Sian et al., 1999; Grillner, 2015).

Negative and Positive Valences

Moving to domains with more direct connections to behavioral health and social dynamics, the negative valence domain encompasses fear, anxiety, frustration, and loss. Within an IMOI context, variations in these systems may be considered abilities serving as individual-level inputs that contribute to the mediators of emergent team processes, affect, behaviors, and cognitions. Behavioral markers of fear, anxiety, and arousal include avoidance, social withdrawal, and characteristic facial and vocal expressions (or blunting thereof), whereas physiological outputs include increased heart rate, decreased heart rate variability, elevated and/or sustained levels of the hormone cortisol and neurotransmitters epinephrine and norepinephrine (defining features of the "fight or flight" stress response), increased inflammatory molecules [e.g., interleukins 1 and 6 (IL-1, IL-6), tumor necrosis factor alpha (TNF-α), C-reactive protein], and reduced nerve growth factors such as brain-derived neurotrophic factor (BDNF; Berntson et al., 1997; Phillips et al., 1998; Howren et al., 2009; Dowlati et al., 2010; Jaggar et al., 2019).

Critical to negative valence processes is the limbic system, a primitive set of structures seated deep within the brain that includes the bed nucleus of the stria terminalis (BNST), amygdala, and hippocampus (Lebow and Chen, 2016). Various clusters of cells (nuclei) within each structure receive and produce an array of neurochemicals that regulate projections to other structures and subsequent subjective, behavioral, and physiological responses to environmental and social stimuli. The BNST is subject to input from the neurotransmitters serotonin and dopamine, steroid hormones (estrogen and testosterone), and oxytocin and releases the inhibitory neurotransmitter GABA in projections to the hypothalamus. The amygdala is responsive to the excitatory neurotransmitter glutamate as well as estrogen hormones, opioid peptides, and oxytocin. Among other functions, the amygdala releases glutamate and corticotropin-releasing hormone (CRH) in projections to the hypothalamus (LeDoux, 2007; Myers and Greenwood-VanMeerveld, 2009). The amygdala, hippocampus, and hypothalamus all receive serotonin input from the dorsal raphe nucleus of the brainstem, with increased serotonin associated with the reallocation of energy and attention toward the precipitating aversive stimuli and reduced receptivity to positive stimuli (Andrews et al., 2015). Of particular relevance to ICE environments are connected with the hypothalamus, which is the leading point of the hypothalamic–pituitary–adrenal (HPA) axis of the biobehavioral stress system. Here, in anticipation of or response to a perceived threat or other excitation, CRH is released from the hypothalamus and binds to the pituitary gland, which releases andrenocorticotrophic hormone (ACTH). ACTH then enters and travels in the bloodstream until it binds to the adrenal glands to stimulate the release of cortisol and epinephrine; cortisol then returns to the hypothalamus in a negative feedback loop to dampen further activation (Pariante and Lightman, 2008). Although acute stress can provide transient boosts to physical and cognitive performance and immunity (Leonard, 2005), chronic stress and trauma can alter the structure and function of these mechanisms, with HPA axis dysregulation associated with myriad physical and neuropsychiatric conditions, including mood and anxiety disorders, cardiometabolic disease, post-traumatic stress, immune dysfunction, and dementia risk (Yehuda, 2001; Padgett and Glaser, 2003; Byers and Yaffe, 2011; Gianaros et al., 2015).

The negative valence domain and systems may dominate discussions of mission risk; however, the positive valence domain is no less relevant to social dynamics and team performance in ICE settings. Within an IMOI team model, the systems underlying positive valence could also be conceptualized as abilities serving as individual-level inputs, particularly critical to enable the reward and reinforcement processes necessary to build and sustain mediators of effective team processes and positive emergent states that feed into performance outcomes.

Behavioral and physiological markers of positive valence are largely the reverse of those characterizing negative valence, i.e., approach behavior and social engagement, characteristic facial and vocal expressions, and reduced activation and/or persistence of physiological stress responses. Circuitry unique to the reward and reinforcement processes involves the mesolimbic reward pathway in the midbrain, featuring the ventral tegmental area (VTA) and nucleus accumbens (NAcc). The experience of pleasure, desire, and active pursuit of a wide variety of reinforcers (e.g., food, water, sex, social interaction, drugs, and art) includes GABA and glutamate input to the VTA, which projects dopamine to the NAcc. Dopamine release from the VTA to NAcc is a characteristic neurobiological definition of reward (Salamone et al., 2005); however, this circuit also connects to the negative valence systems, with inhibitory GABA projections to the BNST, amygdala, and hypothalamus (Salgado and Kaplitt, 2015). Structural and functional aberrations in the reward circuit, including decreased dopamine response to rewards and increased activation of the endogenous opioid system, are associated with anhedonia, addiction risk, social behavior deficits, and mood disorders (Nestler and Carlezon, 2006; Heller et al., 2009; Berridge and Kringelbach, 2015; Supekar et al., 2018).

Cognition and Social Processes

The cognitive domain and associated mechanisms play a role throughout the team lifecycle, with key constructs including memory and cognitive control. The ability to acquire, retain, and recall learned knowledge, skills, and abilities is fundamental for individual and team functioning, particularly in high-performing teams operating in complex mission environments. Clearly, any moderating team cognitive processes such as shared mental models and transactive memory systems would depend on the integrity of the mechanisms enabling memory as individual-level inputs to an IMOI team system. Biologically, declarative memory (representations of facts, events, places, and people) is most associated with the hippocampus, which is part of the limbic system. Accordingly, its connections with the amygdala enable emotional input during encoding and emotional elicitation during recall/expression (Squire, 1992), with recall/reinstatement dependent on the neocortex (McClelland et al., 1995). Key neurochemicals underlying cognitive processing include acetylcholine, glutamate, epinephrine, opioid peptides, and GABA (McGaugh, 1992). A brain region especially relevant to cognitive control and virtually all neurobehavioral domains is the prefrontal cortex (PFC; Fuster, 2001). Evolutionarily speaking, it is a relatively new structure compared to the limbic, midbrain, and brainstem regions and is especially prominent in humans. The PFC receives and integrates input from all sensory and motor regions, as well as the limbic system (Miller and Cohen, 2001). The PFC also projects throughout the brain, including extensive interactions with the hippocampus in the processing and recall of both recent and remote memories and excitatory glutamate projections from the orbitofrontal region of the PFC to the NAcc in reward processing (Lynch, 2004; Frankland and Bontempi, 2005). The PFC is largely known for its role in integrating information and regulating executive function required for judgment and decision making, abstract reasoning and concept formation, and planning for the future and is a major source of inhibitory control throughout the brain. Recent work relevant to both the negative valence and social process domains suggests a relationship between decreased structural and functional integrity of the right orbitofrontal, left dorsolateral, and anterior cingulate cortex regions of the PFC and increased antisocial, violent, and psychopathic behavior (Yang and Raine, 2009), any of which could constitute a critical threat to mission success in ICE operations.

Finally, the social processes domain is clearly related to social dynamics and team performance, with its key constructs of affiliation/attachment and communication. Within an IMOI system, receptivity and capacity for affiliation and effective communication are core skills and abilities for individual team members in the mixed work/social setting of long-duration missions in ICE environments (Landon et al., 2017, 2018; Roma and Bedwell, 2017) and serve as essential individual- and team-level inputs to virtually all mediating team processes, emergent states, and behaviors. Biologically, perhaps the best-known mechanism involved in social processes is the hormone oxytocin. Oxytocin in the brain is produced by cells in the hypothalamus (Lemos, 2012), released *via* the posterior pituitary gland, and binds to receptors in the BNST, amygdala, NAcc, and hippocampus (Boccia et al., 2013). Acute oxytocin reportedly increases gaze to the eye region of human faces, increases trust, improves the ability to infer emotional states in others from facial cues, and enhances the stress-reducing effects of social support (Heinrichs et al., 2003; Ross and Young, 2009), presumably through reduction in social anxiety enabled by the aforementioned projections to the limbic system (Feldman, 2012). However, oxytocin and the social affiliation it enables are not always positive, as oxytocin can strengthen in-group bonds at the expense of out-group relationships, including increased deception and ethnocentrism toward those perceived as "others" (Bartz et al., 2011; De Dreu et al., 2011; Eckstein et al., 2014; Shalvi and De Dreu, 2014). In addition to oxytocin, gonadal hormones progesterone and testosterone are also relevant to social cognition and processes. Although these hormones are produced outside the brain, they can easily pass the blood-brain-barrier and bind to structures such as the BNST, amygdala, hypothalamus, and NAcc. Despite their traditional association with reproductive behaviors, mood, and aggression, recent evidence also suggests that these hormones play a moderating role in human social dynamics, group stability maintenance, and team effectiveness. Specifically, higher progesterone is associated with lower emotion recognition and stronger affective responses to faces (Derntl et al., 2013), whereas higher testosterone is associated with increased fairness behaviors, higher social status, and social inclusion (Edwards et al., 2006; Eisenegger et al., 2010, 2011; Seidel et al., 2013; although see Zyphur et al., 2009).

Taken together, even with this intentionally limited and simplified review of key neurobehavioral domains relevant to individual and team behavioral health and performance in ICE environments, it should be clear that the brain is an extraordinarily complex system unto itself. Indeed, this

multileveled and interactive complexity is in part what enables humans to adapt to such a wide variety of physical, social, and environmental demands. However, the complexity and interconnectedness of these neurobiological systems also make them subject to modification by those very same demands, especially in ICE settings. The following sections describe the importance of several critical components of ICE systems outside the traditional team science disciplines, and how those factors may act on our core neurobehavioral systems to affect and be affected by social dynamics in ICE environments over time.

MULTIDISCIPLINARY CONTRIBUTIONS TO ISOLATED, CONFINED, AND EXTREME TEAMS

Food and Nutrition

Overview of Food and Nutrition

Any operational environment in which people live must include a food system. In addition to the obvious necessity of food to sustain life, the food system has two core roles in supporting human psychosocial health. First, adequate intake, absorption, and utilization of specific nutrients are essential to promote behavioral health and cognitive function on a biochemical level directly or through influence of the gut microbiome. Second, food has a social role as a shared activity, providing a familiar comfort for mealtime gatherings that may become increasingly important in isolation and confinement where other comforts and reminders of home are not available. Food variety, availability, quality, nutrient stability, ease of preparation, dining accommodations, and timing of meals all impact adequate food and nutritional intake and associated behavioral health and social cohesion, as reported previously in reviews of food systems in military, spaceflight, and historic exploration settings (Marriott, 1995; Stuster, 1996, 2016; Douglas et al., 2016).

Space food to date has been processed and individually packaged to support multi-year shelf stability and ease of preparation. Refrigeration is not available for foods on the International Space Station (ISS), with extremely limited availability of fresh produce only when a resupply vehicle docks, which will likely not be available during exploration class missions to Mars. Astronauts on the ISS consume a standard menu and only receive a small selection of shelf-stable personal preference items; therefore, it is restricted in both quantity and variety. Customization of space foods from the standard menu is limited to the addition of condiments and selection of foods within the standard menu food containers. Crew members are not required to consume a specific menu each day, but they are constrained by availability of foods and their crew mates' likes and dislikes. For example, if a crew member likes one specific food item, that food item will only appear in the standard food containers 2–3 times every 7–9 days. Crews are permitted to open a new set of standard menu food containers every 7–9 days, depending on the caloric requirements of the crew during each mission (Douglas et al., 2016).

Nutrition and Social/Team Factors

Specific Nutrients That Affect Individual Mood and Behavior

Nutritional deficits can affect the pathophysiology of mood disorders including depression, which can in turn affect individual performance within a team, healthy, and constructive team interactions, and may cause the withdrawal of that individual from team activities. Zinc deficiency is one example of an essential nutrient for maintenance of normal brain function and has been associated with increased depressive-like and anxiety-related behavior (Roohani et al., 2013; Mitsuya et al., 2015). In addition, low vitamin D status and insufficient omega-3 fatty acids are others that are associated with mood disorders because of their link with the production and action of serotonin, a neurochemical that is typically lower in major and bipolar depression, schizophrenia, and other mood disorders (Patrick and Ames, 2015). Not only do vitamin D receptors exist in the brain, but also low vitamin D status has been shown to negatively affect neural activity and cellular activity in the brain (McCann and Ames, 2008). A higher vitamin D status (serum 25-hydroxyvitamin D) has been demonstrated to significantly reduce risk for depression (Ju et al., 2013); however, vitamin D supplementation studies that have looked at effects on depression have mixed results. Vitamin D has a more profound effect on mitigating symptoms in cases of more severe depression and lower vitamin D status (Shaffer et al., 2014). Several epidemiological studies have found inverse correlations between oily fish consumption and bipolar or depressive symptoms (Grosso et al., 2014).

With increased ionizing radiation exposure on deep space exploration missions, blood-brain barrier function needs to be considered for nutrients that are concentrated in the brain *via* active transport processes. One example is the B-vitamin folate. A compromised blood-brain barrier due to chronic low-dose ionizing radiation exposure or other factors could lead to cerebral folate insufficiency, which has been associated with many neuropsychiatric disorders including depression and schizophrenia (Molero-Luis et al., 2015).

Not only does nutrient intake directly affect nutrient status and behavioral health, but also the nutritional adequacy of the diet is a prime influence on the composition of the gastrointestinal (GI) microbiome (David et al., 2014). GI microbes metabolize available components of the diet, including those indigestible to humans (e.g., fiber and flavonoids not absorbed in the small intestine from fruits and vegetables), into short chain fatty acids, peptides, phenolic acids, and neurotransmitters that may impact social behavior, memory, and cognition through the gut-brain axis (Stilling et al., 2014; Dinan and Cryan, 2017; Vuong et al., 2017; Tengeler et al., 2018). For instance, some *Lactobacillus* species used in food fermentations are capable of producing GABA (Barrett et al., 2012; Ribeiro et al., 2018), which may be associated with reduced anxiety and depression through its actions on the negative valence mechanisms described above (Lydiard, 2003). The GI microbiome has also been suggested to impact production of neurotransmitters such as serotonin, or its precursor, tryptophan (Desbonnet et al., 2008; Wikoff et al., 2009; Wall et al., 2014). Dietary

factors, including fat, fiber, flavonoid, and sugar content of the diet can also influence microbiome diversity. Flavonoid compounds in plants can impact specific strains of bacteria by inhibiting growth of some or promoting growth of others (Nohynek et al., 2006; Xie et al., 2015). Generally, a high fat, low fiber, and high sugar diet decreases bacterial diversity and increases inflammatory processes contributing to metabolic syndrome, insulin resistance, and neuro-inflammation and behavioral disorders (Kim and de La Serre, 2018). Conversely, lower fat, high fiber diets contribute to increased bacterial diversity, decreased inflammation, and strengthening of the gut barrier. There are a number of spaceflight factors that still have unknown effects on the GI microbiome, including the processed food system with a high quantity of sterile foods, and radiation exposure, but it is clear from ground-based research in humans and animals that the microbiome can affect cognitive function and behavior.

Microorganisms with probiotic psychiatric effects, meaning they can produce a health benefit if consumed in adequate amounts, have been described as "psychobiotics" (Dinan et al., 2013). Evidence from both animal studies and human clinical trials supports that ingestion of psychobiotics, many of which are associated with foods and supplements, can reduce symptoms of stress, anxiety, and depression (Stilling et al., 2014; Sampson and Mazmanian, 2015; Douglas and Voorhies, 2017). The GI microbiome may also influence the brain, mood, and behavior through interaction with the immune system (Rothhammer et al., 2018; Sylvia and Demas, 2018) or through production of odorants that act as social cues (Bienenstock et al., 2018). Although human studies in these areas are limited, a preliminary investigation in a confined 105-day human analog study indicated a potential relationship between GI microbial composition and mood (Li et al., 2016). Considering the substantial impact that the GI microbiome may have on cognitive function, neuro-inflammation, and behavior, the impacts of the spaceflight diet, crew food selection, and environment on the GI composition warrant further investigation.

Connections of Food/Nutrition to Team/Social Behaviors

Even with the limitations in the food systems in ICE environments, food is often identified in ISS astronaut debriefs as one of, if not the most, important factors to morale (Douglas et al., 2016). Food was within the 10 most discussed categories identified in an analysis of astronaut journals, both as a source of frustration and as a source of pleasure depending on factors such as the variety, availability (resupply), and quality of chosen items and the adequacy of the space available for group meals (Stuster, 2016). Allowing crew members to self-select what food items they want to consume each day (within the food containers that are opened at that time) yields greater crew satisfaction as documented in ground analogs using closed food systems for extended periods of time (Milon et al., 1996). The European mission simulation study EXEMSI (60-day confinement) results clearly demonstrated that specific menus should not be imposed on the crew, but menu suggestions should be available. They note that in an environment with multiple stressors, food should not be considered as an additional stressor but should allow for personal choices.

The limited quantity and variety of foods in ICE settings can be a potential source of contention. This was demonstrated in the Mars 500 analog, where lack of culturally acceptable variety and differences in cultural eating habits may have cause friction among crew members (Šolcová et al., 2016). It was recommended that more attention should be focused on the design of the food system (nutrition, variety, multicultural expectations, etc.) to prevent issues in future missions. However, food also was one of the most discussed topics and acted as an important natural bridge for the multicultural crew.

The importance of food and group meal times to team cohesion is evident in human exploration accounts (Stuster, 1996, 2016). Exploration researchers have recommended that the entire crew eat together regularly to support communication and prevent subgroup formation (Stuster, 1996). Timing is an important consideration to group meals, and food rehydration and heating equipment on NASA spacecraft must be designed to support simultaneous food preparation and group meals even when schedules are demanding. Even though Skylab was the only space program with high-quality refrigerated and frozen foods, time pressure in relation to meal preparation reportedly reduced the number of group meals (Stuster, 1996). Over the course of a mission, special meals that occur on a predefined basis and celebratory meals have been noted to help mark the passage of time.

Crew self-selection of food items within the limited food system, rather than adherence to a guided menu, can also unintentionally affect nutrient status and resulting behavioral health among individuals. There are examples of chamber studies with closed or semi-closed food systems where crew members did not get enough nutrients through the food system even though the planned food system contained enough of each nutrient. One example where a 60-d closed food system provided nutrient requirements but actual vitamin intake (particularly vitamins B1 and B6) was below the dietary requirements is the European Space Agency's ESA EXEMSI study, which indicates that the crew members were not selecting completely nutritionally balanced meals (Milon et al., 1996). Another example is from Biosphere 2, where a crew of eight lived in an environment with finite natural resources for 2 years. In this system, vitamins D and B12 were deficient according to government RDA standards (Silverstone, 1997). A 105-day chamber study in Russia also showed that crew members who intentionally excluded specific food items, such as protein-rich desserts, became protein deficient and lost body mass (Agureev et al., 2017). These examples underline the importance of food selection and crew preferences in preventing deficiencies in nutrients that can in turn affect behavioral or cognitive health.

The impacts of a limited food system on social and team behaviors may be more severe in future long-duration exploration missions. The food may be sent multiple years ahead of a mission and selection of the crew and therefore limited to a standard menu devoid of individually selected preference foods or fresh foods. If a crew member chooses to eat only limited types of foods from this system, it may cause conflict by unacceptably restricting the availability of those foods for others. Additionally, if a member of the crew limits their food choices

from an allotment of food that has been prepositioned on a lunar or planetary surface, it may prevent the intake of a balanced diet for all crew members and could result in nutritional deficiency and potential downstream effects on physical and behavioral health and performance. Of greater concern to team cohesion would be dishonorable food practices. An incident of food being "plundered" was mentioned in an ISS astronaut journal, which served as an acute social stressor producing feelings of resentment (Stuster, 2010).

The direct introduction of chemicals to the body *via* the nutrients in food is just one component of ICE systems that can directly impact the neurobiological systems underlying adaptation and social dynamics in ICE settings. Invoking the body's physiological systems as work, play, or maintenance activities is another inherent component of ICE systems that can directly alter physiology and impact the key neurobiological systems affecting physical readiness to perform team tasks and cognitively engage in social behaviors.

Exercise and Physical Activity

Overview of Exercise Physiology

In spaceflight, the risk of decreased musculoskeletal health and cardiorespiratory fitness is largely driven by microgravity. In microgravity, humans do not experience continuous daily loads on the body as they would in Earth's gravity, and as a result, bone and muscle tissue weaken. This deconditioning poses danger upon return to Earth and for future missions to the moon and Mars, which may involve planetary surface operations under corresponding gravity-related loads. Exercise is a critical countermeasure to prevent multi-system deconditioning during spaceflight and should also be used to target mitigation of the stressors associated with spaceflight (i.e., isolation, confinement, and other stressors) to promote team cohesion and mission success. Exercise devices in space have improved significantly since the early decades of spaceflight, and current countermeasures onboard the International Space Station (ISS) include a treadmill with a restraining harness and Advanced Resistive Exercise Device (ARED), allowing for cardio and load-bearing workouts for long-duration crew members (Ploutz-Snyder et al., 2015). Similar to military and firefighter physical fitness requirements and guidelines for other physically demanding jobs, crews must maintain adequate physical fitness for their missions. To this end, crew members are scheduled for exercise 6 days a week, for up to two and a half hours per day in-flight.

The favorable effects of regular exercise on multiple physiological systems and psychological health dates back to teachings from Confucius and ancient Greek philosophers who recognized exercise and physical fitness as essential factors to maintain health, strength, and a prolonged life (Berryman, 2010). Current literature has indisputably shown the benefits of regular exercise across multiple domains, including treatment for depression (Cooney et al., 2014), motor skill acquisition (Roig et al., 2012; Statton et al., 2015), cognitive function (Chang et al., 2012), and sleep quality (Reid et al., 2010). Within operational environments, exercise can be used not only as a countermeasure to maintain muscle strength and cardiovascular fitness but also as a critical mediator of stress responses to promote physical and psychological resilience. Regular physical activity buffers against depression and anxiety, and greater calmness, better mood, lower anxiety, and a generally lower susceptibility to life stressors have been shown in trained individuals compared to their less fit counterparts (Silverman and Deuster, 2014). In addition to improving these factors, physically fit individuals experience significantly less stress compared to unfit individuals during physical activity at the same work rate as demonstrated by lower heart rate responses and cortisol levels (Deuster and Silverman, 2013). From the perspective of promoting resilience, studies have demonstrated that self-esteem and self-efficacy are improved through regular physical activity (Delignières et al., 1994; McMurray et al., 2008).

More recently, the state of knowledge on the effects of exercise on neurobiology has expanded and allowed for more detailed understanding of *how* exercise promotes factors such as resilience, stress tolerance, and adherence to exercise. Exercise directly enhances brain function by regulating peripheral and central nervous system growth factors including brain-derived neurotrophic factor (BDNF), insulin-like growth factor 1 (IGF-I), and vascular endothelial-derived growth factor (VEGF). Exercise-induced increases of BDNF and IGF-1 can improve learning and reduce depressive symptoms through supporting the growth and repair of blood vessels and brain tissue that support overall cognitive functioning (Cotman et al., 2007; Silverman and Deuster, 2014). Emerging work suggests that the hormone osteocalcin, which is produced exclusively in bones and maintained or increased with exercise, can act on the brain and may mitigate anxiety and cognitive deficits (Obri et al., 2018; Shan et al., 2019); this is particularly relevant to teams in space, where exposure to the microgravity environment can reduce osteocalcin levels without sufficient exercise (Smith et al., 1999; Garrett-Bakelman et al., 2019). Thus, exercise can directly help support the mechanisms underlying the knowledge, skills, and abilities necessary to sustain team processes and performance throughout a mission.

Exercise and Social/Team Factors

Exercise provides a unique countermeasure to enhance brain health and function by indirectly reducing the peripheral risk factors associated with cognitive decline and directly enhancing the brain health and cognitive function. As described above, the stress response is regulated by the HPA axis, autonomic nervous system, and immune system. Activation of these systems causes release of cortisol and epinephrine to enable the response of other body systems (cardiovascular, musculoskeletal, nervous, and immune) to meet the demands of the challenge presented and then return the body back to normal levels. Importantly, timely termination of the stress response is critical for preventing systemic inflammation, which is detrimental to physical and psychological health over time. Maintaining physical fitness effectively reduces constant systemic inflammation by quickly returning chemicals released during a stress response to baseline levels (Silverman and Deuster, 2014).

Studies addressing the effects of exercise on psychological health usually focus on the individual; however, in the context

of ICE environments, it is critical to also explore how exercise can improve team cohesion and performance. Most mission activities performed during spaceflight missions require crew members to work together, and even if it is not a requirement, activities can typically be completed more efficiently and effectively with the help of crewmates. Extravehicular activity (EVA), colloquially known as a "spacewalk" among astronauts, and other mission-critical team tasks are one of the most important team activities performed on missions and exemplify the need for ICE teams to perform with high levels of team cohesion and cognitive functioning in a high stress environment. Every step of an EVA from training to preparation to return to the vehicle is well-planned and practiced. It requires all crew members to perform their individual tasks well, has situational awareness of each other's well-being and location, effectively communicates with each other and ground support, and offers supporting behaviors to assist each other. Even with optimal preparation, unexpected events occur during EVAs that require the crew members to work together toward a solution. In these cases, it is critical that EVA crew members possess self-efficacy and execute team processes such as collaborative decision making and backup behaviors. Additionally, EVAs are typically 6 or more hours in length and are very physically and cognitively demanding. Fatigue may cause cognitive errors to increase and communication to decrease, so exercise to build endurance for these events is essential. As we progress to future planetary exploration EVAs, especially during longer duration missions, EVAs are likely to be less tightly scripted, and therefore, team cohesion and good team process become even more important as the team must work autonomously to address dynamic challenges.

The most effective combinations of exercise volume, intensity, and modality to promote psychological health are not known and likely vary between individuals. Most studies in this area have focused on cardiovascular-based exercise rather than resistance exercise training. It appears that moderate to vigorous intensity aerobic exercise is the most effective (Chang et al., 2012), likely due to the fact that the cascade of catecholamine and growth factor responses is minimal with lower intensity exercise. The effects of resistance exercise on brain health are less studied; however, preliminary evidence suggests that higher load, low repetition resistance exercise stimulates areas of the brain differently than lower load, higher repletion exercise (Kraemer et al., 2013). Understanding the molecular and brain area specific responses associated with different exercise and physical activity profiles during spaceflight and other ICE mission settings will be critical in optimizing exercise hardware, software, and prescriptions for maintaining physical and behavioral health and performance capacity for individuals and teams in extreme mission operations.

Sleep/Wake/Work Rhythms

Overview of Sleep and Fatigue

ICE operational environments often include irregular or unnatural work schedules, light/dark cycles, and sleeping environments. For example, Antarctic researchers and submariners may not see the sun for months, while astronauts in low Earth orbit see a sunrise or a sunset every 45 min. Excerpts from astronaut journals collected during spaceflight missions have identified fatigue and sleep as a major source of stress and relief, mentioned hundreds of times (e.g., Stuster, 2010, 2016). In contrast to pure muscle fatigue, mental fatigue is the "inability to function at one's optimum level, because physical and mental exertion (of all waking activities, not only work) exceeds existing capacity" (Gander et al., 2007). Sleep is a necessary biological process that allows the brain and body to recover from the day's scheduled and unscheduled physical, cognitive, and social activities. Humans on average prefer approximately 8–8.5 h of sleep per night to maintain health and cognitive functioning (Klerman and Dijk, 2005). Notably, astronauts often do not receive a full night's sleep while on a mission, instead averaging 6 h of sleep per night, due to the physical and psychological stressors inherent in an operational mission (Barger et al., 2014). Sleep supports many physiological processes such as maintaining muscle, organ, and immune functioning and encourages repair and restoration through the release of chemicals such as growth hormone (Kim et al., 2015). During sleep, cerebrospinal fluid within the brain flushes out waste products of cell functioning that accumulates during waking hours, effectively cleaning the brain (Xie et al., 2013). Sleep also supports memory consolidation. Outside influences may cause fatigue such as the sleep environment, the time of day and circadian rhythm, quantity and quality of sleep, and total or partial sleep deprivation. Sleep environments that are too hot/cold, noisy, bright, and prevent reclined positions reduce sleep duration and may lead to more awakenings. Relying on sleep during typical times of alertness, or working during hours typically reserved for sleep (e.g., pulling an "all-nighter"), results in poor quality and insufficient sleep. Sleep loss may be both an acute issue and a chronic issue; that is, sleep deprivation may come in the form of missing all or part of a typical night's sleep, or a reduction in sleep duration for a period of several nights. Both acute and chronic sleep restrictions negatively affect individual performance and well-being (Cohen et al., 2010).

There are also several factors that may influence individual sleep and fatigue patterns. Studies have found that individual sleep needs and preferences as well as the response to sleep loss and fatigue vary according to genotype (Groeger et al., 2008; Vandewalle et al., 2009). These differences in the underlying genotypes may drive affect, behaviors, and cognition. For example, variants in the PER3 gene expressed in the suprachiasmatic nucleus (SCN) of the hypothalamus that regulates sleep and circadian rhythms have been associated with the differential activation of the parietal and temporal lobes of the brain under conditions of sleep loss, resulting in poorer performance (Vandewalle et al., 2009). In other words, some individuals are more vulnerable to the effects of fatigue and require more recovery from fatigue than others. These and other influences of fatigue are well documented in the literature, as are the outcomes in the multiple neurobehavioral domains. As a brief list of common outcomes, fatigue has been linked to affective decrements in emotional stability, self-regulation, positive affect, and motivation; behavioral outcomes of reduced physical activity, less accurate assessment of risk, and less and

poorer quality communication; and cognitive outcomes of cognitive slowing, reduced attention and recall, poor decision making, and increased risk of errors (Chabal et al., 2018; Banks et al., 2019). When placing these findings in a team context, individual differences in reactions to sleep loss, work overload, and schedule shifting can impact each team member in a unique way, introducing variability in performance and social functioning that must be addressed by the team.

Fatigue and Social/Team Factors

Sleep need and vulnerability to fatigue are primarily individual-level input variables in the IMOI model. Differences related to fatigue vulnerability, and an individual's chronotype (i.e., whether the individual is a morning lark or night owl) stems from endogenous individual differences and general physiological health. However, these individual-level inputs may directly influence patterns of interacting with team members. For example, in the Mars-520 mission simulation analog study, one of the six crew members was a habitual napper, which reduced their interactions with other crew members by 20%, while another crew member developed a free-running sleep-wake schedule in which his circadian rhythm (and thus, regular interactions) became misaligned with all other crew members (Basner et al., 2013). These crew members' asynchrony effectively reduced the crew's collective knowledge and skills, altered the team structure and team size, and reduced the manpower for team processes such as systems and goal monitoring, backup behaviors, and coordination. Communication, an essential component of teamwork, is decremented at the individual level under conditions of fatigue. The few team studies of fatigue and communication, conducted most frequently in military populations, found teams either reduced or stopped communications, which decreased performance, and sought more visual forms of information (Whitmore et al., 2008; Fletcher et al., 2012).

In a closed environment such as a long-duration space expedition or a deployed military submarine team, team members function as both coworkers and roommates. Spending less time together due to misaligned sleep/wake/work schedules may not only affect team task cohesion (i.e., working well together toward a goal) but also influence team social cohesion (i.e., shared attachment and liking) through reduced time spent sharing meals, engaged in recreational activities, or being available to provide and receive social support. A reduction in time spent together, particularly as it may be expressed differently among circadian misaligned team members, may create fractures within the team. As team cohesion has been positively linked to team performance (Mathieu et al., 2015), reduced social support and team cohesion related to circadian misalignments may result in poor team outcomes. The cohesion-performance relationship has also been found to be reciprocal in studies of isolated teams in Antarctica and mission simulations (Kozlowski et al., 2015). Thus, reduced team cohesion begets poor performance, which further reduces cohesion, and fatigue acts as an amplifier of this downward spiral. Other affective states of team confidence and trust may also suffer as a fatigued team member is more likely to demonstrate emotional instability, commit cognitive lapses, or withdraw from the team altogether. Identification of others' needs for social and emotional support may also be neglected as sleep-deprived individuals are less able to recognize facial displays of human emotions (van der Helm et al., 2010). Over time, teams that are not able to rely on the regular presence, consistent performance and support, and emotional stability of all team members are likely to see a reduction in team performance and team functioning that accumulates as this negative pattern persists. Consequent issues related to poor team performance may also negatively influence each individual team members' ability to sleep as they ruminate on negative team situations and performance outcomes. The level of fatigue, either driven by psychological reactions to a team situation or by physical needs (e.g., staying awake 36 h to address an emergency), becomes inputs for the next cycle of the IMOI, influencing the team through each individual's vulnerability to the new level of fatigue. Notably, the team may be able to compensate for the fatigued individual in such a way that they avoid the decrement to performance. For example, a laboratory study of team decision making found errors increased at the individual level, but these effects were attenuated by team membership (Baranski et al., 2007). We currently do not know what degree of fatigue within each team member and across the team is the tipping point for the decline in performance and functioning. Determining this threshold, particularly for small teams in a high-risk ICE operational environments with irregular work schedules or non-Earth-like light/dark cycles, would allow optimization of mission planning and timely deployment of interventions to support individual and team behavioral health and performance.

Habitability and Systems Design

Overview of Habitability and Human Factors Design

By its nature, human occupation of extreme environments requires specially designed habitats and equipment to allow operational teams to achieve their mission objectives and maintain safety. Indeed, the "extreme" portion of ICE typically refers to a dangerous external geophysical environment incompatible with human physiology, health, and well-being, including the lack of or toxic atmosphere, extreme altitude (above or below sea level), extreme heat or cold (or rapid shifts between the two), non-24 h light-dark cycles, reduced gravity, wildlife threats (e.g., predatory animals, microorganisms, toxins), or potential exposure to radiation and extreme weather phenomena (e.g., solar flares, high winds, dust storms, rough seas, blizzards, and volcanism). An extreme level of even necessary isolation brought about by physical constraints, physical confinement, austere environmental conditions with little to no natural sensory stimulation, and social loss due to the inability to communicate with others outside the immediate team in real time all have the potential to impact both individual and team function. A habitat that not only protects from physical external threats but supports individual health and performance and facilitates positive team dynamics must be carefully designed. A poorly designed habitat can negatively impact crew members by inducing acute and chronic stress responses in the individuals living and working in the operational

environment. These effects may be magnified under increased mission duration and isolation and could constitute a chronic stressor (Celentano et al., 1963; Mohanty et al., 2006). Several features of habitats that are important to team function in situations of extreme isolation and confinement are discussed below. Essentially, the habitat should enable effective performance while accommodating group activities and providing sufficient privacy and means of escape from the mixed work/social setting of closed ICE mission environments.

Habitability, Human Factors, and Social/Team Factors

Group Activities

ICE habitats should allow for a crew to gather together within the same space for not only work functions but also recreational opportunities. As discussed by Ozbay et al. (2007), low social support has been associated with physiological and neuroendocrine indices of heightened stress reactivity, including elevated heart rate, increased blood pressure, and heightened cardiovascular and neuroendocrine responses to stressors. Habitats designed for long-duration missions should ensure adequate physical space to facilitate social support.

One of the major contributors to interpersonal conflict highlighted in polar and spaceflight expeditions is the tendency for the formation of subgroups within the crew (Stuster, 1996). Providing an environment that supports group communication may mitigate this issue and lead to a more cohesive team (Bender and Fracchia, 1971). As mentioned, Stuster suggested that meals may offer this type of communication and social support opportunity, where the entire crew can gather to prepare their food and dine together. Consequently, it is important to provide a space in the habitat that allows for this type of casual group interaction. Evidence from a study of ISS astronaut journals emphasizes the need for this space to facilitate group communication and enhance team cohesion (Stuster, 2016).

Evidence for the importance of dining together led to the creation of a NASA Human-System Standard (NASA, 2015), which states that crew members shall have this capability to support crew psychological health and well-being (NASA Standards 7.1.2.5 Dining Accommodations). The standards provide a baseline for future spaceflight programs, which design vehicle habitats with consideration to crew health within mission resource limitations and mission length and distance. This entails consideration for sufficient physical volume and designs the mission timeline and food system (e.g., ability to prepare meals at the same time) to support team meals. The Standard serves as one clear example to highlight the importance NASA places on allowing the crew to share physical space to support team cohesion. The design of the common galley area should also be considered, which should include a table that accommodates the entire crew without inadvertently creating tension. For example, Raymond Loewy, a "Habitability Consultant" for the Saturn-Apollo and Skylab programs, had a triangular table installed in the Skylab wardroom, so that "no man from the three-person crew could be at its head" (Mohanty et al., 2006). In many cases, the galley where crew members gather to share meals can also provide sufficient volume for other group recreation as well as work-related team tasks. Indeed, the importance of recreation to psychological health and well-being has been researched extensively. In the context of space exploration, both individual (e.g., reading) and group (e.g., watching a movie) recreation opportunities should be provided. The habitat should therefore accommodate both types of stress-reducing recreational activities.

For work-related team tasks, the galley or other areas designed to accommodate multiple crew members should carefully consider the nature of the team task as it relates to noise interfering with communication, physical or sensory interference of each person performing their duties in concert with the other, and whether the location of the team task blocks access to other important areas (e.g., sleep quarters), which may cause team frictions and frustrations, and negatively influence performance and efficiency (Kearney, 2016). Other critical factors to ensure teams are able to share information, foster trust, and coordinate efficiently include allowing common spaces for communication (e.g., digital whiteboards and shared displays), physical layouts that allow for eye contact and mutual viewing, and norms and standards for common labeling, stowage locations of tools and equipment, and adequate work spaces.

Privacy

While it is important to ensure that the volume and layout of a habitat facilitates team cohesion and performance through shared spaces, purposely private spaces for each crew member should also be provided, particularly in vehicles intended to support longer duration missions. Terrestrial studies have demonstrated that the experience of privacy—that is, *privacy* as a dynamic and dialectic interaction with others, whereby privacy represents the level of selective control one has over sharing one's self with others (Altman, 1977)—is related to the architecture of privacy (Laurence et al., 2013), such as the design of a workspace with four walls. Hence, architectural private spaces facilitate the experience of privacy, which has been shown to be related to improved work performance (Karlin et al., 1979; DeCroon et al., 2005). The provision of a private space also allows for withdrawal from increased social density. In an assessment of social density and perceived control in high density residential neighborhoods, individuals living in areas with stores (compared to individuals living in residential areas without stores) reported more crowding, less ability to regulate social interactions, and lower perceptions of control (Fleming et al., 1987). In addition, they evidenced higher stress levels, including more somatic and emotional distress, and elevated urinary epinephrine, norepinephrine, and dopamine.

One exploration researcher contends that the majority of interpersonal conflicts arise from relatively minor issues that become exacerbated due to the extreme isolation and inability to escape one's crewmates (Stuster, 2010). He asserts that the constant interpersonal interaction caused by a confined environment is a source of stimulation (and exacerbated by a smaller crew), and people need to occasionally withdraw from this stimulation in order to cope with the stressors of the mission and environment. The habitat should facilitate the individual crew members' ability to withdraw from the rest

of the crew, in order to conduct solitary activities. If no specific area is provided for privacy, crew members will likely improvise and modify their environments in order to achieve some privacy. Notably, these consequences are likely to accrue in the continued absence of privacy. The ability to withdraw and have physical (auditory and visual) privacy can help mitigate interpersonal conflict and support team health and performance.

The provision of an individual sleeping quarter has been the subject of debate for years. The Risk and Management Team of NASA's Human Exploration and Operations Mission Directorate (HEOMD) published a report detailing lessons learned from the ISS program and recommendations for future exploration programs (Lengyel and Newman, 2014). Among these recommendations, the suggestion is that "crew comfort and privacy must be 'front and center'" for spacecraft designed for long-duration space missions and recommends that future exploration vehicles provide crew member with a private sleep quarter, despite the engineering constraints on volume and habitat size. The authors cite feedback from crew members about the importance of having a private sleep quarter they can personalize and use for privacy. Evidence from ISS crew debriefs indicates sleep quarters that are valued and necessary spaces for conducting personal activities, and crew members emphasize the psychological benefit of having these private accommodations (Whitmore et al., 2013). Crew members also noted the importance of having the ability to decorate and personalize their private crew quarters (Kearney, 2016). Evidence for the benefit of providing crew members with a private sleeping quarter for long-duration missions has also been captured by NASA Standard 7.9.2 Private Quarters, which states that private quarters shall be provided to support crew health and performance for missions longer than 30 days. Whether or not an individual sleeping quarter is provided per crew member, the ability to retreat and achieve privacy from the rest of the crew members should be provided by the habitat. Both visual and auditory privacy should be considered in the design of private spaces. Chronic stress due to reduced privacy and increased social density of such environments may be further compounded by acute stress events related to habitability (e.g., temporary damage to part of the habitat reducing overall net habitable volume and increasing crowding for a short time). More generally, chronic and acute stressors related to habitability may interact with stressors related to any of the other topic areas we have discussed in this article, resulting in a continuous threat to the behavioral health, performance, and effectiveness of the crew.

OPPORTUNITIES FOR RESEARCH AND APPLICATION

Examining the interaction of these seemingly disparate research areas of biology with team research is overdue, but there are several specific gaps in the literature that may serve as starting points. Uniting each of these areas should be a focus on the brain. That is, identifying the complex chemical interactions and neurobiological mechanisms influenced by nutrition, exercise, fatigue, habitability, and interactions with other individuals should acknowledge the potentially compounding effects of other areas in research designs. The resulting social and team behaviors of this interplay have received some targeted attention (e.g., studying the influence of one particular molecule on mood or tendency to withdraw from the team), but simultaneous consideration of multiple influencers on the brain is the next step. Throughout this review, we integrated several frameworks, including the IMOI model of team performance, the NIMH RDoC framework for basic neurobehavioral functioning across multiple levels of analysis, and the unique characteristics of ICE environment contexts. Ultimately, if understanding and enhancing team performance and social dynamics are the priority, then we believe that the IMOI framework is capable of serving as a guiding framework for research and development in the behavioral biology of extreme teams. Indeed, the IMOI model is not rooted in team performance but is rather an adaptation of systems theory and modeling. We consider our expansion of the individual input level in the IMOI model to include biologically relevant variables not so much a radical departure from organizational theory than a more realistic (albeit complicated) consideration of factors acting on the brain to affect individual and team behavioral health and performance over time. Characterizing these interrelationships and developing evidenced-based best practices and countermeasures is the exciting challenge facing the applied research community.

For nutrition, physical outcomes of inflammation and changes to the gut microbiome influenced by diet may also influence individual stress and physical and cognitive readiness to perform on the team. Research into providing adequate nutrition to sustain brain and body functioning with limited resources in a closed system should seek to understand potential affective, behavior, and cognitive effects of specific nutrients and foods. Researchers must also inform dietary countermeasures by understanding optimal methods for encouraging continued consumption of nutritious foods with a likely restricted variety, perhaps by leveraging social influence, team processes, and reward circuitry. Examining the social importance of shared meals for encouraging consumption, bonding as a team, and fulfilling social support and relaxation needs is a multifaceted issue naturally suited to a multidisciplinary approach incorporating biological, behavioral, cognitive, and social factors.

These issues are also applicable to exercise physiology research, which similarly investigates sustaining motivation to exercise over time, the benefits of group and competitive exercise, the use of exercise to reduce stress, and other psychological benefits to maintaining physical readiness and brain health to perform in a team. However, much of the data reported in these fields are based on study populations not representative of astronauts or other high-performing teams in long-duration extreme mission operations (Hillman et al., 2008; Teixeira et al., 2012). It is critical to recognize individual preferences, specific environmental challenges, and availability of exercise hardware and exercise options in extreme environments and to examine the volume, intensity, and types of exercises that are most effective toward facilitating psychological health and team performance and cohesion in ICE settings.

Similar to other biologically oriented literature bases, fatigue and sleep are a robust area of research at the individual level, but there is a notable dearth of research at the team level (Chabal et al., 2018; Banks et al., 2019). Empirical studies are needed to predict likely effects of an individual on a team, for example, a fatigued individual exhibiting poor problem solving during a team task would likely delay or result in a non-optimal solution for the team. However, the types of tasks and situations in which teams may be able to mitigate the fatigued state of a member are unknown. In a tightly coupled system, each team member that is not operating at full capacity will have a disproportionate influence on the team outcomes. Many industries make use of validated biomathematical models of fatigue (Van Dongen, 2004) to determine how much sleep and during what time of day sleep is needed to support safety and performance. Relatedly, the IMOI model allows researchers a starting point to systematically examine fatigue as an individual input variable affecting all parts of the model. Integration of these models, along with the integration of additional biological variables, would offer organizations more robust scheduling of teams and timely countermeasure intervention for sustained performance. Furthermore, health management systems, employed across many organizations in many industries to manage the safety and well-being of employees and customers, are currently directed at the individual or organizational policy level and do not include an integrated, comprehensive approach incorporating all behavioral biology topics discussed in this article. These systems would also benefit from leveraging team factors (e.g., backup and supporting behaviors that provide team members the skills to recognize decrements in oneself and others) and take actions to implement countermeasures that support the team member as well as the safety, performance, and functioning of the whole team. Quantification of the success of these programs incorporating team factors and using multi-level experimental designs allows understanding for how teams may best be leveraged to prevent and mitigate negative effects stemming from the multitude of biological causes.

Finally, researchers and practitioners alike in the field of habitability and human factor design may benefit from research that provides a better understanding of the risk of the compounding needs of biological factors in affecting team-related processes and outcomes to provide improved countermeasures within habitat and equipment design for isolated, confined, and extreme environments. More research is needed as to the acute and chronic neurobiological reactions in the brain and other body systems that may be influenced by the physical environment. The physical environment may also directly influence team processes and team and individual outcomes by engendering cohesion and limiting conflict with adequate space and design in which to perform team tasks and recreation, as well as provide individual refuge and privacy. More generally, the duration of living and working in such an environment will exacerbate the effects of environmental stressors; however, the nature of that dynamic relationship over extreme long durations such as a Mars mission is not known. Determining psychological thresholds for tolerance of habitat and systems design variations for missions of varying durations will enable engineers and mission planners to meet the needs for different mission profiles.

CONCLUSIONS AND THE PATH FORWARD

Over the course of this selective review, it is clear that multidisciplinary science for understanding teams in ICE environments is both a valuable endeavor to move the field forward and a daunting challenge. However, there are many existing structural and scientific integration efforts that may facilitate future research and applications. The first key is forming interdisciplinary research partnerships. These may be accomplished through top-down approaches as policymakers and research funding entities release calls for appropriately funded multidisciplinary research. These organizations may also proactively offer support and guidance to multidisciplinary research teams related to methods of communicating and collaborating between teams with different field-specific norms and languages. For example, the National Institutes of Health's (NIH) National Cancer Institute hosts a Team Science Toolkit that enables multidisciplinary teams to overcome common hurdles in partnering with others from disparate fields[2]. Creating research questions that are fundamentally multidisciplinary and soliciting proposals with experts from several areas of expertise will prompt researchers in these fields to reach out beyond their typical circles to form new partnerships. Most of this funding originates from government agencies such as the NIH or the National Science Foundation (NSF), which also provide funding opportunities for social neuroscience through their Social, Behavioral, and Economic Sciences (SBE), Behavioral and Cognitive Sciences (BCS), and Social and Economic Sciences (SES) programs. Defense agencies and other organizations that rely on ICE operations (e.g., transoceanic shipping, energy sector, polar research agencies) also have an interest in optimizing team performance and functioning over long durations. Military operations with units such as those deployed in the field and on ships and submarines more akin to the closed systems of spaceflight would likely benefit from integrated approaches to team science and countermeasure development (Goodwin et al., 2018). Optimization of soldier (i.e., the individual-level system) and unit (i.e., the team-level system) performance while on deployment (i.e., the team-in-the-environment system) drives leaders to consider the whole soldier, creating an environment that is conducive to exploring multidisciplinary, cutting-edge research. Researchers should seek out these organizations' calls for proposals.

From a bottom-up approach, researchers can design experiments that address multiple fields. For example, biomarkers collected as part of an exercise protocol to understand recovery times for different exercise prescriptions may be analyzed for stress hormones that are of interest to psychological researchers. Team researchers may also be able to observe subsequent team

[2]https://www.teamsciencetoolkit.cancer.gov/Public/ToolkitTeam.aspx

interactions following these exercise episodes to understand other interpersonal outcomes of different exercise routines, informing exercise countermeasures that may benefit the physical and psychological health of team members. This research study may be further broadened as sleep and fatigue researchers collect data related to pre- and post-exercise fatigue and sleep needs related to different exercise protocols and nutritional inputs, given varying levels of stress hormones, and so on. The complexity of this type of research also demands careful thinking about research design, sample size and statistical power, and leveraging already existing multidisciplinary datasets for initial exploratory analyses and hypothesis generation such as the NASA Life Sciences Data Archive[3]. Using existing data is one way to minimize costs. For large-scale experiments, such as what is conducted in spaceflight mission simulation analogs with dozens of investigators examining many different factors for the same set of participants, data-sharing agreements between investigator teams from different fields may allow planned multidisciplinary collaboration or hold potential for integrated *post hoc* analyses. As time and resources for research are not unlimited, collaborative integration also offers a cost-effective approach to conducting research.

Team research is especially challenging in operational environments due to the sample size problem; that is, each team may be composed of several individuals, but that team is just an n of 1 for any team-level variable. Layering research questions from several fields may require large sample sizes, which is multiplied by the need for sufficiently powered team-level data. Integrated data-mining and application of advanced analytical techniques capable of processing "big data" (e.g., machine learning) may provide findings related to the understudied intersection of different fields and other risks to team functioning (Lazer et al., 2009; Goswami et al., 2013; Luciano et al., 2018)[4]. Also, agent-based modeling experts can parameterize complex, integrated, multidisciplinary models with large-scale existing data. Using agent-based models to conduct virtual experiments allows for investigation of many different specific scenarios, which would otherwise require large numbers of research participants (Epstein, 2006). Current supercomputers, many available from government organizations to any researcher with necessary research approvals and funding, allow this type of data analysis to occur in a matter of hours or days for tens of thousands of virtually simulated experiments. Integrating data across multiple measurement methods and tools supports the identification of the most efficient, yet valid, method of measuring each variable of interest, reducing overall measurement burden on study participants, which is a concern for teams in operational environments.

A multidisciplinary approach to sustaining healthy individual and team performance, well-being, and social interactions may realize more efficiencies and effectiveness when monitoring the team and implementing countermeasures. Integrated monitoring and analysis may help the team and support personnel obtain comprehensive and more accurate assessments of team performance and functioning, individual health and well-being, and identify changing effects on the individuals within the team over time. Multi-pronged interventions may be more effective. For example, if the team collectively is fatigued due to an unexpected emergency waking them in the middle of the night, a multidisciplinary countermeasure package may address how the team may be rescheduled to allow recovery sleep, the design of the sleep environment for adequate privacy and lighting to support sleep, and what foods will enable sleep and provide more sustained energy upon waking so that they are able to recover and perform, etc., without any one countermeasure imposing an unacceptable or disruptive burden. Additionally, understanding each individual team member's unique systems and needs within a proactively individualized medicine approach (Evans and Relling, 2004; Topol, 2014) may allow countermeasures to be tailored and implemented at both the individual and team levels. Ultimately, the complexity in addressing the multiple pathways that increase risks to individual and team behavioral health and performance is challenging for researchers and practitioners alike. However, multiple pathways that increase risk also provide multiple pathways to reduce risk for teams who work, live, serve, and explore in extreme environments.

AUTHOR CONTRIBUTIONS

PR and LL conceived the project and designed the review. PR, LL, GD, MD, AW, MG, and SZ wrote the paper. All authors made substantial contributions and reviewed and approved the completed manuscript.

FUNDING

LL, MD, MG, and SZ are supported by KBR's Human Health and Performance Contract NNJ15HK11B through the National Aeronautics and Space Administration. LL and PR are also supported in part by NASA Human Research Program Directed Projects *Identification and Validation of BHP Standard Measures in HERA for Transport* and *CBS Operational Performance Measures* (P. G. Roma, PI). GD and AW are supported by NASA's Human Health and Performance Directorate and Human Research Program. The authors of this article are entirely responsible for its content and the decision to submit the work for publication. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the US Government, the National Aeronautics and Space Administration, KBR, or the University of Texas Medical Branch.

ACKNOWLEDGMENTS

We thank Dr. Juan M. Dominguez, Department of Psychology, University of Texas at Austin, for critical comments on the manuscript.

[3]https://lsda.jsc.nasa.gov/

[4]https://www.darpa.mil/work-with-us/ai-next-campaign

REFERENCES

Agureev, A. N., Afonin, B. V., Sedova, E. A., Solovieva, A. A., Valuev, V. A., and Sidorenko, L. A. (2017). Nutritional status in the experiment with 105-day isolation as the first phase of the Mars-500 project. *Hum. Physiol.* 43, 793–801. doi: 10.1134/S0362119717070027

Altman, I. (1977). Privacy regulation: culturally universal or culturally specific? *J. Soc. Issues* 33, 66–84. doi: 10.1111/j.1540-4560.1977.tb01883.x

Altun, A., and Ugur-Altun, B. (2007). Melatonin: therapeutic and clinical utilization. *Int. J. Clin. Pract.* 61, 835–845. doi: 10.1111/j.1742-1241.2006.01191.x

Amico, J. A., Tenicela, R., Johnston, J., and Robinson, A. G. (1983). A time-dependent peak of oxytocin exists in cerebrospinal fluid but not in plasma of humans. *J. Clin. Endocrinol. Metab.* 57, 947–951. doi: 10.1210/jcem-57-5-947

Andrews, P. W., Bharwani, A., Lee, K. R., Fox, M., and Thomson, J. A. Jr. (2015). Is serotonin an upper or a downer? The evolution of the serotonergic system and its role in depression and the antidepressant response. *Neurosci. Biobehav. Rev.* 51, 164–188. doi: 10.1016/j.neubiorev.2015.01.018

Anker, P. (2005). The ecological colonization of space. *Environ. Hist.* 10, 239–268. doi: 10.1093/envhis/10.2.239

Ashkanasy, N. M., Becker, W. J., and Waldman, D. A. (2014). Neuroscience and organizational behavior: avoiding both neuro-euphoria and neuro-phobia. *J. Organ. Behav.* 35, 909–919. doi: 10.1002/job.1952

Banks, S., Landon, L. B., Dorrian, J., Waggoner, L. B., Centofanti, S. A., Roma, P. G., et al. (2019). Effects of fatigue on teams and their role in 24/7 operations. *Sleep Med. Rev.* 48:101216. doi: 10.1016/j.smrv.2019.101216

Baranski, J. V., Thompson, M. M., Lichacz, F. M., McCann, C., Gil, V., Pastò, L., et al. (2007). Effects of sleep loss on team decision making: motivational loss or motivational gain? *Hum. Factors* 49, 646–660. doi: 10.1518/001872007x215728

Barger, L. K., Flynn-Evans, E. E., Kubey, A., Walsh, L., Ronda, J. M., Wang, W., et al. (2014). Prevalence of sleep deficiency and use of hypnotic drugs in astronauts before, during, and after spaceflight: an observational study. *Lancet Neurol.* 13, 904–912. doi: 10.1016/S1474-4422(14)70122-X

Barrett, E., Ross, R. P., O'Toole, P. W., Fitzgerald, G. F., and Stanton, C. (2012). γ-Aminobutyric acid production by culturable bacteria from the human intestine. *J. Appl. Microbiol.* 113, 411–417. doi: 10.1111/j.1365-2672.2012.05344.x

Bartz, J. A., Zaki, J., Bolger, N., and Ochsner, K. N. (2011). Social effects of oxytocin in humans: context and person matter. *Trends Cogn. Sci.* 15, 301–309. doi: 10.1016/j.tics.2011.05.002

Basner, M., Dinges, D. F., Mollicone, D., Ecker, A., Jones, C. W., Hyder, E. C., et al. (2013). Mars 520-d mission simulation reveals protracted crew hypokinesis and alterations of sleep duration and timing. *Proc. Natl. Acad. Sci. USA* 110, 2635–2640. doi: 10.1073/pnas.1212646110

Becker, W. J., and Cropanzano, R. (2010). Organizational neuroscience: the promise and prospects of an emerging discipline. *J. Organ. Behav.* 31, 1055–1059. doi: 10.1002/job.668

Bender, H. E., and Fracchia, J. (1971). *Designer's handbook: Environmental planning for group stability*. NASA Technical Report for Contract NAS 9-10998. Houston, TX: NASA Johnson Space Center.

Berntson, G. G., Bigger, J. T., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., et al. (1997). Heart rate variability: origins, methods, and interpretive caveats. *Psychophysiology* 34, 623–648. doi: 10.1111/j.1469-8986.1997.tb02140.x

Berridge, K. C., and Kringelbach, M. L. (2015). Pleasure systems in the brain. *Neuron* 86, 646–664. doi: 10.1016/j.neuron.2015.02.018

Berryman, J. W. (2010). Exercise is medicine: a historical perspective. *Curr. Sports Med. Rep.* 9, 195–201. doi: 10.1249/JSR.0b013e3181e7d86d

Bienenstock, J., Kunze, W. A., and Forsythe, P. (2018). Disruptive physiology: olfaction and the microbiome–gut–brain axis. *Biol. Rev.* 93, 390–403. doi: 10.1111/brv.12348

Boccia, M. L., Petrusz, P., Suzuki, K., Marson, L., and Pedersen, C. A. (2013). Immunohistochemical localization of oxytocin receptors in human brain. *Neuroscience* 253, 155–164. doi: 10.1016/j.neuroscience.2013.08.048

Brady, J. V. (1990). Toward applied behavior analysis of life aloft. *Behav. Sci.* 35, 11–23. doi: 10.1002/bs.3830350103

Brady, J. V. (2005). Behavioral health: the propaedeutic requirement. *Aviat. Space Environ. Med.* 76, B13–B24. Available at: https://www.ingentaconnect.com/content/asma/asem/2005/00000076/a00106s1/art00003

Byers, A. L., and Yaffe, K. (2011). Depression and risk of developing dementia. *Nat. Rev. Neurol.* 7, 323–331. doi: 10.1038/nrneurol.2011.60

Celentano, J., Amorelli, D., and Freeman, G. (1963). Establishing a habitability index for space stations and planetary bases. Paper presented at the Manned Space Laboratory Conference.

Chabal, S., Welles, R., Haran, F. J., and Markwald, R. (2018). Effects of sleep and fatigue on teams in a submarine environment. *Undersea Hyperb. Med.* 45, 257–272. doi: 10.22462/05.06.2018.2

Chang, Y. K., Labban, J. D., Gapin, J. I., and Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: a meta-analysis. *Brain Res.* 1453, 87–101. doi: 10.1016/j.brainres.2012.02.068

Checinska, A., Probst, A. J., Vaishampayan, P., White, J. R., Kumar, D., Stepanov, V. G., et al. (2015). Microbiomes of the dust particles collected from the international space station and spacecraft assembly facilities. *Microbiome* 3:50. doi: 10.1186/s40168-015-0116-3

Clark, L. A., Cuthbert, B., Lewis-Fernández, R., Narrow, W. E., and Reed, G. M. (2017). Three approaches to understanding and classifying mental disorder: ICD-11, DSM-5, and the National Institute of Mental Health's Research Domain Criteria (RDoC). *Psychol. Sci. Public Interest* 18, 72–145. doi: 10.1177/1529100617727266

Cohen, D. A., Wang, W., Wyatt, J. K., Kronauer, R. E., Dijk, D. J., Czeisler, C. A., et al. (2010). Uncovering residual effects of chronic sleep loss on human performance. *Sci. Transl. Med.* 2:14ra3. doi: 10.1126/scitranslmed.3000458

Cohrs, S. (2008). Sleep disturbances in patients with schizophrenia. *CNS Drugs* 22, 939–962. doi: 10.2165/00023210-200822110-00004

Cooney, G., Dwan, K., and Mead, G. (2014). Exercise for depression. *J. Am. Med. Assoc.* 311, 2432–2433. doi: 10.1001/jama.2014.4930

Cotman, C. W., Berchtold, N. C., and Christie, L. A. (2007). Exercise builds brain health: key roles of growth factor cascades and inflammation. *Trends Neurosci.* 30, 464–472. doi: 10.1016/j.tins.2007.06.011

Cuthbert, B. N., and Kozak, M. J. (2013). Constructing constructs for psychopathology: the NIMH research domain criteria. *J. Abnorm. Psychol.* 122, 928–937. doi: 10.1037/a0034028

David, L. A., Maurice, C. F., Carmody, R. N., Gootenberg, D. B., Button, J. E., Wolfe, B. E., et al. (2014). Diet rapidly and reproducibly alters the human gut microbiome. *Nature* 505, 559–563. doi: 10.1038/nature12820

De Dreu, C. K., Greer, L. L., Van Kleef, G. A., Shalvi, S., and Handgraaf, M. J. (2011). Oxytocin promotes human ethnocentrism. *Proc. Natl. Acad. Sci. USA* 108, 1262–1266. doi: 10.1073/pnas.1015316108

DeChurch, L., Wang, W., Harris, A., and Contractor, N. (2018). Mapping the modern science of teams. Presented at the Interdisciplinary Network for Group Research (INGRoup) Annual Conference, Bethesda, MD.

DeCroon, E., Sluiter, J., Kuijer, P. P., and Frings-Dresen, M. (2005). The effect of office concepts on worker health and performance: a systematic review of the literature. *Ergonomics* 48, 119–134. doi: 10.1080/00140130512331319409

Delignières, D., Marcellini, A., Brisswalter, J., and Legros, P. (1994). Self-perception of fitness and personality traits. *Percept. Mot. Skills* 78, 843–851. doi: 10.2466/pms.1994.78.3.843

Derntl, B., Hack, R. L., Kryspin-Exner, I., and Habel, U. (2013). Association of menstrual cycle phase with the core components of empathy. *Horm. Behav.* 63, 97–104. doi: 10.1016/j.yhbeh.2012.10.009

Desbonnet, L., Garrett, L., Clarke, G., Bienenstock, J., and Dinan, T. G. (2008). The probiotic Bifidobacteria infantis: an assessment of potential antidepressant properties in the rat. *J. Psychiatr. Res.* 43, 164–174. doi: 10.1016/j.jpsychires.2008.03.009

Deuster, P. A., and Silverman, M. N. (2013). Physical fitness: a pathway to health and resilience. *U.S. Army Med. Dep. J.* 24–35.

Dinan, T. G., and Cryan, J. F. (2017). Microbes, immunity, and behavior: psychoneuroimmunology meets the microbiome. *Neuropsychopharmacology* 42, 178–192. doi: 10.1038/npp.2016.103

Dinan, T. G., Stanton, C., and Cryan, J. F. (2013). Psychobiotics: a novel class of psychotropic. *Biol. Psychiatry* 74, 720–726. doi: 10.1016/j.biopsych.2013.05.001

Douglas, G. L., Cooper, M., Bermudez-Aguirre, D., and Sirmons, T. (2016). *Risk of performance decrement and crew illness due to an inadequate food system*. Houston, TX: NASA.

Douglas, G. L., and Voorhies, A. A. (2017). Evidence based selection of probiotic strains to promote astronaut health or alleviate symptoms of illness on long duration spaceflight missions. *Benefic. Microbes* 8, 727–737. doi: 10.3920/BM2017.0027

Dowlati, Y., Herrmann, N., Swardfager, W., Liu, H., Sham, L., Reim, E. K., et al. (2010). A meta-analysis of cytokines in major depression. *Biol. Psychiatry* 67, 446–457. doi: 10.1016/j.biopsych.2009.09.033

Dubocovich, M. L. (2007). Melatonin receptors: role on sleep and circadian rhythm regulation. *Sleep Med.* 8, 34–42. doi: 10.1016/j.sleep.2007.10.007

Ebling, F. J. (1996). The role of glutamate in the photic regulation of the suprachiasmatic nucleus. *Prog. Neurobiol.* 50, 109–132. doi: 10.1016/S0301-0082(96)00032-9

Eckstein, M., Scheele, D., Weber, K., Stoffel-Wagner, B., Maier, W., and Hurlemann, R. (2014). Oxytocin facilitates the sensation of social stress. *Hum. Brain Mapp.* 35, 4741–4750. doi: 10.1002/hbm.22508

Edwards, D. A., Wetzel, K., and Wyner, D. R. (2006). Intercollegiate soccer: saliva cortisol and testosterone are elevated during competition, and testosterone is related to status and social connectedness with teammates. *Physiol. Behav.* 87, 135–143. doi: 10.1016/j.physbeh.2005.09.007

Eisenegger, C., Haushofer, J., and Fehr, E. (2011). The role of testosterone in social interaction. *Trends Cogn. Sci.* 15, 263–271. doi: 10.1016/j.tics.2011.04.008

Eisenegger, C., Naef, M., Snozzi, R., Heinrichs, M., and Fehr, E. (2010). Prejudice and truth about the effect of testosterone on human bargaining behaviour. *Nature* 463, 356–359. doi: 10.1038/nature08711

Emurian, H. H., Canfield, K., Roma, P. G., Gasior, E. D., Brinson, Z. S., Hienz, R. D., et al. (2009). Behavioral systems management of confined microsocieties: an agenda for research and applications. Proceedings of the 39th International Conference on Environmental Systems (paper number 2009-01-2423), Warrendale, PA, SAE International.

Epstein, J. M. (2006). *Generative social science: Studies in agent-based computational modeling*. Princeton, NJ: Princeton University Press.

Evans, W. E., and Relling, M. V. (2004). Moving towards individualized medicine with pharmacogenomics. *Nature* 429, 464–468. doi: 10.1038/nature02626

Feldman, R. (2012). Oxytocin and social affiliation in humans. *Horm. Behav.* 61, 380–391. doi: 10.1016/j.yhbeh.2012.01.008

Fiore, S. M., Wiltshire, T. J., Sanz, E. J., Pajank, M. E., and Center, J. S. (2015). Critical team cognitive processes for long-duration exploration missions. NASA TM-2015-218583.

Fleming, I., Baum, A., and Weiss, L. (1987). Social density and perceived control as mediators of crowding stress in high-density residential neighborhoods. *J. Pers. Soc. Psychol.* 52, 899–906.

Fletcher, A., Wesensten, N. J., Kandelaars, K., and Balkin, T. J. (2012). *Measuring and predicting sleep and performance during military operations*. Silver Spring, MD: Walter Reed Army Institute of Research.

Foxall, G. R. (2014a). Cognitive requirements of competing neuro-behavioral decision systems: some implications of temporal horizon for managerial behavior in organizations. *Front. Hum. Neurosci.* 8:184. doi: 10.3389/fnhum.2014.00184

Foxall, G. R. (2014b). The marketing firm and consumer choice: implications of bilateral contingency for levels of analysis in organizational neuroscience. *Front. Hum. Neurosci.* 8:472. doi: 10.3389/fnhum.2014.00472

Frankland, P. W., and Bontempi, B. (2005). The organization of recent and remote memories. *Nat. Rev. Neurosci.* 6, 119–130. doi: 10.1038/nrn1607

Fuster, J. M. (2001). The prefrontal cortex—an update: time is of the essence. *Neuron* 30, 319–333. doi: 10.1016/S0896-6273(01)00285-9

Gander, P. H., Purnell, H. M., Garden, A., and Woodward, A. (2007). Work patterns and fatigue-related risk among junior doctors. *Occup. Environ. Med.* 64, 733–738. doi: 10.1136/oem.2006.030916

Garrett-Bakelman, F. E., Darshi, M., Green, S. J., Gur, R. C., Lin, L., Macias, B. R., et al. (2019). The NASA twins study: a multidimensional analysis of a year-long human spaceflight. *Science* 364:eaau8650. doi: 10.1126/science.aau8650

Gianaros, P. J., Kuan, D. C. H., Marsland, A. L., Sheu, L. K., Hackman, D. A., Miller, K. G., et al. (2015). Community socioeconomic disadvantage in midlife relates to cortical morphology via neuroendocrine and cardiometabolic pathways. *Cereb. Cortex* 27, 460–473. doi: 10.1093/cercor/bhv233

Gitelson, J. I., Lisovsky, G. M., and MacElroy, R. D. (2003). *Manmade closed ecological systems*. New York: CRC Press.

Golden, S. J., Chang, C. H., and Kozlowski, S. W. (2018). Teams in isolated, confined, and extreme (ICE) environments: review and integration. *J. Organ. Behav.* 39, 701–715. doi: 10.1002/job.2288

Goodwin, G. F., Blacksmith, N., and Coats, M. R. (2018). The science of teams in the military: contributions from over 60 years of research. *Am. Psychol.* 73, 322–333. doi: 10.1037/amp0000259

Goswami, N., Batzel, J. J., Clément, G., Stein, T. P., Sharp, M. K., Blaber, A. P., et al. (2013). Maximizing information from space data resources: a case for expanding integration between research disciplines. *Eur. J. Appl. Physiol.* 113, 1645–1654. doi: 10.1007/s00421-012-2507-5

Goswami, N., Roma, P. G., De Boever, P., Clément, G., Hargens, A. R., Loeppky, J. A., et al. (2012). Using the moon as a high-fidelity analogue environment to study biological and behavioural mechanisms of long-duration space exploration. *Planet. Space Sci.* 74, 111–120. doi: 10.1016/j.pss.2012.07.030

Grillner, S. (2015). Action: the role of motor cortex challenged. *Curr. Biol.* 25, R508–R511. doi: 10.1016/j.cub.2015.04.023

Groeger, J. A., Viola, A. U., Lo, J. C., von Schantz, M., Archer, S. N., and Dijk, D. J. (2008). Early morning executive functioning during sleep deprivation is compromised by a PERIOD3 polymorphism. *Sleep* 31, 1159–1167. doi: 10.5665/sleep/31.8.1159

Grosso, G., Galvano, F., Marventano, S., Malaguarnera, M., Bucolo, C., Drago, F., et al. (2014). Omega-3 fatty acids and depression: scientific evidence and biological mechanisms. *Oxid. Med. Cell. Longev.* 2014:313570. doi: 10.1155/2014/313570

Haus, E. (2007). Chronobiology in the endocrine system. *Adv. Drug Deliv. Rev.* 59, 985–1014. doi: 10.1016/j.addr.2007.01.001

Heinrichs, M., Baumgartner, T., Kirschbaum, C., and Ehlert, U. (2003). Social support and oxytocin interact to suppress cortisol and subjective responses to psychosocial stress. *Biol. Psychiatry* 54, 1389–1398. doi: 10.1016/S0006-3223(03)00465-7

Heller, A. S., Johnstone, T., Shackman, A. J., Light, S. N., Peterson, M. J., Kolden, G. G., et al. (2009). Reduced capacity to sustain positive emotion in major depression reflects diminished maintenance of fronto-striatal brain activation. *Proc. Natl. Acad. Sci. USA* 106, 22445–22450. doi: 10.1073/pnas.0910651106

Hillman, C. H., Erickson, K. I., and Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nat. Rev. Neurosci.* 9, 58–65. doi: 10.1038/nrn2298

Howren, M. B., Lamkin, D. M., and Suls, J. (2009). Associations of depression with C-reactive protein, IL-1, and IL-6: a meta-analysis. *Psychosom. Med.* 71, 171–186. doi: 10.1097/PSY.0b013e3181907c1b

Ilgen, D. R., Hollenbeck, J. R., Johnson, M., and Jundt, D. (2005). Teams in organizations: from input-process-output models to IMOI models. *Annu. Rev. Psychol.* 56, 517–543. doi: 10.1146/annurev.psych.56.091103.070250

Jaggar, M., Fanibunda, S. E., Ghosh, S., Duman, R. S., and Vaidya, V. A. (2019). "The neurotrophic hypothesis of depression revisited: new insights and therapeutic implications" in *Neurobiology of depression*. eds. J. Quevedo, A. F. Carvalho, and C. A. Zarate (Cambridge, MA: Academic Press), 43–62.

Ju, S. Y., Lee, Y. J., and Jeong, S. N. (2013). Serum 25-hydroxyvitamin D levels and the risk of depression: a systematic review and meta-analysis. *J. Nutr. Health Aging* 17, 447–455. doi: 10.1007/s12603-012-0418-0

Karlin, R. A., Rosen, L. S., and Epstein, Y. M. (1979). Three into two doesn't go: a follow-up on the effects of overcrowded dormitory rooms. *Personal. Soc. Psychol. Bull.* 5, 391–395.

Kearney, A. R. (2016). Team health and performance in spaceflight habitats. NASA/TM-2016-219274.

Killeen, P. R. (2018). The futures of experimental analysis of behavior. *Behav. Anal. Res. Pract.* 18, 124–133. doi: 10.1037/bar0000100

Kim, J. S., and de La Serre, C. B. (2018). Diet, gut microbiota composition and feeding behavior. *Physiol. Behav.* 192, 177–181. doi: 10.1016/j.physbeh.2018.03.026

Kim, T. W., Jeong, J. H., and Hong, S. C. (2015). The impact of sleep and circadian disturbance on hormones and metabolism. *Int. J. Endocrinol.* 2015:591729. doi: 10.1155/2015/591729

Klerman, E. B., and Dijk, D. J. (2005). Interindividual variation in sleep duration and its association with sleep debt in young adults. *Sleep* 28, 1253–1259. doi: 10.1093/sleep/28.10.1253

Kozlowski, S. W. J., Chang, C. H., Perry, S. B., Pearce, M., Dixon, A. J., and Santoro, J. M. (2015). Capturing team process dynamics. Presented at the Annual Conference for the Society for Industrial/Organizational Psychologists, Philadelphia, PA.

Kozlowski, S. W. J., and Ilgen, D. R. (2006). Enhancing the effectiveness of work groups and teams. *Psychol. Sci. Public Interest* 7, 77–124. doi: 10.1111/j.1529-1006.2006.00030.x

Kozlowski, S. W. J., and Klein, K. J. (2000). "A multilevel approach to theory and research in organizations: contextual, temporal, and emergent processes" in *Multilevel theory, research and methods in organizations: Foundations, extensions, and new directions* (San Francisco, CA: Jossey-Bass), 3–90.

Kraemer, W. J., Flanagan, S. D., Volek, J. S., Nindl, B. C., Vingren, J. L., Dunn-Lewis, C., et al. (2013). Resistance exercise induces region-specific adaptations in anterior pituitary gland structure and function in rats. *J. Appl. Physiol.* 115, 1641–1647. doi: 10.1152/japplphysiol.00687.2013

Krakauer, J. W., Ghazanfar, A. A., Gomez-Marin, A., MacIver, M. A., and Poeppel, D. (2017). Neuroscience needs behavior: correcting a reductionist bias. *Neuron* 93, 480–490. doi: 10.1016/j.neuron.2016.12.041

Landon, L. B., Rokholt, C., Slack, K. J., and Pecena, Y. (2017). Selecting astronauts for long-duration exploration missions: considerations for team performance and functioning. *Reach* 5, 33–56. doi: 10.1016/j.reach.2017.03.002

Landon, L. B., Slack, K. J., and Barrett, J. D. (2018). Teamwork and collaboration in long-duration space missions: going to extremes. *Am. Psychol.* 73, 563–575. doi: 10.1037/amp0000260

Laurence, G. A., Fried, Y., and Slowik, L. H. (2013). "My space": a moderated mediation model of the effect of architectural and experienced privacy and workspace personalization on emotional exhaustion at work. *J. Environ. Psychol.* 36, 144–152. doi: 10.1016/j.jenvp.2013.07.011

Lazer, D., Pentland, A. S., Adamic, L., Aral, S., Barabasi, A. L., Brewer, D., et al. (2009). Life in the network: the coming age of computational social science. *Science* 323, 721–723. doi: 10.1126/science.1167742

Lebow, M. A., and Chen, A. (2016). Overshadowed by the amygdala: the bed nucleus of the stria terminalis emerges as key to psychiatric disorders. *Mol. Psychiatry* 21, 450–463. doi: 10.1038/mp.2016.1

LeDoux, J. (2007). The amygdala. *Curr. Biol.* 17, R868–R874. doi: 10.1016/j.cub.2007.08.005

Lee, N., Senior, C., and Butler, M. J. (2012). The domain of organizational cognitive neuroscience: theoretical and empirical challenges. *J. Manag.* 38, 921–931. doi: 10.1177/0149206312439471

Lemon, R. N. (2008). Descending pathways in motor control. *Annu. Rev. Neurosci.* 31, 195–218. doi: 10.1146/annurev.neuro.31.060407.125547

Lemos, J. R. (2012). "Magnocellular neurons" in *Encyclopedia of life sciences*. ed. S. K. Kendall (Chichester: John Wiley & Sons Ltd.), 19–21.

Lengyel, D. M., and Newman, J. S. (2014). International space station lessons learned for space exploration. NASA Public Lessons Learned System Database, Entry, 12603.

Leonard, B. E. (2005). The HPA and immune axes in stress: the involvement of the serotonergic system. *Eur. Psychiatry* 20, S302–S306. doi: 10.1016/s0924-9338(05)80180-4

Li, L., Su, Q., Xie, B., Duan, L., Zhao, W., Hu, D., et al. (2016). Gut microbes in correlation with mood: case study in a closed experimental human life support system. *Neurogastroenterol. Motil.* 28, 1233–1240. doi: 10.1111/nmo.12822

Luciano, M. M., Mathieu, J. E., Park, S., and Tannenbaum, S. I. (2018). A fitting approach to construct and measurement alignment: the role of big data in advancing dynamic theories. *Organ. Res. Methods* 21, 592–631. doi: 10.1177/1094428117728372

Lydiard, R. B. (2003). The role of GABA in anxiety disorders. *J. Clin. Psychiatry* 64, 21–27. Available at: https://www.psychiatrist.com/jcp/article/pages/2003/v64s03/v64s0304.aspx

Lynch, M. A. (2004). Long-term potentiation and memory. *Physiol. Rev.* 84, 87–136. doi: 10.1152/physrev.00014.2003

Marriott, B. M. (1995). *Not eating enough: Overcoming underconsumption of military operational rations*. Washington, DC: National Academies Press.

Mathieu, J. E., Kukenberger, M. R., D'innocenzo, L., and Reilly, G. (2015). Modeling reciprocal team cohesion–performance relationships, as impacted by shared leadership and members' competence. *J. Appl. Psychol.* 100, 713–734. doi: 10.1037/a0038898

Maynard, M. T., Kennedy, D. M., and Resick, C. J. (2018). Teamwork in extreme environments: lessons, challenges, and opportunities. *J. Organ. Behav.* 39, 695–700. doi: 10.1002/job.2302

McCann, J. C., and Ames, B. N. (2008). Is there convincing biological or behavioral evidence linking vitamin D deficiency to brain dysfunction? *FASEB J.* 22, 982–1001. doi: 10.1096/fj.07-9326rev

McClelland, J. L., McNaughton, B. L., and O'reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: insights from the successes and failures of connectionist models of learning and memory. *Psychol. Rev.* 102, 419–457. doi: 10.1037/0033-295X.102.3.419

McGaugh, J. L. (1992). "Neuromodulatory systems and the regulation of memory storage" in *Neuropsychology of memory*. eds. L. R. Squire, and N. Butters (New York, NY: Guilford Press), 386–401.

McMurray, I., Connolly, H., Preston-Shoot, M., and Wigley, V. (2008). Constructing resilience: social workers' understandings and practice. *Health Soc. Care Community* 16, 299–309. doi: 10.1111/j.1365-2524.2008.00778.x

Miller, E. K., and Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annu. Rev. Neurosci.* 24, 167–202. doi: 10.1146/annurev.neuro.24.1.167

Milon, H., Decarli, B., Adine, A. M., and Kihm, E. (1996). "Food intake and nutritional status during EXEMSI" in *Advances in space biology and medicine*. Vol. 5. ed. S. L. Bonting (Amsterdam: Elsevier), 79–91.

Mitsuya, H., Omata, N., Kiyono, Y., Mizuno, T., Murata, T., Mita, K., et al. (2015). The co-occurrence of zinc deficiency and social isolation has the opposite effects on mood compared with either condition alone due to changes in the central norepinephrine system. *Behav. Brain Res.* 284, 125–130. doi: 10.1016/j.bbr.2015.02.005

Mohanty, S., Jørgensen, J., and Nyström, M. (2006). Psychological factors associated with habitat design for planetary mission simulators. *Space 2006*, 1–12. doi: 10.2514/6.2006-7345

Molero-Luis, M., Serrano, M., O'Callaghan, M. M., Sierra, C., Pérez-Dueñas, B., García-Cazorla, A., et al. (2015). Clinical, etiological and therapeutic aspects of cerebral folate deficiency. *Expert. Rev. Neurother.* 15, 793–802. doi: 10.1586/14737175.2015.1055322

Murray, M. M., and Antonakis, J. (2019). An introductory guide to organizational neuroscience. *Organ. Res. Methods* 22, 6–16. doi: 10.1177/1094428118802621

Myers, B., and Greenwood-VanMeerveld, B. (2009). Role of anxiety in the pathophysiology of irritable bowel syndrome: importance of the amygdala. *Front. Neurosci.* 3:47. doi: 10.3389/neuro.21.002.2009

NASA (2015). Space flight human system standards. Volume 2: human factors, habitability, and environmental health. Rev. A. Available at: https://www.nasa.gov/sites/default/files/atoms/files/nasa-std-3001-vol-2a.pdf (Accessed November 5, 2019).

Nestler, E. J., and Carlezon, W. A. Jr. (2006). The mesolimbic dopamine reward circuit in depression. *Biol. Psychiatry* 59, 1151–1159. doi: 10.1016/j.biopsych.2005.09.018

Nohynek, L. J., Alakomi, H. L., Kähkönen, M. P., Heinonen, M., Helander, I. M., Oksman-Caldentey, K. M., et al. (2006). Berry phenolics: antimicrobial properties and mechanisms of action against severe human pathogens. *Nutr. Cancer* 54, 18–32. doi: 10.1207/s15327914nc5401_4

Obri, A., Khrimian, L., Karsenty, G., and Oury, F. (2018). Osteocalcin in the brain: from embryonic development to age-related decline in cognition. *Nat. Rev. Endocrinol.* 14, 174–182. doi: 10.1038/nrendo.2017.181

Ozbay, F., Johnson, D. C., Dimoulas, E., Morgan, C. A. III., Charney, D., and Southwick, S. (2007). Social support and resilience to stress: from neurobiology to clinical practice. *Psychiatry (Edgemont)* 4, 35–40.

Padgett, D. A., and Glaser, R. (2003). How stress influences the immune response. *Trends Immunol.* 24, 444–448. doi: 10.1016/S1471-4906(03)00173-X

Pariante, C. M., and Lightman, S. L. (2008). The HPA axis in major depression: classical theories and new developments. *Trends Neurosci.* 31, 464–468. doi: 10.1016/j.tins.2008.06.006

Patrick, R. P., and Ames, B. N. (2015). Vitamin D and the omega-3 fatty acids control serotonin synthesis and action, part 2: relevance for ADHD, bipolar disorder, schizophrenia, and impulsive behavior. *FASEB J.* 29, 2207–2222. doi: 10.1096/fj.14-268342

Perrow, C. (1984). *Normal accidents: Living with high risk systems*. New York: Basic Books.

Phillips, M. L., Young, A. W., Scott, S., Calder, A. J., Andrew, C., Giampietro, V., et al. (1998). Neural responses to facial and vocal expressions of fear and disgust. *Proc. R. Soc. Lond. Ser. B Biol. Sci.* 265, 1809–1817. doi: 10.1098/rspb.1998.0506

Pilz, L. K., Carissimi, A., Oliveira, M. A., Francisco, A. P., Fabris, R. C., Medeiros, M. S., et al. (2018). Rhythmicity of mood symptoms in individuals at risk for psychiatric disorders. *Sci. Rep.* 8:11402. doi: 10.1038/s41598-018-29348-z

Ploutz-Snyder, L., Ryder, J., English, K., Haddad, F., and Baldwin, K. (2015). *Evidence report: Risk of impaired performance due to reduced muscle mass, strength, and endurance*. Houston, TX: NASA Johnson Space Center. Available at: https://humanresearchroadmap.nasa.gov/Evidence/reports/Muscle.pdf (Accessed November 5, 2019).

Reid, K. J., Baron, K. G., Lu, B., Naylor, E., Wolfe, L., and Zee, P. C. (2010). Aerobic exercise improves self-reported sleep and quality of life in older adults with insomnia. *Sleep Med.* 11, 934–940. doi: 10.1016/j.sleep.2010.04.014

Ribeiro, S. C., Domingos-Lopes, M. F., Stanton, C., Ross, R. P., and Silva, C. C. (2018). Production of γ-aminobutyric acid (GABA) by *Lactobacillus otakiensis* and other *Lactobacillus* sp. isolated from traditional Pico cheese. *Int. J. Dairy Technol.* 71, 1012–1017. doi: 10.1111/1471-0307.12527

Roig, M., Skriver, K., Lundbye-Jensen, J., Kiens, B., and Nielsen, J. B. (2012). A single bout of exercise improves motor memory. *PLoS One* 7:e44594. doi: 10.1371/journal.pone.0044594

Roma, P. G., and Bedwell, W. L. (2017). "Key factors and threats to team dynamics in long-duration extreme environments" in *Research on managing groups and teams (vol. 18), team dynamics over time: Advances in theory, methods, and practice*. eds. E. Salas, W. B. Vessey, and L. B. Landon (Bingley, UK: Emerald Publishing Limited), 155–187.

Roohani, N., Hurrell, R., Kelishadi, R., and Schulin, R. (2013). Zinc and its importance for human health: an integrative review. *J. Res. Med. Sci.* 18, 144–157.

Rosenwasser, A. M. (2009). Functional neuroanatomy of sleep and circadian rhythms. *Brain Res. Rev.* 61, 281–306. doi: 10.1016/j.brainresrev.2009.08.001

Ross, H. E., and Young, L. J. (2009). Oxytocin and the neural mechanisms regulating social cognition and affiliative behavior. *Front. Neuroendocrinol.* 30, 534–547. doi: 10.1016/j.yfrne.2009.05.004

Rothhammer, V., Borucki, D. M., Tjon, E. C., Takenaka, M. C., Chao, C. C., Ardura-Fabregat, A., et al. (2018). Microglial control of astrocytes in response to microbial metabolites. *Nature* 557, 724–728. doi: 10.1038/s41586-018-0119-x

Salamone, J. D., Correa, M., Mingote, S. M., and Weber, S. M. (2005). Beyond the reward hypothesis: alternative functions of nucleus accumbens dopamine. *Curr. Opin. Pharmacol.* 5, 34–41. doi: 10.1016/j.coph.2004.09.004

Salas, E., Reyes, D. L., and McDaniel, S. H. (2018). The science of teamwork: progress, reflections, and the road ahead. *Am. Psychol.* 73, 593–600. doi: 10.1037/amp0000334

Salgado, S., and Kaplitt, M. G. (2015). The nucleus accumbens: a comprehensive review. *Stereotact. Funct. Neurosurg.* 93, 75–93. doi: 10.1159/000368279

Sampson, T. R., and Mazmanian, S. K. (2015). Control of brain development, function, and behavior by the microbiome. *Cell Host Microbe* 17, 565–576. doi: 10.1016/j.chom.2015.04.011

Sarter, M., Givens, B., and Bruno, J. P. (2001). The cognitive neuroscience of sustained attention: Where top-down meets bottom-up. *Brain Res. Rev.* 35, 146–160. doi: 10.1016/s0165-0173(01)00044-3

Seidel, E. M., Silani, G., Metzler, H., Thaler, H., Lamm, C., Gur, R. C., et al. (2013). The impact of social exclusion vs. inclusion on subjective and hormonal reactions in females and males. *Psychoneuroendocrinology* 38, 2925–2932. doi: 10.1016/j.psyneuen.2013.07.021

Shaffer, J. A., Edmondson, D., Wasson, L. T., Falzon, L., Homma, K., Ezeokoli, N., et al. (2014). Vitamin D supplementation for depressive symptoms: a systematic review and meta-analysis of randomized controlled trials. *Psychosom. Med.* 76, 190–196. doi: 10.1097/PSY.0000000000000044

Shalvi, S., and De Dreu, C. K. (2014). Oxytocin promotes group-serving dishonesty. *Proc. Natl. Acad. Sci. USA* 111, 5503–5507. doi: 10.1073/pnas.1400724111

Shan, C., Ghosh, A., Guo, X. Z., Wang, S. M., Hou, Y. F., Li, S. T., et al. (2019). Roles for osteocalcin in brain signalling: implications in cognition- and motor-related disorders. *Mol. Brain* 12:23. doi: 10.1186/s13041-019-0444-5

Sian, J., Youdim, M. B. H., Riederer, P., and Gerlach, M. (1999). "Biochemical anatomy of the basal ganglia and associated neural systems" in *Basic neurochemistry: Molecular, cellular and medical aspects. 6th Edn*. eds. G. J. Siegel, B. W. Agranoff, R. W. Albers, S. K. Fisher, and M. D. Uhler (Philadelphia: Lippincott-Raven).

Silverman, M. N., and Deuster, P. A. (2014). Biological mechanisms underlying the role of physical fitness in health and resilience. *Interface Focus* 4:20140040. doi: 10.1098/rsfs.2014.0040

Silverstone, S. E. (1997). Food production and nutrition for the crew during the first 2-year closure of biosphere 2. *Life Support Biosph. Sci.* 4, 167–178.

Smith, S. M., Wastney, M. E., Morukov, B. V., Larina, I. M., Nyquist, L. E., Abrams, S. A., et al. (1999). Calcium metabolism before, during, and after a 3-mo spaceflight: kinetic and biochemical changes. *Am. J. Physiol. Regul. Integr. Comp. Physiol.* 277, R1–R10.

Šolcová, I. P., Šolcová, I., Stuchlíková, I., and Mazehóová, Y. (2016). The story of 520 days on a simulated flight to Mars. *Acta Astronaut.* 126, 178–189. doi: 10.1016/j.actaastro.2016.04.026

Squire, L. R. (1992). Memory and the hippocampus: a synthesis from findings with rats, monkeys, and humans. *Psychol. Rev.* 99, 195–231. doi: 10.1037/0033-295X.99.2.195

Statton, M. A., Encarnacion, M., Celnik, P., and Bastian, A. J. (2015). A single bout of moderate aerobic exercise improves motor skill acquisition. *PLoS One* 10:e0141393. doi: 10.1371/journal.pone.0141393

Stilling, R. M., Dinan, T. G., and Cryan, J. F. (2014). Microbial genes, brain & behaviour–epigenetic regulation of the gut–brain axis. *Genes Brain Behav.* 13, 69–86. doi: 10.1111/gbb.12109

Stuster, J. (1996). *Bold endeavors: Lessons from polar and space exploration*. Annapolis, MD: Naval Institute Press.

Stuster, J. (2010). Behavioral issues associated with isolation and confinement: review and analysis of astronaut journals. National Aeronautics and Space Administration. NASA/TM-2010-216130.

Stuster, J. (2016). Behavioral issues associated with long duration space expeditions: review and analysis of astronaut journals. Phase 2 final report. NASA/TM-2016-218603.

Supekar, K., Kochalka, J., Schaer, M., Wakeman, H., Qin, S., Padmanabhan, A., et al. (2018). Deficits in mesolimbic reward pathway underlie social interaction impairments in children with autism. *Brain* 141, 2795–2805. doi: 10.1093/brain/awy191

Sylvia, K. E., and Demas, G. E. (2018). A gut feeling: microbiome-brain-immune interactions modulate social and affective behaviors. *Horm. Behav.* 99, 41–49. doi: 10.1016/j.yhbeh.2018.02.001

Teixeira, P. J., Carraça, E. V., Markland, D., Silva, M. N., and Ryan, R. M. (2012). Exercise, physical activity, and self-determination theory: a systematic review. *Int. J. Behav. Nutr. Phys. Act.* 9, 78. doi: 10.1186/1479-5868-9-78

Tengeler, A. C., Kozicz, T., and Kiliaan, A. J. (2018). Relationship between diet, the gut microbiota, and brain function. *Nutr. Rev.* 76, 603–617. doi: 10.1093/nutrit/nuy016

Topol, E. J. (2014). Individualized medicine from prewomb to tomb. *Cell* 157, 241–253. doi: 10.1016/j.cell.2014.02.012

Vadnie, C. A., and McClung, C. A. (2017). Circadian rhythm disturbances in mood disorders: insights into the role of the suprachiasmatic nucleus. *Neural Plast.* 2017:1504507. doi: 10.1155/2017/1504507

van der Helm, E., Gujar, N., and Walker, M. P. (2010). Sleep deprivation impairs the accurate recognition of human emotions. *Sleep* 33, 335–342. doi: 10.1093/sleep/33.3.335

Van Dongen, H. P. A. (2004). Comparison of mathematical model predictions to experimental data of fatigue and performance. *Aviat. Space Environ. Med.* 75(Suppl. 3), A15–A36. Available at: https://www.ingentaconnect.com/content/asma/asem/2004/00000075/a00103s1/art00003

Vandewalle, G., Archer, S. N., Wuillaume, C., Balteau, E., Degueldre, C., Luxen, A., et al. (2009). Functional magnetic resonance imaging-assessed brain responses during an executive task depend on interaction of sleep homeostasis, circadian phase, and PER3 genotype. *J. Neurosci.* 29, 7948–7956. doi: 10.1523/JNEUROSCI.0229-09.2009

Vuong, H. E., Yano, J. M., Fung, T. C., and Hsiao, E. Y. (2017). The microbiome and host behavior. *Annu. Rev. Neurosci.* 40, 21–49. doi: 10.1146/annurev-neuro-072116-031347

Wall, R., Cryan, J. F., Ross, R. P., Fitzgerald, G. F., Dinan, T. G., and Stanton, C. (2014). "Bacterial neuroactive compounds produced by psychobiotics"

in *Microbial endocrinology: The microbiota-gut-brain axis in health and disease*. eds. M. Lyte and J. F. Cryan (New York, NY: Springer), 221–239.

Whitmore, J., Chaiken, S., Fischer, J., Harrison, R., and Harville, D. (2008). Sleep loss and complex team performance. Air Force Research Lab Human Effectiveness Directorate Biosciences and Protection Division (No. AFRL-RH-BR-TR-2008-0005).

Whitmore, M., McGuire, K., Margerum, S., Thompson, S., Allen, C., Bowen, C., et al. (2013). *Evidence report: Risk of incompatible vehicle/habitat design*. Houston, TX: NASA Johnson Space Center.

Wikoff, W. R., Anfora, A. T., Liu, J., Schultz, P. G., Lesley, S. A., Peters, E. C., et al. (2009). Metabolomics analysis reveals large effects of gut microflora on mammalian blood metabolites. *Proc. Natl. Acad. Sci. USA* 106, 3698–3703. doi: 10.1073/pnas.0812874106

Xie, L., Kang, H., Xu, Q., Chen, M. J., Liao, Y., Thiyagarajan, M., et al. (2013). Sleep drives metabolite clearance from the adult brain. *Science* 342, 373–377. doi: 10.1126/science.1241224

Xie, Y., Yang, W., Tang, F., Chen, X., and Ren, L. (2015). Antibacterial activities of flavonoids: structure-activity relationship and mechanism. *Curr. Med. Chem.* 22, 132–149. doi: 10.2174/0929867321666140916113443

Yang, Y., and Raine, A. (2009). Prefrontal structural and functional brain imaging findings in antisocial, violent, and psychopathic individuals: a meta-analysis. *Psychiatry Res. Neuroimaging* 174, 81–88. doi: 10.1016/j.pscychresns.2009.03.012

Yehuda, R. (2001). Biology of posttraumatic stress disorder. *J. Clin. Psychiatry* 62(Suppl. 17), 41–46. Available at: https://www.psychiatrist.com/jcp/article/pages/2001/v62s17/v62s1708.aspx

Zyphur, M. J., Narayanan, J., Koh, G., and Koh, D. (2009). Testosterone-status mismatch lowers collective efficacy in groups: evidence from a slope-as-predictor multilevel structural equation model. *Organ. Behav. Hum. Decis. Process.* 110, 70–79. doi: 10.1016/j.obhdp.2009.05.004

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Landon, Douglas, Downs, Greene, Whitmire, Zwart and Roma. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

frontiers in Psychology

OPINION
published: 04 September 2020
doi: 10.3389/fpsyg.2020.02128

The Evolution and Maturation of Teams in Organizations: Convergent Trends in the New Dynamic Science of Teams

Marissa L. Shuffler[1], *Eduardo Salas*[2] *and Michael A. Rosen*[3]*

[1] College of Behavioral Social and Health Sciences, Clemson University, Clemson, SC, United States, [2] Department of Psychology, Rice University, Houston, TX, United States, [3] Department of Anesthesiology and Critical Care Medicine, Johns Hopkins University School of Medicine, Baltimore, MD, United States

Keywords: teams and groups, time, teamwork, work team, team training

OPEN ACCESS

Edited by:
Ishani Aggarwal,
Brazilian School of Public and Business Administration, Brazil

Reviewed by:
Esther Sackett,
Santa Clara University, United States
Anna T. Mayo,
Johns Hopkins University, United States

***Correspondence:**
Michael A. Rosen
mrosen44@jhmi.edu

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *18 June 2020*
Accepted: *30 July 2020*
Published: *04 September 2020*

Citation:
Shuffler ML, Salas E and Rosen MA (2020) The Evolution and Maturation of Teams in Organizations: Convergent Trends in the New Dynamic Science of Teams. Front. Psychol. 11:2128. doi: 10.3389/fpsyg.2020.02128

Teams play a central role in the most innovative (Ahmadpoor and Jones, 2019), safety critical (Salas et al., 2020), and economically impactful work (Duhigg, 2016). They pervade modern organizations and drive performance outcomes (LePine et al., 2008; Hughes et al., 2016) and worker well-being (Welp and Manser, 2016; Mathieu et al., 2017). Consequently, researchers across a broad array of disciplines have focused on teams as an object of inquiry. Understanding and improving team functioning is a complex multi-level scientific problem, and, over the decades, much has been learned (Salas et al., 2018). The science of teams comprises a broad and deep knowledge base of both theory and empirical evidence, including topics such as structural inputs to team performance (e.g., team member composition, organizational context, effects of technology) and team interaction processes and emergent states (e.g., leadership, communication, mutual trust, collective efficacy). However, while the science of teams is strong, much remains to be discovered–especially from a temporal perspective. Calls for dynamic views of teams are not new (Cronin et al., 2011), but the field is shifting in numerous theoretical and methodological ways. The confluence of driving forces magnifying in intensity (i.e., modern work becoming more collaborative) and restraining forces reducing in intensity (i.e., traditional, resource-intensive measurement methods giving way to new unobtrusive, embedded metrics) allows for the science of teams to explore new directions in the dynamics of teams.

This new phase of team science is concerned with the *temporality of teams*: how teams evolve and mature, and how team dynamics play out over time. Accordingly, the purpose of this special issue is to offer current theory and research that describes the state of temporality in team science thus far, identifies future research needs, and highlight impactful insights for practice. The articles in this special issue represent work across the broad spectrum of research incorporating time in new ways. In this commentary, we identify eight themes in dynamic approaches to teams, and highlight how articles in this special issue exemplify these trends in the field (See **Table 1**). More specifically, we note that dynamics are impacting the fundamental theory and methods of the science of teams (Themes 1–4), the types of team phenomena being investigated (Themes 5–6), and application of team science in context (Theme 7) and to interventions that promote team effectiveness (Theme 8).

METHODS AND THEORIES OF TEAM DYNAMICS ARE CO-EVOLVING TOWARD A MORE ROBUST SET OF CONCEPTUAL AND ANALYTIC TOOLS

New theories require new measurement methods and new methods enable different conceptualizations of team dynamics. This co-evolution of method and theory is currently underway and involves both advances in data acquisition and analysis (Rosen et al., 2015). For example, systems dynamics, and more broadly complexity science, has long

TABLE 1 | Overarching themes across the special issue regarding temporality and the science of teams.

Theme	Description and implications for the science of teams
Theory and methods for advancing a dynamic science of teams	
1. Methods and theories of team dynamics are co-evolving, moving through a phase of discovery and diversity toward a more robust and stable set of conceptual and analytic tools	• New measurement methods are enabling the development and application of new theoretical frameworks • Methodological practices vary widely in current research evaluating team dynamics • Best practices are beginning to emerge including guidance linking methods to dynamic team phenomena
2. The science of teams is becoming multi (time) scale, not just multi-level, and future research will investigate phenomena across very short and very long timescales	• Research is pursuing an understanding of team member interactions that play out at very short timescales • Research is pursuing team functioning over long time scales • Future research will begin to understand how phenomena operating at one time scale influence those operating at much different time scales
3. Team research is revisiting traditionally static or stable characteristics of teams, and future research will better characterize how those characteristics or their effects change over time	• Traditionally, team inputs have been viewed as static, or time invariant • Many of the traditional team inputs or their effects on team interactions and outcomes have been shown to change over time • Team science will incorporate an understanding of how these factors or their effects change over time
4. The science of teams incorporates ever broader ranges of individual factors and will routinely include the biological and physiological dynamics of team members	• Biological and physiological phenomena are being included in models and studies of team functioning • This research area will advance quickly due to parallel advances in other areas of social and organizational sciences
Dynamic team phenomena being researched	
5. Learning in teams is critical in modern organizations, and the science of teams is uncovering the dynamics of team learning processes and the context of learning	• Learning is inherently temporal • Research is refining a dynamic understanding of team learning processes as well as how the context of learning emerges and changes over time
6. Emotions are central to teams, and the science of teams is uncovering the dynamics of the ebb, flow, and mutual influence of affect amongst team members	• Emotions of team members rise and fall, and influence one another in complex ways • Research is beginning to incorporate dynamic views and methods of affect measurement into studies • A more dynamic understanding of team affect can inform many research topics, including a wide range of team interpersonal processes
Context of research, generalizability, and interventions from a dynamic science of teams	
7. High risk/high stake industries are leading the way for team dynamics research, but the science of teams must attend to generalizability across settings	• Much of the research on team dynamics is coming from a limited set of organizational settings • Empirical studies of team functioning may be more context bound than less temporally focused studies • The science of teams will need to establish methods and practices for establishing generalizability of highly dynamic models and studies
8. A better understanding of team dynamics can drive new and adaptive interventions to shape dynamics	• Traditional methods of team development are being revisited given the emerging science of team dynamics • New, dynamic, and adaptive interventions will emerge, both from the research community and from practice

been an inspiration to theory development for team and group researchers (Arrow et al., 2000). In this issue, Meinecke et al. (2019) elaborate on this theoretical lens and describe the application of state-space grids to the challenges of operationalizing systems dynamics concepts for measuring and understanding team dynamics. Relatedly, Marques-Quinteiro et al. (2019) use a complex adaptive systems perspective and latent growth modeling to explore the interplay of behavior and affect in teams. These studies employ conceptually similar frameworks and disparate methods to explore important teamwork issues. This diversity is healthy for the field. However, as the measurement and analytic toolbox grows, it is important to codify what is known about what methods are appropriate for which team phenomenon and under which conditions. Delice et al. (2019) provide a valuable framework for mapping methodological choices to facets of team dynamics. As Kolbe and Boos (2019) clearly articulate, historically, methods that meaningfully capture team dynamics tend to be more labor intensive than those that measure team phenomena at a much lower temporal resolution. For example, communication coding at the utterance level requires far more researcher time than summative ratings of communication, and even current implementations of automated methods are more complicated and effortful to conduct than survey research. However, methods are advancing quickly. We foresee more and better methodological options in coming years, which will allow for and require new ways of theorizing about teams.

THE SCIENCE OF TEAMS IS BECOMING MULTI (TIME) SCALE, NOT JUST MULTI-LEVEL

Pursuing a dynamic approach to teams requires decisions about how time is conceptualized and operationalized (Mohammed et al., 2009). Conceptually, how is time being incorporated

into theory and hypotheses? Operationally, decisions need to be made about appropriate temporal granularity or resolution for measurement, and how this supports the valid measurement of different phenomena. This includes thinking longitudinally about teams existing and changing over very long periods of time [e.g., research on teams on long duration space exploration missions, (Bell et al., 2019); or functioning in other Isolated, Confined and Extreme (ICE) environments; (Landon et al., 2019)], as well as looking at very "thin slices" of interaction across multiple streams of data (i.e., linguistic and paralinguistic communication, physiological activation, behavior; Rosen et al., 2018). There is exciting work in each of these ranges of timescales for team dynamics; however, there is very little that integrates them both. From research on interpersonal dynamics outside of work team settings we know that patterns on one time scale (e.g., seconds to milliseconds) can predict patterns over very different timescales [e.g., years; (Gottman et al., 2002)]. To progress, the field needs more cross-timescale studies, refined methods for conducting such analyses, and conceptual tools for building multi-scale (not just multi-level) theory. Future research will investigate phenomena across differing (i.e., short, long) time scales.

TEAM SCIENCE IS REVISITING TRADITIONALLY STATIC OR STABLE TEAM CHARACTERISTICS

Everything changes. So, exactly how stable are team inputs? Does their relationship to team dynamics and outcomes change over time? These questions drive important research in team dynamics focused on better understanding stability and change in teams (Kerrissey et al., 2020). First, research is elucidating how the relationship between inputs and team dynamics or outcomes shifts as a function of time. For example, Burke et al. (2019) investigate how the instrumentality of different team roles changes over extended team missions. Second, research is revisiting how aspects of teams traditionally viewed as stable and unchanging through a team performance episode, do in fact change and how this relates to outcomes. Bedwell (2019) explores how membership fluidity impacts shared mental model development. As described by Benishek and Lazzara (2019), our understanding of these and other team attributes once conceived of as time invariant will be reevaluated and allow us to refine what we thought were stable team attributes. Undoubtedly, future research will better extrapolate how team characteristics and their effects change over time.

TEAM SCIENCE NOW INCORPORATES EVER BROADER RANGES OF INDIVIDUAL FACTORS TO INCLUDE THE BIOLOGICAL AND PHYSIOLOGICAL DYNAMICS OF TEAM MEMBERS

The science of teams has pursued multi-level approaches for decades (Klein and Kozlowski, 2000); however, the strata continue to deepen. It is no longer just individuals nested in teams, but biological attributes and physiological processes nested within individuals within teams within larger organizational entities and time. Landon et al. (2019) provide a wide ranging and integrative review of the topic as it relates to performance within ICE settings, and Stevens et al. (2019) provide a remarkable example of how patterns of physiological activation across team members can be identified and used to predict team outcomes. These articles are exemplars of the emerging area of team physiological dynamics, which has accelerated rapidly in recent years (Kazi et al., 2019). The science of teams can progress quickly in this area by exploring related areas of social (Cacioppo et al., 2000) and organizational neuroscience (Becker et al., 2011) and interpersonal physiological dynamics outside of work team contexts (Palumbo et al., 2017). The rapid improvement in wearable physiological measurement devices make the collection of this type of data increasingly feasible, even in field settings. Consequently, physiological measurement in team studies will become increasingly common, and methods and theory will mature rapidly. As this work matures, measurement and theory development will have to address linkages between these lower level biological states and processes, and higher level, abstract constructs such as mutual trust and support or other team processes and emergent states. Innovative approaches to handling these issues have been introduced (Luciano et al., 2018), but much more remains to be done.

THE SCIENCE OF TEAMS IS UNCOVERING THE DYNAMICS OF TEAM LEARNING PROCESSES AND THE IMPACT OF CONTEXT ON LEARNING

Demands for continuous improvement are commonplace in today's organizations [e.g., Toussaint and Ehrlich (2017)]. Market competition is frequently steep, and external and internal environments shift [e.g., Autor et al. (2016)]. To succeed, teams need to learn from their experiences and the experiences of others. Consequently, team learning has emerged as both a critical team process and a type of performance investigated from a dynamic perspective. Given that learning inherently involves change, time is central to team learning. Wiese and Burke (2019) critically review extant team learning research and formulate a temporal model of how team learning unfolds over time. In addition to the learning process itself, the local conditions within the team and its context influence if or how learning happens. This learning climate has historically been viewed as a relatively stable or slow-moving phenomenon. However, Harvey et al. (2019) apply systems dynamics modeling to forward a theory of team learning climate, and how it rises and falls with changes in levels of psychological safety, cohesion, efficacy, and goal orientation within the team. Again, several of these constructs previously considered time invariant can be reexamined through a dynamic lens to move the field forward.

THE SCIENCE OF TEAMS IS UNCOVERING THE DYNAMICS OF THE EBB, FLOW, AND MUTUAL INFLUENCE OF AFFECT AMONGST TEAM MEMBERS

Affect is not a novel concept to the science of teams; in fact, emotions are central to effective teamwork (Salas et al., 2018). The roles of trust, cohesion, collective orientation and numerous other attitudes, emotional states and dispositional variables on team effectiveness have been widely researched. However, this new dynamic-focused approach to teams allows for a more nuanced understanding of how affect changes over time, how it influences and is influenced by other team phenomena over time, and how the effect of team members is shared.

In our special issue, the dynamic nature of affect is explored using similar methodological approaches, yet with two very different sets of constructs in order to expand our understanding of how teams may grow and change in their affective states over time. Woodley et al. (2019) utilize latent growth and consensus emergence modeling techniques to investigate changes in team potency over time. Marques-Quinteiro et al. (2019) also apply latent growth modeling, but to cohesion and its relationship to coordination and performance. Advances in understanding the dynamics of affect in teams can help to address a wide range of issues in the study of team functioning, from stress, burnout, and well-being, to conflict management and relationship building. While not limited to interpersonal team processes, a more dynamic understanding of affect in teams can certainly advance this critical aspect of teams.

HIGH RISK/HIGH STAKE INDUSTRIES ARE LEADING THE WAY FOR TEAM DYNAMICS RESEARCH, BUT THE SCIENCE OF TEAMS MUST ATTEND TO GENERALIZABILITY ACROSS SETTINGS

Context matters, and certain industries have embraced the importance of team dynamics as the links between team functioning and valued organizational outcomes in that industry are particularly salient. Articles in this special address spaceflight (Bell et al., 2019; Pendergraft et al., 2019) military (Demir et al., 2019; Johnston et al., 2019), healthcare (Stevens et al., 2019), and isolated and confined environments (Landon et al., 2019). While this list of industries is by no means exhaustive of those pursuing team-based work strategies or engaged in research efforts to understand and improve team dynamics, it is representative of the key contributors. Advancing the science of teams through dynamic approaches can add detail and specificity to the models (e.g., higher granularity of measurements) and many of the theories and analytic approaches applied to date emphasize principles such as sensitivity to initial conditions, all of which suggest that more dynamic models may be more tightly bound to their context. The maturation of dynamic approaches to the science of teams requires parallel developments in how research handles context in studies, specifically the role context plays constraining and enabling the occurrence and meaning of different team dynamics (Johns, 2006). Better methods for representing and interpreting context will be crucially important to a robust science of team dynamics.

A BETTER UNDERSTANDING OF TEAM DYNAMICS CAN DRIVE NEW AND ADAPTIVE INTERVENTIONS FOR TEAM EFFECTIVENESS

As a practical matter, a more refined understanding of team dynamics is valuable to organizations only if it can be translated into mechanisms for improved performance. A more robust understanding of how team dynamics drive performance outcomes enables new and improved interventions to support effective team dynamics. This includes advancing our knowledge about how to most effectively use familiar interventions like meetings (Mroz et al., 2019) and team training (Johnston et al., 2019), as well as more novel approaches like automated feedback in virtual teams (Glikson et al., 2019) and well-being interventions (Wiese and Burke, 2019). The future will continue to see extension and refinement of tried and true methods of team development informed by more dynamic understanding of teams as well as new forms of real-time support for teams and use of synthetic agents as team members and coaches (Demir et al., 2019). As is often the case, practice may lead research in the area of intervention development. Researchers should look to innovations in the field and capitalize on them to generate insights into underlying mechanisms of team dynamics.

CONCLUSION

The time has arrived for a serious treatment of time in all aspects of research on teams. The need for dynamic approaches to understanding teams has long been heralded. The articles in this special issue demonstrate that the field is delivering on that vision of research on teams, a vision that places temporality at the center of both theory, methods, and evidence-driven applications. We are at the leading edge of this transformation of the field. Theory is still nascent for team phenomenon over and across very long or very short timescales. Methodological practices are in a divergent, exploratory phase where wide variation of new methods is observed and best practices have yet to emerge. But the progress over recent years is remarkable, and the value of pursuing a science of team temporality is clear.

AUTHOR CONTRIBUTIONS

All authors were involved in drafting and reviewing final manuscript.

FUNDING

This work was partially supported by a grant from the National Aeronautics and Space Administration (#NNX17AB55G; PI: MR), and the National Science Foundation (#1654054, PI: MS).

REFERENCES

Ahmadpoor, M., and Jones, B. F. (2019). Decoding team and individual impact in science and invention. *Proc. Natl. Acad. Sci. U. S. A.* 116, 13885–13890. doi: 10.1073/pnas.1812341116

Arrow, H., McGrath, J. E., and Berdahl, J. L. (2000). *Small Groups as Complex Systems: Formation, Coordination, Development, and Adaptation*. Thousand Oaks, CA: SAGE Publications.

Autor, D., Dorn, D., Hanson, G. H., Pisano, G., and Shu, P. (2016). *Foreign competition and domestic innovation: Evidence from US patents (p. w22879)*. Cambridge, MA: National Bureau of Economic Research. doi: 10.3386/w22879

Becker, W. J., Cropanzano, R., and Sanfey, A. G. (2011). Organizational neuroscience: Taking organizational theory inside the neural black box. *J. Manag.* 37, 933–961. doi: 10.1177/0149206311398955

Bedwell, W. L. (2019). Adaptive team performance: the influence of membership fluidity on shared team cognition. *Front. Psychol.* 10:2266. doi: 10.3389/fpsyg.2019.02266

Bell, S. T., Brown, S. G., and Mitchell, T. (2019). What we know about team dynamics for long-distance space missions: a systematic review of analog research. *Front. Psychol.* 10:811. doi: 10.3389/fpsyg.2019.00811

Benishek, L. E., and Lazzara, E. H. (2019). Teams in a new era: some considerations and implications. *Front. Psychol.* 10:1006. doi: 10.3389/fpsyg.2019.01006

Burke, C. S., Georganta, E., and Marlow, S. (2019). A bottom up perspective to understanding the dynamics of team roles in mission critical teams. *Front. Psychol.* 10:1322. doi: 10.3389/fpsyg.2019.01322

Cacioppo, J. T., Berntson, G. G., Sheridan, J. F., and McClintock, M. K. (2000). Multilevel integrative analyses of human behavior: social neuroscience and the complementing nature of social and biological approaches. *Psychol. Bull.* 126, 829–843. doi: 10.1037/0033-2909.126.6.829

Cronin, M. A., Weingart, L. R., and Todorova, G. (2011). Dynamics in groups: are we there yet? *Acad. Manag. Ann.* 5, 571–612. doi: 10.1080/19416520.2011.590297

Delice, F., Rousseau, M., and Feitosa, J. (2019). Advancing teams research: what, when, and how to measure team dynamics over time. *Front. Psychol.* 10:1324. doi: 10.3389/fpsyg.2019.01324

Demir, M., McNeese, N. J., and Cooke, N. J. (2019). The evolution of human-autonomy teams in remotely piloted aircraft systems operations. *Front. Commun.* 4:50. doi: 10.3389/fcomm.2019.00050

Duhigg, C. (2016). *What Google Learned From Its Quest to Build the Perfect Team*. The New York Times. Available online at: https://www.nytimes.com/2016/02/28/magazine/what-google-learned-from-its-quest-to-build-the-perfect-team.html?smid=pl-share (accessed July 28, 2020).

Glikson, E., Woolley, A. W., Gupta, P., and Kim, Y. J. (2019). Visualized automatic feedback in virtual teams. *Front. Psychol.* 10:814. doi: 10.3389/fpsyg.2019.00814

Gottman, J. M., Murray, J. D., Swanson, C. C., Tyson, R., and Swanson, K. R. (2002). *The Mathematics of Marriage: Dynamic Nonlinear Models*. Cambridge, MA: MIT Press. doi: 10.7551/mitpress/4499.001.0001

Harvey, J., Leblanc, P., and Cronin, M. A. (2019). Beyond separate emergence: a systems view of team learning climate. *Front. Psychol.* 10:1441. doi: 10.3389/fpsyg.2019.01441

Hughes, A. M., Gregory, M. E., Joseph, D. L., Sonesh, S. C., Marlow, S. L., Lacerenza, C. N., et al. (2016). Saving lives: a meta-analysis of team training in healthcare. *J. Appl. Psychol.* 101, 1266–1304. doi: 10.1037/apl0000120

Johns, G. (2006). The essential impact of context on organizational behavior. *Acad. Manag. Ann.* 31, 386–408. doi: 10.5465/amr.2006.20208687

Johnston, J. H., Phillips, H. L., Milham, L. M., Riddle, D. L., Townsend, L. N., DeCostanza, A. H., et al. (2019). A team training field research study: extending a theory of team development. *Front. Psychol.* 10:1480. doi: 10.3389/fpsyg.2019.01480

Kazi, S., Khaleghzadegan, S., Dinh, J. V., Shelhamer, M. J., Sapirstein, A., Goeddel, L. A., et al. (2019). Team physiological dynamics: a critical review. *Hum. Factor.* doi: 10.1177/0018720819874160. [Epub ahead of print].

Kerrissey, M. J., Satterstrom, P., and Edmondson, A. C. (2020). Into the fray: adaptive approaches to studying novel teamwork forms. *Org. Psychol. Rev.* 10, 62–86. doi: 10.1177/2041386620912833

Klein, K. J., and Kozlowski, S. W. J. (2000). *Multilevel Theory, Research, and Methods in Organizations: Foundations, Extensions, and New Directions*. San Francisco, CA: Wiley.

Kolbe, M., and Boos, M. (2019). Laborious but elaborate: the benefits of really studying team dynamics. *Front. Psychol.* 10:1478. doi: 10.3389/fpsyg.2019.01478

Landon, L. B., Douglas, G. L., Downs, M. E., Greene, M. R., Whitmire, A. M., Zwart, S. R., et al. (2019). The behavioral biology of teams: multidisciplinary contributions to social dynamics in isolated, confined, and extreme environments. *Front. Psychol.* 10:2571. doi: 10.3389/fpsyg.2019.02571

LePine, J. A., Piccolo, R. F., Jackson, C. L., Mathieu, J. E., and Saul, J. R. (2008). A meta-analysis of teamwork processes: tests of a multidimensional model and relationships with team effectiveness criteria. *Personnel Psychol.* 61, 273–307. doi: 10.1111/j.1744-6570.2008.00114.x

Luciano, M. M., Mathieu, J. E., Park, S., and Tannenbaum, S. I. (2018). A fitting approach to construct and measurement alignment: the role of big data in advancing dynamic theories. *Org. Res. Method.* 21, 592–632. doi: 10.1177/1094428117728372

Marques-Quinteiro, P., Rico, R., Passos, A. M., and Curral, L. (2019). There is light and there is darkness: on the temporal dynamics of cohesion, coordination, and performance in business teams. *Front. Psychol.* 10:847. doi: 10.3389/fpsyg.2019.00847

Mathieu, J. E., Hollenbeck, J. R., van Knippenberg, D., and Ilgen, D. R. (2017). A century of work teams in the journal of applied psychology. *J. Appl. Psychol.* 102, 452–467. doi: 10.1037/apl0000128

Meinecke, A. L., Hemshorn de Sanchez Clara, S., Lehmann-Willenbrock, N., and Buengeler, C. (2019). Using state space grids for modeling temporal team dynamics. *Front. Psychol.* 10:863. doi: 10.3389/fpsyg.2019.00863

Mohammed, S., Hamilton, K., and Lim, A. (2009). *The Incorporation of Time in Team Research: Past, Current, and Future. Team Effectiveness in Complex Organizations: Cross-Disciplinary Perspectives and Approaches*. (New York, NY: Routledge/Taylor and Francis Group), 321–348.

Mroz, J. E., Landowski, N., Allen, J. A., and Fernandez, C. (2019). Organizational meeting orientation: setting the stage for team success or failure over time. *Front. Psychol.* 10:812. doi: 10.3389/fpsyg.2019.00812

Palumbo, R. V., Marraccini, M. E., Weyandt, L. L., Wilder-Smith, O., McGee, H. A., Liu, S., et al. (2017). Interpersonal autonomic physiology: a systematic review of the literature. *Personal. Soc. Psychol. Rev.* 21, 99–141. doi: 10.1177/1088868316628405

Pendergraft, J. G., Carter, D. R., Tseng, S., Landon, L. B., Slack, K. J., and Shuffler, M. L. (2019). Learning from the past to advance the future: the adaptation and resilience of NASA's spaceflight multiteam systems across four eras of spaceflight. *Front. Psychol.* 10:1633. doi: 10.3389/fpsyg.2019.01633

Rosen, M. A., Dietz, A. S., and Kazi, S. (2018). *Beyond Coding Interaction: New Horizons in Interaction Analysis. The cambridge handbook of group interaction analysis*. (New York, NY: Cambridge University Press), 142–161. doi: 10.1017/9781316286302.009

Rosen, M. A., Dietz, A. S., Yang, T., Priebe, C. E., and Pronovost, P. J. (2015). An integrative framework for sensor-based measurement of teamwork in healthcare. *JAMIA* 22, 11–18. doi: 10.1136/amiajnl-2013-002606

Salas, E., Bisbey, T. M., Traylor, A. M., and Rosen, M. A. (2020). Can teamwork promote safety in organizations? *Ann. Rev. Org. Psychol. Org. Behav.* 7, 283–313. doi: 10.1146/annurev-orgpsych-012119-045411

Salas, E., Reyes, D. L., and McDaniel, S. H. (2018). The science of teamwork: progress, reflections, and the road ahead. *Am. Psychol.* 73, 593–600. doi: 10.1037/amp0000334

Stevens, R., Galloway, T., and Willemsen-Dunlap, A. (2019). Advancing our understandings of healthcare team dynamics from the simulation room to the operating room: a neurodynamic perspective. *Front. Psychol.* 10:1660. doi: 10.3389/fpsyg.2019.01660

Toussaint, J. S., and Ehrlich, S. P. (2017). Five changes great leaders make to develop an improvement culture. *NEJM Catalyst* 3. [Epub ahead of print].

Welp, A., and Manser, T. (2016). Integrating teamwork, clinician occupational well-being and patient safety—development of a conceptual framework based on a systematic review. *BMC Health Services Res.* 16:1535. doi: 10.1186/s12913-016-1535-y

Wiese, C. W., and Burke, C. S. (2019). Understanding team learning dynamics over time. *Front. Psychol.* 10:1417. doi: 10.3389/fpsyg.2019.01417

Woodley, H. J. R., McLarnon, M. J. W., and O'Neill, T. A. (2019). The emergence of group potency and its implications for team effectiveness. *Front. Psychol.* 10:992. doi: 10.3389/fpsyg.2019.00992

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2020 Shuffler, Salas and Rosen. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Advantages of publishing in Frontiers

OPEN ACCESS
Articles are free to read for greatest visibility and readership

FAST PUBLICATION
Around 90 days from submission to decision

HIGH QUALITY PEER-REVIEW
Rigorous, collaborative, and constructive peer-review

TRANSPARENT PEER-REVIEW
Editors and reviewers acknowledged by name on published articles

Frontiers
Avenue du Tribunal-Fédéral 34
1005 Lausanne | Switzerland

Visit us: www.frontiersin.org
Contact us: info@frontiersin.org | +41 21 510 17 00

REPRODUCIBILITY OF RESEARCH
Support open data and methods to enhance research reproducibility

DIGITAL PUBLISHING
Articles designed for optimal readership across devices

FOLLOW US
@frontiersin

IMPACT METRICS
Advanced article metrics track visibility across digital media

EXTENSIVE PROMOTION
Marketing and promotion of impactful research

LOOP RESEARCH NETWORK
Our network increases your article's readership