WOMEN'S FOOTBALL: PREDICTION, PREVENTION AND PERFORMANCE

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WOMEN'S FOOTBALL: PREDICTION, PREVENTION AND PERFORMANCE

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Physical Preparation in Female Rugby Codes: An Investigation of Current Practices

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Female sports have recently seen a dramatic rise in participation and professionalism world-wide. Despite progress, the infrastructure and general sport science provisions in many female sports are behind their male counterparts. From a performance perspective, marked differences in physical and physiological characteristics can be seen between the sexes. Although physical preparation practices for male athletes are known, there are currently no published literature pertaining exclusively to female athletes. This information would provide invaluable data for both the researcher and practitioner alike. This survey therefore aimed to examine current practices utilized in female rugby codes (union, league, and sevens). A questionnaire assessing seasonal physical preparation practices, recovery, monitoring and sport science technology, and unique aspects in female rugby was developed. Thirty-seven physical preparation practitioners (32 males, 5 females) responded to the questionnaire. Most participants (78%) worked with national or regional/state level female athletes. Performance testing was more frequently assessed in the pre- (97%) and in-season (86%), than off-season (23%). Resistance, cardiovascular, sprint and plyometric training, and recovery sessions were all believed to be important to enhancing performance and implemented by most participants ($\geq$ 89%). Sport science technologies were commonly (54%) utilized to inform current practice. Menstrual cycle phase was monitored by 22% of practitioners. The most frequently reported unique considerations in female rugby codes included psycho-social aspects (41%), the menstrual cycle (22%), and physical differences (22%). Practitioners working with female rugby can use the presented data to inform and develop current practices.

Keywords: performance, strength, conditioning, sport, athlete, women, survey

INTRODUCTION

Female sports have recently seen a dramatic rise in participation, professionalism, and profiles world-wide. New female sports leagues (e.g., Australian Football League Women's, Football Association Women's Super League, Rugby Football Union's Premier 15's) have been developed which have been vital in improving exposure, professionalism and infrastructure to female athletes.

Despite this progress, anecdotal evidence suggests the infrastructure and general sport science provisions for many female athletes are behind that of male athletes. Sportswomen who compete at comparable levels to sportsmen may have less access to sports performance support (e.g., medical and sport science), this may be a result of lower financial investment (International Working Group on Women and Sport WSI, 2007; Fink, 2015). From a performance perspective, marked differences between the sexes can be seen in anthropometric (Quarrie et al., 1995; Brazier et al., 2018; Sella et al., 2019), movement demands (Ball et al., 2019), physical performance (Sella et al., 2019; Owen et al., 2020) and physiological characteristics (Sheel, 2016). Decreased levels of skeletal muscle mass (Abe et al., 2003), lower rates of muscular fatiguability (Hicks et al., 2001), lower maximum velocity, strength and power have all been previously reported (Quarrie et al., 1995; Brazier et al., 2018; Ball et al., 2019) in females. Additionally, female athletes must consider their menstrual and oral contraceptive pill cycles which may influence athletic performance (Elliott-Sale et al., 2020; McNulty et al., 2020). As there is a lack of female-specific sports performance representation in research studies, female-specific research is urgently needed (Emmonds et al., 2019). Given both the aforementioned contextual and biological sex differences, sports performance research involving male participants cannot necessarily be applied to female cohorts (Emmonds et al., 2019).

While an evidence base from research studies is typically slow to emerge, practice may evolve at a faster rate (Coutts, 2016; Jones B. et al., 2017). Within male athlete literature, the strength and conditioning (S&C) practices (e.g., physical testing, speed, and power training) of various sports have been previously described (Ebben and Blackard, 2001; Ebben et al., 2004, 2005; Simenz et al., 2005; Gee et al., 2011; Winwood et al., 2011; Jones T. et al., 2016; Pote and Christie, 2016; Crowley et al., 2018; Robinson et al., 2019). Research describing the S&C practices applied to male athletes found considerable heterogeneity which suggests either, limited consensus on best-practice or that there are multiple methods available to achieve an end-result. Despite this, these studies have provided thorough overviews of S&C practices which have direct application to applied practitioners when developing physical preparation programmes. To date, there is no research describing S&C practices within a female only cohort, which may be different to male athletes.

Rugby codes (league, union, and sevens) are physiologically demanding intermittent contact sports that involve high-intensity movements (e.g., sprinting and tackling) interspersed with low to moderate intensity activities (e.g., jogging) (Read et al., 2018; Whitehead et al., 2018; Ball et al., 2019; Sella et al., 2019; Weaving et al., 2019; Sheppy et al., 2020). Female rugby sevens demonstrates a greater relative distance demand when compared to both female rugby union and league (∼80–120 vs. ∼75 $\text{m}\cdot\text{min}^{-1}$) (Ball et al., 2019; Emmonds et al., 2020; Sheppy et al., 2020). Furthermore, although there is minimal female rugby code collision demand literature available, the relative impacts per game in rugby union and league may be greater than in rugby sevens (Suarez-Arrones et al., 2014; Ball et al., 2019; Sella et al., 2019). In line with sport science literature investigating male athletes, an emerging evidence base, quantifying the anthropometric (Gabbett, 2007; Nyberg and Penpraze, 2016; Agar-Newman et al., 2017), physical (Jones B. et al., 2016; Agar-Newman et al., 2017; Clarke et al., 2017) and physiological (Gabbett, 2007; Suarez-Arrones et al., 2012; Clarke et al., 2014; Nyberg and Penpraze, 2016) profiles of female rugby players have supported practitioners by developing their understanding of the requirements in female rugby. Despite the emerging evidence base, no study has reported the S&C practices applied in female rugby.

Physical preparation pertains to all aspects related to physical performance development and requires consideration of contextual factors (e.g., sex, sport, and playing position) influencing injury and performance. Due to the demands of rugby match-play (e.g., repeated collisions and sprints), physical strength, speed and cardiovascular fitness are integral to successful performance (Jones B. et al., 2016; Clarke et al., 2017; Emmonds et al., 2020; Sheppy et al., 2020). These demands may lead to fatigue which is associated with feelings of tiredness, and muscle function decrements (Twist and Highton, 2013). Appropriately timed recovery modalities can enhance physiological and psychological function post-rugby match-play (Tavares et al., 2017). There has been a recent rise in the use of, and research in, sport science monitoring technologies (Cardinale and Varley, 2017). The use of these technologies can assist the practitioner's day-to-day decision making. In order to develop female rugby physical preparation practices, we must initially understand the current landscape. Comprehensive information regarding these practices would be a vital resource for the applied practitioner. This has implications for developing comprehensive physical preparation programmes and continuing professional development to optimize physical performance and decrease injury risk in female rugby. Previous S&C practices research (Ebben and Blackard, 2001; Ebben et al., 2004, 2005; Simenz et al., 2005; Gee et al., 2011; Winwood et al., 2011; Jones T. et al., 2016; Crowley et al., 2018; Robinson et al., 2019) investigating male athletes have not represented holistic approaches to physical preparation, as certain key aspects to physical performance (e.g., recovery and monitoring) have not been explored. Therefore, the aim of this study was to explore a comprehensive approach to physical preparation practices currently utilized in female rugby codes.

MATERIALS AND METHODS

Design of Study

The questionnaire was adapted from a previous survey (Ebben and Blackard, 2001) which has been used extensively to assess S&C practices in team sports (Ebben and Blackard, 2001; Ebben et al., 2004, 2005; Simenz et al., 2005; Jones T. et al., 2016). Adaptation of the original instrument was performed to expand on gaps in questionnaire design by including additional sections (e.g., recovery, monitoring, and sports science technology) which allows a more comprehensive overview of current practices. Pilot testing for both content and face validity was then performed by experienced (> 5 years) S&C coaches and research-practitioners (Bolarinwa, 2015; Jones B. et al., 2017). The questionnaire (**Data Sheet 1**) comprised of seven sections;

participant characteristics, pre-season, in-season and off-season physical preparation, recovery, monitoring and sport science technology, and unique aspects in female rugby. Sections on physical preparation seasonal phases (i.e., pre-season, in-season, and off-season) included sub-sections on physical testing, and resistance, cardiovascular, sprint and plyometric training. The self-administered, online questionnaire was circulated, via email, and social media (e.g., Twitter), to participants working within female rugby at any level of competition.

Participants

Prior to any experimental procedures commencing Leeds Beckett University Research Ethics Committee approved the study (#59730). All participants were informed of the risks and benefits of the study before signing an electronic informed consent form. Participants were included in the study if they provided physical preparation support to female rugby athletes (e.g., S&C coaches), at any level of competition.

Procedures

The questionnaire was circulated electronically from April to August 2019. Participants provided their education and coaching qualifications prior to engaging in the questionnaire. Follow-up correspondence, via email, and social media, to encourage non-responders to complete the questionnaire was sent out 3 weeks after initial circulation. Responses were collected and analyzed with Qualtrics software (Qualtrics, Provo, USA) and Microsoft Office 365 ProPlus Excel (version 1902; Microsoft Corporation, Redmond, WA, USA). Only completed questionnaires were included in the final analysis.

Data Analyses

The survey contained fixed and open-ended response questions. Answers to open-ended questions were analyzed according to the inductive, and then deductive content analysis method (Elo and Kyngäs, 2008), as a means of identifying, analyzing and reporting common patterns (main categories) within the data. Content analysis has been performed in related studies (Gee et al., 2011; Jones T. et al., 2016). Inductive content analysis was initially performed by identifying the main categories via familiarization and open coding, grouping, categorization and abstraction of the raw data. When the main categories were developed, a deductive analysis was used to confirm that all raw data categories were represented. Raw data were defined by actual responses of participants. Both inductive and deductive analysis was performed independently by two investigators (OH and BN). As conflicts between the investigators relating to main categories were minor (e.g., word choice), a third investigator was not necessary. Data were presented as frequencies and/or percentages unless otherwise stated.

RESULTS

Participant Characteristics

Thirty-seven participants responded to the questionnaire (**Table 1**). Participant's degrees were obtained in S&C or Sport and Exercise Science-related fields. Participants were accredited by the United Kingdom Strength and Conditioning Association (35%), the Australian Strength and Conditioning Association (27%), the National Academy of Sports Medicine (USA; 8%). Other certifications held by participants included "*Australian Weightlifting Federation*" ("*italicized text*" are direct quotations taken from the questionnaire), "*Certified Physical Preparation Specialist,*" "*EXOS Performance Specialist*" and "*Westside Barbell Accreditation.*" Nineteen percent of participants held dual certifications with professional associations, while 22% were not certified. Participants worked in both a team and individual environment (59%) or only a team environment (41%).

TABLE 1 | Participant characteristics.

	Frequency [n (%)]
Sex	
Female	5 (14)
Male	32 (86)
Age^a in years	29.4 ± 5.0
Level of competition	
International	5 (14)
National	20 (54)
Regional/State	9 (24)
Recreational/Local	3 (8)
Country of employment	
United Kingdom and Northern Ireland	22 (59)
Australia	8 (22)
Canada	2 (5)
New Zealand	2 (5)
Spain	1 (3)
France	1 (3)
South Africa	1 (3)
Rugby codes^b	
Rugby union	28 (56)
Rugby sevens	15 (30)
Rugby league	7 (14)
Formal education	
Doctorate degree	2 (5)
Master's degree	24 (65)
Bachelor's degree	9 (24)
High school equivalent	2 (5)

^{a}mean ± SD. ^{b}thirty percent of participants reported working across multiple codes. Values might not add up to exactly 100% due to rounding.

Eight participants identified their roles as "*head,*" "*lead*" or "*senior*" "*athletic performance,*" "*performance*" or "*S&C*" coaches. Twenty-four participants identified as S&C coaches, one of which specialized as a "*women's strength and conditioning coach*" and another with a dual sport science and S&C role. Further respondents identified as 1 "*athletic development coach,*" 1 "*performance coach,*" 1 "*performance specialist,*" 1 "*performance sport and fitness officer,*" and 1 "*physical performance coach.*"

Training Phase Duration and Weekly Micro-Cycles

Pre-, in- and off-season durations are depicted in **Figure 1** and typical pre-, in-, and off-season training micro-cycles are depicted in **Figure 2**.

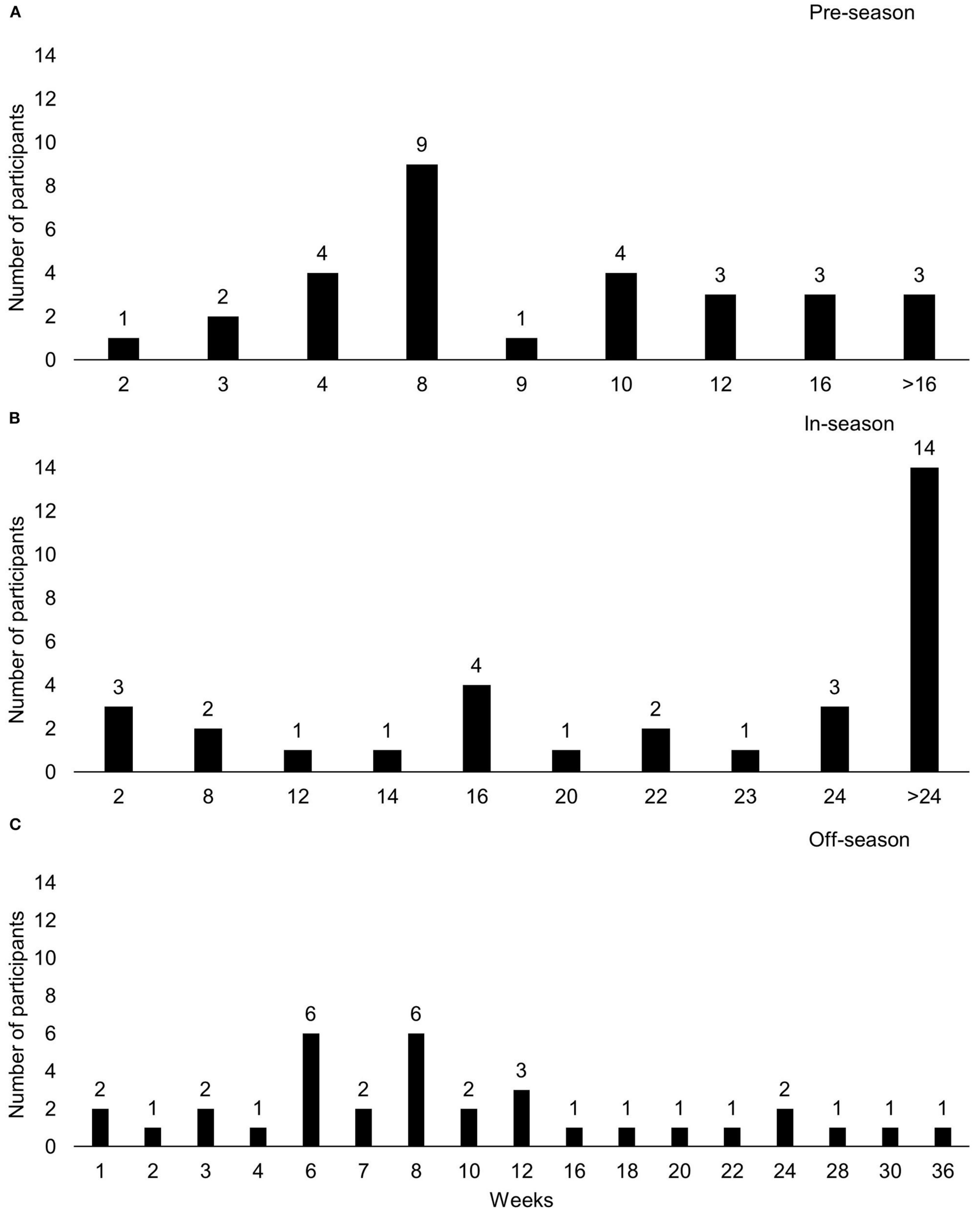

FIGURE 1 | Training phase duration for **(A)** pre-season, **(B)** in-season, and **(C)** off-season.

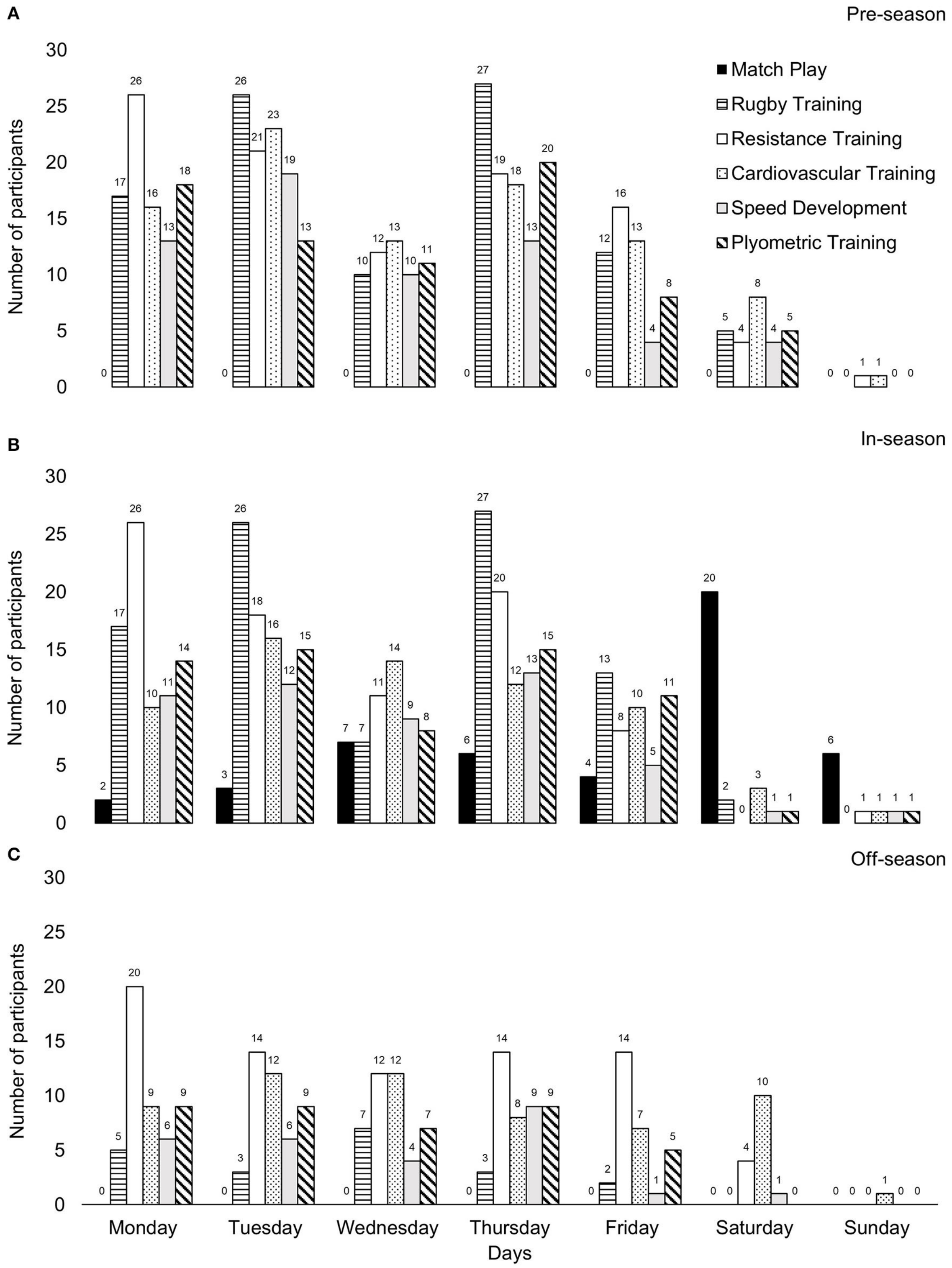

FIGURE 2 | Typical weekly micro-cycles for **(A)** pre-season, **(B)** in-season, and **(C)** off-season.

Physical Performance Testing

Participants conducted physical performance testing during pre- (97%), in- (86%), and off-season (23%) phases. Responses for non-inclusion of physical performance testing were content analyzed and resulted in three main categories: (a) logistics, (b) miscellaneous, and (c) recovery focus (**Table 2**).

TABLE 2 | Non-inclusion of physical performance testing.

Main category	No. of responses	Select raw data representing responses to this question
Logistics	20	Contact with players is minimal and do not have the resources to manage this in the off season. During off-season players return to their local clubs or other sports.
Miscellaneous*	6	Women from 16 to 30+ [years of age] at all different levels of experience, inconsistently turning up, and some do not know how to play the game properly yet, whilst some play [at the international level]. Not worth taking a session away. Due to the stigma and anxious feelings "testing" promotes I don't really see it was a must during the competitive season.
Recovery focus	4	Focus is on mental and physical recovery. Primarily for a psychological break for the athletes.

**answers that could not be associated with any of the broad identified themes.*

Aspects of physical performance tested during seasonal phases are depicted in **Figure 3**. The most commonly reported test of acceleration was 10 m sprint time in the pre- (46%), in- (46%), and off-season (18%). The 5-0-5 test was the most common method of assessing agility/change of direction ability, reported by 55% of participants across all phases. Other agility/change of direction tests included the "*5-10-5*" and "*T-Test.*" Tests of anaerobic capacity included "*3s peak power Watt bike,*" "*anaerobic deficit 3x300s,*" "*ERU anaerobic running test*" and "*Watt bike 6s PPO.*" Participants most frequently used a 1.2 km time trial as an aerobic test during pre- (46%), in- (32%), and off-season (11%). The maximal Yo-Yo Intermittent Recovery Test was a commonly used alternative aerobic test in the pre- (16%) and in-season (16%).

Sums of 6–8 skinfolds were used during the pre-season (19%) and in-season (11%) to assess body composition. The Sit and Reach test was the only reported flexibility assessment. Muscular endurance tests included "*muscular capacity for calf,*" "*muscular capacity for hamstring,*" "*side bridge hold,*" "*inverted row,*" "*calf/hamstring/trunk/upper body pulling capacity,*" and "*sit ups (1 min)—max.*" Muscular power was assessed via a jump variation by 98% of participants during all phases. The counter-movement jump was the most commonly utilized jump variation during pre- (27%), in- (20%), and off-season (3%). Other jump variations used to test power included "*drop jump,*" "*broad jump,*" "*triple broad jump,*" "*Opto jump 15s RVJ,*" "*squat jump,*" "*RSI jumps.*" Non-jump power testing included "*VBT pull up, back squat/Bulgarian split squat and bench press.*" The bench press, squat and pull-up were the most common muscular strength tests in all phases. During the pre-season, these tests were used by 57, 51, and 43% of participants, respectively. Between 1 and 5 repetitions were used to measure strength on the reported lifts. Other strength tests included "*deadlift,*" "*power clean,*" "*prone row,*" "*bench pull,*" "*isometric mid-thigh pull,*" and "*maximal isometric hamstring bridge.*" Maximum velocity was tested by 40 m sprints with splits at 20 m or 30 m; or by an 80 m sprint with a radar gun. Other physical performance aspects that were tested include "*body mass,*" "*anthropometrics,*" "*fatigue monitoring,*" and "*maturation and motor control.*"

Resistance Training

All participants believed resistance training was beneficial to female rugby performance. Participants indicated that players were obliged to resistance train in the pre-season (89%) and in-season (86%). During the off-season, 54% of participants stated that players had a choice whether to resistance train, and 41% stated players were obliged to train. Resistance training was prescribed 3 days a week in the pre-season (54%) and off-season (41%). In-season resistance training was prescribed 2 days per week by 68% of participants. Session duration typically lasted 45–60 min during the pre- (49%), in- (43%), and off-season (49%). Pre-season resistance training sessions were typically a combination of supervised and unsupervised (49%), or only supervised sessions (46%). Sessions were typically performed either pre-rugby training (49%) or on non-rugby training days (38%). In-season resistance training sessions were typically all supervised (54%) or a combination of supervised and unsupervised sessions (41%). These sessions were usually performed either pre-rugby training (51%) or on non-rugby training days (43%). Off-season resistance training was typically unsupervised (62%).

Cardiovascular Training

Cardiovascular training was believed to be beneficial to female rugby performance (97%). Cardiovascular fitness training was mandatory during the pre- (78%) an in-season (70%). During the off-season phase, 54% of participants indicated that players had a choice whether to train cardiovascular fitness or not. Cardiovascular training was typically prescribed on 2 days a week in the pre- (49%), in- (49%), and off-season (51%). Pre- and in-season cardiovascular training sessions were generally a combination of supervised and unsupervised sessions, indicated by 59% of participants for both phases. Eighty-six percent of participants indicated that these sessions were integrated within rugby training sessions for both phases. Off-season cardiovascular training sessions were generally all unsupervised sessions (59%).

Sprint Training

All participants stated that they believed sprint training was beneficial to female rugby performance. Sprint training was implemented by 95% of participants. Participants not implementing sprint training (5%) provided the following reasons:

> "*not enough time [...] to deliver speed component*"

and

> "*more practical to complete conditioning within the gym due to my lack of availability as the S&C coach to complete pitch based sessions.*"

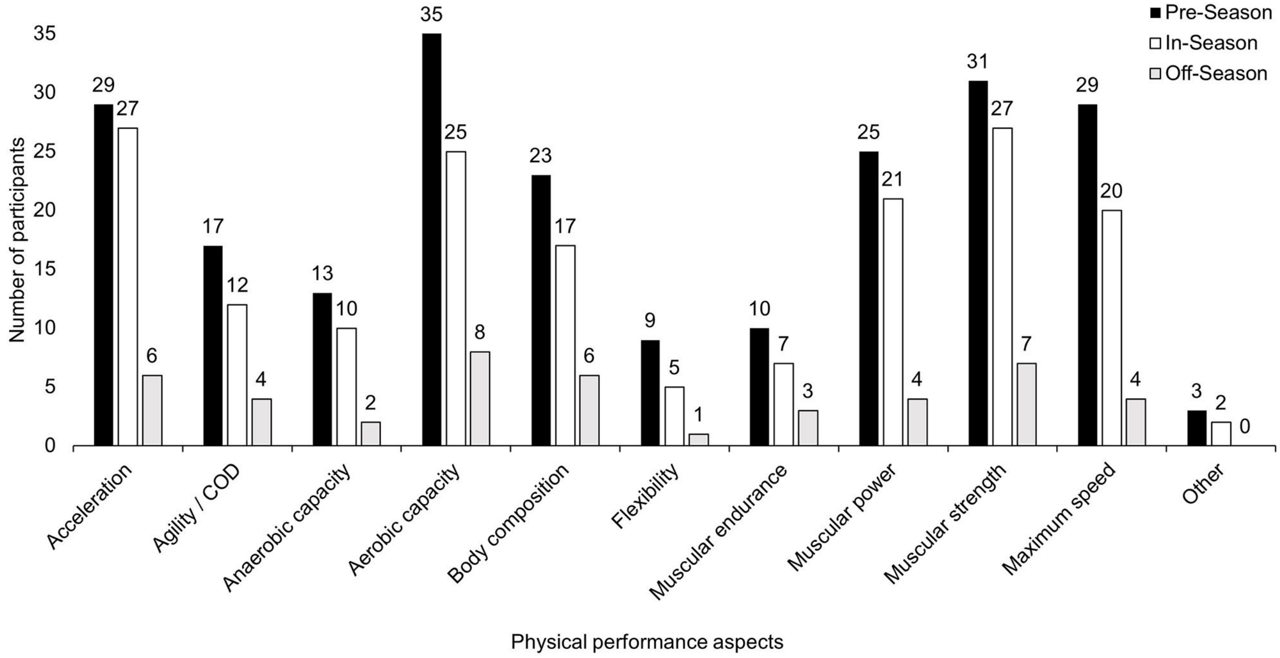

FIGURE 3 | Aspects of physical performance tested at different phases of the season. COD, change of direction.

TABLE 3 | Purpose of sprint training implementation.

Main category	No. of responses	Select raw data representing responses to this question
Sprint performance enhancement	14	Improve running efficiency, increase performance. Sprint training can improve anaerobic speed reserve. Technically develop running efficiency.
Injury risk reduction	10	Injury Prevention. Sprint training can potentially reduce injury risk. Injury prevention/resilience.
Key rugby demand	7	Maximal sprint is necessary in rugby demands. Sprint capacity is considered one of the key factors to be successful in rugby.
Speed exposure	7	Exposure to top speed. To expose athletes to maximal speed.
Miscellaneous	3	Build on stamina and fitness. Improve all aspects of the force-velocity curve. Sprint training is the simplest way to develop single limb strength.

Responses for implementation of sprint training resulted in five main categories: (a) sprint performance enhancement, (b) injury risk reduction, (c) key rugby demand, (d) speed exposure, (e) miscellaneous (**Table 3**).

Sprint training sessions were generally supervised during the pre- (70%) and in-season (68%). Pre-season sprint training prescription were typically one (38%) or two (48%) times per week. In-season sprint training prescription were one (54%) or two times (38%) per week. During the off-season, 41% of participants did not implement sprint training, while 30% implemented sessions once per week.

Plyometric Training

All participants stated that they believed that plyometric training benefited female rugby performance. Plyometric training was implemented by 95% of participants. Participants who did not implement plyometric training (5%) provided the following reasons:

> "*Our program is far from perfect, constantly growing and this will be layered in to what we do using an intentful prep pre-weights. Low-hanging fruit needed to be addressed first, speed and aerobic development*"

and

> "*not enough time to deliver plyometric component.*"

Reasons for plyometric training implementation resulted in four main categories: (a) athletic performance enhancement, (b) injury risk reduction, (c) rugby performance enhancement, (d) miscellaneous (**Table 4**). During both pre- and in-season plyometric training sessions typically occurred as an integration within resistance training sessions (73, 70%), pre-sprint training (68, 70%), or pre-resistance training (57, 51%).

Recovery

Recovery sessions were believed to be beneficial for enhancing female rugby performance (89%) and were commonly implemented (76%). Participants who did not implement recovery sessions (24%) provided the following reasons:

TABLE 4 | Purpose of plyometric training implementation.

Main category	No. of responses	Select raw data representing responses to this question
Athletic performance enhancement	17	Improves acceleration, change of direction, jumping and sprinting performance. Develop stretch shorten cycle activity/muscle pre-excitation. To prevent energy leaks, enhance stiffness, neuromuscular efficiency, coordination.
Injury risk reduction	9	Injury prevention. Reduce injury. Minimizing injury risk.
Rugby performance enhancement	3	A key determinant of successful performance in many sporting actions in rugby.
Miscellaneous	2	Good for the core and creates muscles endurance. To develop the skill of movement.

> "*Not full time with just that team, girls aren't full time or paid. Recovery is highly encouraged and information on how and what they should do is given and it is their choice if they do it (majority do)*"

and

> "*Not enough time to implement only training twice a week*"

Recovery modalities are described in **Figure 4**. Reasons for implementing recovery sessions resulted in six main categories: (a) improve recovery time, (b) physiological regeneration, (c) injury risk reduction, (d) psychological regeneration, (e) performance enhancement, and (d) miscellaneous (**Table 5**). Implementation of recovery sessions into the weekly micro-cycle were performed on non-training days (62%), pre- (24%), and post- (30%) resistance training, pre- (16%) and post- (41%) rugby training and post-match play (59%).

Monitoring and Sport Science Technology

Monitoring athlete wellness (e.g., mood, stress, muscle soreness, and sleep) was believed to be beneficial for assessing recovery status in rugby (92%) and undertaken by 76% of participants. Wellness monitoring frequency occurred every day (24%), every session (22%), every week (19%), multiple days per week (14%), or was not monitored (22%). Monitoring of menstrual cycle phase was performed by 22% of participants. Training and match loads were monitored by 76% of participants. Sport science technologies to assist decision making are described in **Figure 5**. Responses of how sport science technologies assist participants resulted in three main categories: (a) informs practice, (b) monitoring, (c) miscellaneous (**Table 6**).

Unique Aspects of Consideration Within Female Rugby

Responses of unique aspects of consideration (e.g., contextual, physiological, and physical) in the physical preparation of female rugby resulted in eight main categories: (a) psycho-social aspects, (b) menstrual cycle, (c) physical differences, (d) external commitments, (e) variability, (f) education, (g) limited access and, (h) miscellaneous (**Table 7**).

DISCUSSION

The present study is the first to comprehensively describe the physical preparation practices in female rugby. A total of 37 participants responded to the questionnaire, this is in-line with previous studies investigating male athletes which have received between 20 and 43 responses (Ebben and Blackard, 2001; Simenz et al., 2005; Gee et al., 2011; Jones T. et al., 2016, 2017; Robinson et al., 2019). This study accounted for a multitude of aspects that influence physical performance (i.e., seasonal changes in physical preparation, recovery, monitoring and sport science technology, and unique considerations in female rugby). The most common physical performance tests included acceleration, aerobic capacity, muscular strength, and maximum velocity measures. Testing was performed most often in pre- and in-season phases. Resistance, cardiovascular, sprint and plyometric training, and recovery sessions were believed to be important to enhancing female rugby performance and implemented by most participants. Practitioners typically reported the purpose of sport science technologies were to inform current practice (54%) (e.g., provide data to plan future sessions) or monitor players (41%) (e.g., tracking training load and well-being). Menstrual cycle phase was not commonly monitored, with only 22% of participants tracking it. The most frequently reported unique considerations in female rugby codes included psycho-social aspects (41%), the menstrual cycle (22%), and physical differences (22%). To the authors knowledge, this is the first study to provide an overview of physical preparation practices exclusively in female athletes.

The importance of physical testing appeared to vary during different seasonal phases. The most commonly assessed aspects of physical fitness in the pre-season were aerobic capacity and muscular strength, while in-season, acceleration and muscular strength took precedence. These findings reflect practices in elite male rugby, where despite testing not being sub-categorized into seasonal phases, aspects of physical fitness were assessed by >78% of participants (Jones T. et al., 2016). Differences in testing emphasis in female rugby from pre-season to in-season may reflect training emphasis changes across phases which is in-line with other female team sports (Brown and Lopez, 2016; Duggan et al., 2020). Overall, physical testing was predominately conducted in the pre- (97%) and in-season (86%) phases, with only 23% of participants fitness testing in the off-season. Reasons for off-season testing may be to assess and mitigate negative changes in physiological characteristics (Stokes et al., 2020). This is similar to elite male rugby, where percentages of participants conducting physical testing dropped from 95% during the in-season to 53% in the off-season (Jones T. et al., 2016). Both male and female rugby may face similar logistical issues in the off-season with a lack of player access.

Strength and resistance training are considered beneficial to female rugby performance (Reilly, 1997; Argus et al., 2012). Up to 81% of participants indicated that 45–60 min resistance training

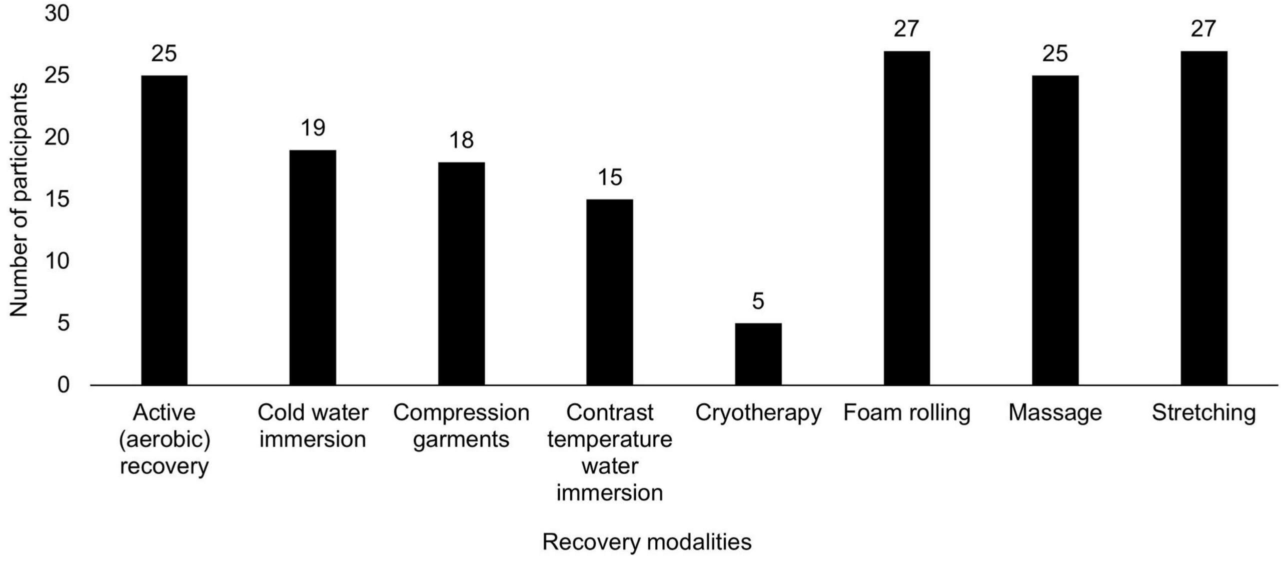

FIGURE 4 | Recovery modalities.

TABLE 5 | Purpose of recovery session implementation.

Main category	No. of responses	Select raw data representing responses to this question
Improve recovery time	8	Improve the ability of the athlete to recover between sessions. Because the faster the athletes recover, the sooner they are able to train again. Lesson the time it takes players to recover.
Physiological regeneration	6	Promote tissue regeneration, nervous system homeostasis. Decrease inflammation. Flush lymphatic system.
Injury risk reduction	6	To prevent over-training and injuries. Reduce injury risk. Reduce the risk of injury
Psychological regeneration	2	To improve mental perception of recovery. Well-being.
Performance enhancement	2	Improve performance. Ensure optimum performance.
Miscellaneous	1	Improve their longevity in the sport.

sessions were prescribed 2–3 days a week across all season phases (81%). This is similar to findings in male academy rugby league where U16 players were exposed to ∼3 resistance training sessions per week of ∼50 min in both pre- and in-season phases (McCormack et al., 2020). Conversely, U19 rugby league players were exposed to greater resistance training frequency during the pre-season (4.4 ± 0.7) compared to the middle of the in-season (3.2 ± 0.6) (McCormack et al., 2020) which may highlight that greater sport science provision to male players is afforded as they progress through the pathway. Poor access to players was a commonly reported logistical challenge for practitioners working within female rugby (**Tables 2**, **7**). Available contact time should therefore emphasize movements that yield the best return on investment. Consistency in exposure to, and development of, the athletic motor skill competencies (e.g., lower body uni- and bi-lateral concentric and eccentric training, upper body pushing and pulling in both vertical and horizontal planes) will act as the foundation for more complex future training (e.g., weightlifting and high velocity movements) (Lloyd et al., 2015). Additionally, implementation of injury risk reduction strategies specific to the female rugby player should be embedded within a comprehensive physical preparation programme. For example, as anterior cruciate ligament injuries are a burden in female rugby (Fuller et al., 2017; Toohey et al., 2019), incorporation of neuromuscular training (e.g., landing stabilization) should be prioritized (Petushek et al., 2019).

Despite aerobic capacity underling the ability for repeated high intensity efforts, which are key demands of rugby, the requirements of high aerobic capacity in both male and female rugby players are uncertain (Duthie et al., 2003). Participants may use aerobic capacity testing in the pre-season in order to prescribe cardiovascular fitness training and inform session parameters (e.g., work interval intensity and duration, rest interval intensity and duration, number of sets and reps) (Buchheit and Laursen, 2013). This may be used to create underlying physiological cardiovascular adaptations in order to ensure that aerobic capacity is not a limiting factor to performance (Glaister, 2005). During the in-season, cardiovascular fitness sessions were integrated within rugby training (86%), this time-efficient design allows technical and tactical skills to be developed in unison with positive physiological adaptation. In a mixed-sex sample of adolescent handball players, implementation of small-sided games (2 sessions per week of 2–4 games lasting 2 min 30 s—4 min duration interspersed with 30 s passive recovery over 10 weeks) have been used to create improvements in both repeat sprint ability and 30–15 Intermittent Fitness Test scores by ∼4 and ∼6%, respectively (Buchheit et al., 2009). Strong working relationships between rugby coaches and practitioners are vital

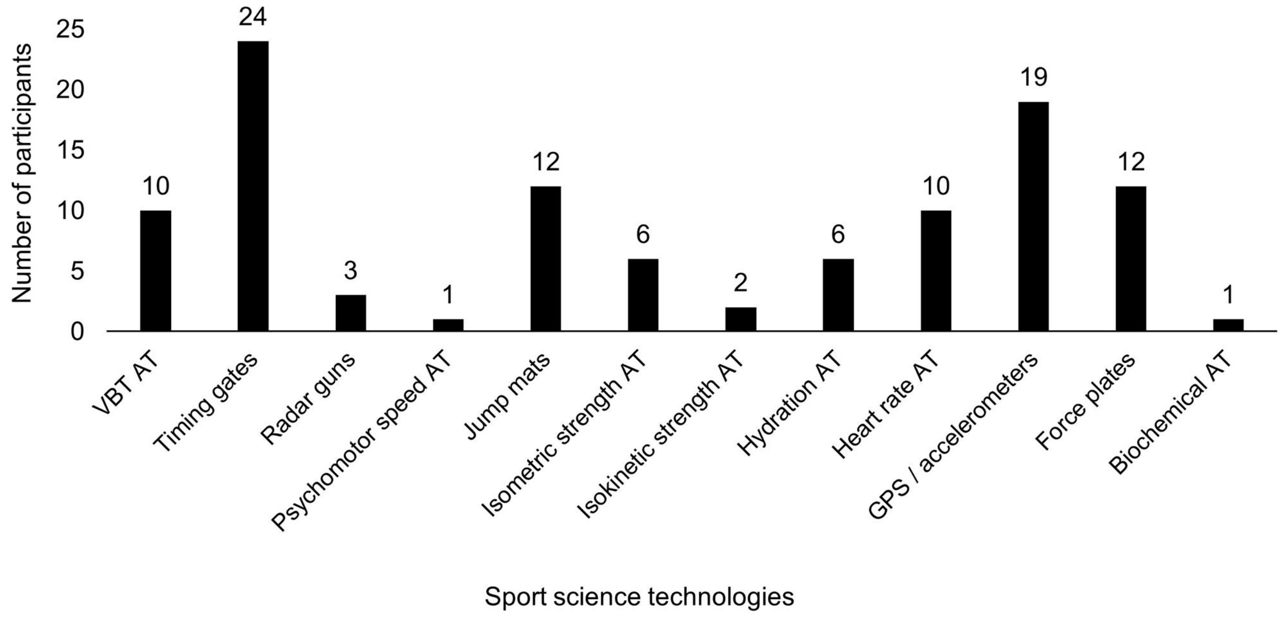

FIGURE 5 | Sport science technologies utilized by participants. AT, assessment tools; GPS, global positioning systems; VBT, velocity-based training.

to facilitate these types of collaborations which enhance technical, tactical, and physiological adaptations.

Rugby is physiologically and biomechanically demanding, resulting in muscle damage and inflammation (Tavares et al., 2017). These stress responses can negatively influence perceptual and neuromuscular function, which can persist for up to 4 days (Tavares et al., 2017). Furthermore, recent research suggests that female sex hormones influence the physiological recovery response (Hackney et al., 2019). Previous research has demonstrated the effectiveness of recovery modalities (e.g., cold-water immersion and compression garments) for enhancing creatine kinase clearance and neuromuscular function, decreasing delayed-onset muscle soreness and improving perceived recovery (Tavares et al., 2017). The discrepancy between participants who perceived recovery sessions as beneficial to rugby performance (89%) and those who implemented sessions (76%) may be due to contextual factors (e.g., developing nature of female rugby, limited time and resources), thus player education on at-home recovery session modalities and their importance may be a practical solution to an applied problem.

Wellness monitoring was deemed important to female rugby performance by 92% of participants. Although tracking of wellness, match and training loads were found to be prevalent (76%), which aligns with a recent training load survey in amateur male and female rugby union (Griffin et al., 2020), menstrual cycle phase was only monitored by 22% of participants. There is an emerging body of evidence suggesting that the menstrual cycle may influence athletic performance (Findlay et al., 2020; McNulty et al., 2020), internal training load (Cristina-Souza et al., 2019) and injury risk (Herzberg et al., 2017). This evidence, coupled with participant views that the menstrual cycle is an important aspect of consideration in female rugby (**Table 7**), suggests that monitoring of cycle phase, associated symptoms, training load, and wellness may be crucial for sex-specific sports performance. Previous literature has suggested a laboratory-based three-step procedure for menstrual cycle phase verification (Schaumberg et al., 2017). As this procedure may not be feasible in applied settings, an individualized approach to monitoring menstrual cycle-related symptoms may be more appropriate (McNulty et al., 2020). Future longitudinal research investigating the relationships between the menstrual cycle, training loads and wellness may be a key unique feature for developing understanding of performance factors in female sport.

Psycho-social aspects were a key unique feature of female rugby considerations. To the authors' knowledge, there are no sex-specific coaching effectiveness literature pertaining to psycho-social aspects (Sargent and Barker, 2018). Despite this, psycho-social sex differences have been described in the literature, suggesting that empathy, and connections are of higher value to females compared to males (Cunningham and Roberts, 2012). This literature is echoed by participants who have stated that players require more individual contact to support emotional well-being (**Table 7**). Considering this, practitioners should be cognizant of coaching style (e.g., autonomy-supportive vs. controlling) (Amorose and Anderson-Butcher, 2015) and should emphasize building strong rapport and professional relationships with female players. Additionally, a key discussion point identified within female rugby is the gender identity paradox where players may display feminine behaviors while engaged in a physically demanding sport that has been traditionally aligned with masculinity (Joncheray et al., 2016). Practitioners

TABLE 6 | Purpose of sport science technologies.

Main category	No. of responses	Select raw data representing responses to this question
Informs practice	20	Supplies me and the sports coaches with objective data to inform session planning. To provide data to help objectify our coaching decisions. Plan and prescribe for future training sessions.
Monitoring	15	To monitor the athlete well-being and readiness to train and play across the weeks. Load monitoring. Track improvements in performance.
Miscellaneous	6	Provides much more accurate results compared to measuring manually. Providing tools to give them [athletes] an advantage gets me buy in. To support discussions with athletes. They make it easier to collect simple data.

TABLE 7 | Unique aspects of consideration in female rugby.

Main category	No. of responses	Select raw data representing responses to this question
Psycho-social aspects	15	More social aspects need to be integrated. Psychologically it is very important to pay attention to players within women's rugby, and to have regular conversation to see how they are feeling/progressing. They wear their emotions on their sleeve more than men do and therefore may require an individual conversation more often. The stigmas associated with lifting weights within a female population.
Menstrual cycle	8	I think it is important to be aware of how it can influence their mood, energy levels, and physical performance and therefore adjust expectations of the athlete at certain times in their cycle.
Physical differences	8	Gym based training experience [is often low]. Their strength parameters and benchmarks are lower than men's. Women tend to have a more accentuated/frequent knee valgus and this might be a factor of [injury] risk.
External commitments	4	Children and juggling full time work!!! Ladies are amazing in that they run their household, work, and train. Even our contracted International level players have full-time work or study commitments in-season.
Variability	4	Huge variance in … attitude within S&C, attendance, knowledge. The girls selected are of a vast range of skill and athleticism as well which makes it difficult to program.
Education	3	Education and understanding as to why physical preparation is so important for athletes. Coaching staff are still quite old school meaning most of what you want to achieve as an S&C coach is hindered because of lack of [sports coach] education.
Limited access	2	No[t] having access to players on a regular basis.
Miscellaneous	2	Because it is underfunded, athletes are not as professional as you want them to be which makes it a challenge for them to do anything outside of training.

should consider how this paradox could affect players willingness to engage in physical preparation programmes due to female athletes' desire to achieve both high performance levels and simultaneously conform to identified feminine behaviors and body type. Practitioners should therefore be aware of these factors when emphasizing the importance of adherence to physical preparation programmes to female players.

Furthermore, physical differences were stated to be a unique consideration by 22% of participants. Some participant responses highlighted low (and variable) training age, low strength, and accentuated knee valgus of female rugby players when compared to men. Reduction of excessive knee valgus may therefore be an important consideration for injury risk reduction in female rugby. As greater lower body strength may decrease knee valgus during both jumping (Jacobs and Mattacola, 2005) and squatting (Claiborne et al., 2006) tasks, lower body strength development is recommended for the female rugby player. Appropriate coaching and training interventions for the female athlete may eliminate any relative strength deficit compared to males (Burger and Burger, 2002). Therefore, early introduction of periodised strength training is vital to the safe athletic development of the female rugby player.

The duration of season phases varied greatly. Due to limitations in questionnaire design, pre- and in-season phase length data were not all able to be captured to the specific week. The large variation seems to be context-specific, as phase duration of female rugby varies across countries and codes. For example, the Australian 2019 Super W rugby union season was played over 5 rounds compared to the 18-round 2018–19 Premier 15 rugby union season in England. This contrasts with the 7-round 2019 Men's National Rugby Championship (Australia) and 22-round 2018–19 Men's Premiership Rugby season (England). The differences may highlight the current landscape of female sport, the developing professionalization, infrastructure and participation in female rugby in various countries. Therefore, practitioners should consider their sporting setting when applying presented findings into practice.

Results from this study have highlighted great heterogeneity in physical preparation practices in female rugby which may signify context-specific constraints or a lack of consensus on a best-practice approach which is similar to findings investigating male athletes (Ebben and Blackard, 2001; Ebben et al., 2004, 2005; Simenz et al., 2005; Gee et al., 2011; Winwood et al., 2011; Jones T. et al., 2016; Pote and Christie, 2016; Crowley et al., 2018; Robinson et al., 2019). Some participants of this study may work within large multidisciplinary teams where responsibilities of certain aspects of physical preparation may fall outside of their remit, in these cases data may be skewed and should therefore be viewed with caution. As rugby codes exhibit differences with respect to physical demands, the practical application of these research findings should be implemented with consideration to the practitioners' context. Due to recruitment methods, the included participants may not constitute a representative sample, discretion should therefore be applied when interpreting results. As 92% of participants surveyed worked with international, national or regional/state level players, practitioners now have a source of data describing physical preparation practices in a high standard of female rugby. Future researchers could use the presented data to design experimental protocols examining the effect of physical preparation practices on various aspects of performance or investigate unique considerations of female rugby in further detail, and their relationships with performance.

PRACTICAL APPLICATIONS

Physical preparation practitioners working with female rugby codes, or games with similar demands, can use presented findings as a resource to further inform and develop current practices. As practitioners in female sport often have limited player contact time, due to low financial investment and other factors, emphasis on time efficient training must be stressed. Player education on the physical preparation process may assist in compliance with training when supervision is not feasible. Strong professional relationships with players and coaching staff may assist in the integration of technical, tactical and physical preparation elements. Menstrual cycle phase and associated symptom tracking should be integrated within wellness monitoring, as a consideration for the female athlete. Furthermore, practitioners should consider the unique aspects of female rugby, such as psycho-social aspects and physical differences.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

This study involving human participants was reviewed and approved by Leeds Beckett University Research Ethics Committee. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

OH, SE, GR, and BJ: conceptualization and design. OH and BN: data interpretation and analysis. OH: original draft preparation. OH, BN, SE, GR, and BJ: reviewing and editing. All authors contributed to the the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2020.584194/full#supplementary-material

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Preparing for an Australian Football League Women's League Season

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The aims were to investigate the externally measured weekly loads, and the distribution intensity relative to the 1-min maximal mean (MM) intensity of matches. Athletes ($n = 28$) wore 10 Hz GNSS devices during training and matches. For the descriptive analysis, a range of movement variables were collected, including total distance, high-speed distance, very high-speed distance, acceleration, and acceleration load. Using raw GNSS files, 1-min moving averages were calculated for speed ($m \cdot min^{-1}$) and acceleration ($m \cdot s^{-2}$), and were multiplied by time, specifying total distance (m), and by body mass to quantify impulse ($kN \cdot s^{-1}$). The distribution of distance and impulse accumulated at varied intensities relative to MMs was calculated, with percentages ranging from zero to 110%. Drills were categorized as either; warm-ups, skill drills, games (i.e., small-sided games), conditioning and matches. Linear mixed models determined if the distribution of intensity within each threshold (>50%) varied between drill types and matches, and if the distribution within drill types varied across the season. Effects were described using standardized effect sizes (ES) and 90% confidence limits (CL). Compared to matches, a higher proportion of distance was accumulated at 50% of the MM within warm-ups and conditioning (ES range 0.86–1.14). During matches a higher proportion of distance was accumulated at 60% of MM when compared to warms ups, skill drills and conditioning (0.73–1.87). Similarly, greater proportion of distance was accumulated between 70 and 100% MM in matches compared to skill drills and warm-ups (1.05–3.93). For impulse, matches had a higher proportion between 60 and 80% of the MM compared to conditioning drills (0.91–3.23). There were no other substantial differences in the proportion of impulse between matches and drill types. When comparing phases, during competition there was a higher proportion of distance accumulated at 50% MM than general preparation (1.08). A higher proportion of distance was covered at higher intensities within matches compared to drills. The proportion of impulse was higher between 60 and 80% MM within matches compared to conditioning. Practitioners can therefore ensure athletes are not only exposed to the intensities common within competition, but also the volume accumulated is comparable, which may have positive performance outcomes, but is also extremely important in the return to play process.

Keywords: acceleration, speed, team sport, GPS, intensity

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INTRODUCTION

The Australian Football League Women's (AFLW) is a national, two-conference competition comprizing 14 teams across five states of Australia. The AFLW has expanded since its inaugural season in 2017 by increasing the number of teams in the competition and the number of games played in a season–which has attracted more support, funding and ultimately professionalism to the sport. AFLW has similar playing rules to the men's Australian Football League (AFL) competition, with the main purpose of advancing the ball down the field by either kicking or "handballing" the ball and scoring points by kicking the ball between the upright posts (Robertson et al., 2016; Johnston et al., 2018). Although there are some modifications compared to AFL (Clarke et al., 2018), AFLW can also be described as a high-intensity, intermittent team sport (Clarke et al., 2018; Thornton et al., 2020). Typically, AFLW athletes cover between ∼5–7 km during each match, with ∼50 min of playing time (Clarke et al., 2018; Thornton et al., 2020), equating to a mean running speed ($m \cdot min^{-1}$) of between 102 and 128 $m \cdot min^{-1}$. Running speed constantly changes during matches, resulting in a mean acceleration of 0.44 $m \cdot s^{-2}$ (Thornton et al., 2020), reflecting the importance appropriately training this capacity. Running efforts are interspersed with rest intervals (walking or standing still) and technical skills such as kicking, tackling, and marking. These data (Clarke et al., 2018, 2019) provide an understanding of the volume, intensity and type of locomotive activity covered in matches that can be useful in optimizing training prescriptions – an area of AFLW that has not yet been presented in the scientific literature.

As demonstrated across numerous team sports (Delaney et al., 2016, 2017,a; Duthie et al., 2019), assessing the mean intensity of competition does not provide accurate information regarding the most intense passages of play. If maximum playing intensity achieved during matches is not accounted for in the training plan, this may result in athletes not being optimally prepared for competition which may negatively impact athletes and potentially increase the risk of injury. Moving averages have been established as an effective and simple method to quantify fluctuations in intensity that occur during team-sport competition (Cunningham et al., 2018). Moving averages involve calculating the mean of a variable over a select period (i.e., 1 min), then forward shifting over the length of the dataset, where the maximum value of that period is then extracted (Johnston et al., 2020). This maximal mean (MM) value can be calculated across a range of movement variables, and regardless of the variable assessed, a consistent finding in research is an evident decline in intensity as the duration of the moving average increases (Delaney et al., 2016, 2017,a; Duthie et al., 2019; Thornton et al., 2020). Practically, MMs can be used as a guideline regarding the intensity of drills of differing duration with the purpose of exposing athletes to match intensity [i.e., during small-sided games (SSG)] (Duthie et al., 2019). Whilst MMs are extremely useful in the prescription of such training drills, it must be noted that the "peak" or maximal value attained throughout a match only occurs once, therefore not reflecting the overall fluctuating intensity of the match (Johnston et al., 2020). Indeed, one study showed little difference between professional and semi-professional rugby league competition in 1–10-min MMs; suggesting that these periods may not reflect the overall demands of competition (Johnston et al., 2019). Athletes may only reach this MM value or near this for 1-min of the game, therefore it may be unnecessary to expose athletes to this intensity for large volumes (Johnston et al., 2020), as per typical periodization principles. Further work is required to determine the quantity of work that is required at these intensities.

Recently, an alternative method of describing the intensity of competition has been investigated where the distribution of volume covered relative to the 1-min MM value for a range of variables was presented (Johnston et al., 2020). Specifically, the intensity accumulated relative to the MM value was expressed in 10% buckets (i.e., 110–100%, 100–90%, all the way to 0). The distribution (%) of volume was used rather than simply volume accumulated as this standardizes the variables assessed, and accounts for differing game time. In this research (Johnston et al., 2020), most match activities (quantified using total distance, accelerometer load, and impulse) were performed at ∼60% of peak match intensity for both professional Australian football (i.e., AFL) and rugby league (i.e., NRL) (Johnston et al., 2020). Further, within AFL, for the three movement variables investigated, athletes accumulated 13% of total distance, 7% of total impulse, and 11% of the total accelerometer load above 70% of the 1-min MM (Johnston et al., 2020). Together, this information emphasizes that perhaps prescribing training simply by using the MM value may result in excessive volume covered at intensities that are not sustained for periods of time during competition (Johnston et al., 2020). As such, it would be useful for practitioners to understand the distribution of intensity within drills (particularly skill-based drills), providing information that would help prescribe training that accurately reflects the volume covered at various intensities of competition.

Therefore, the purpose of this investigation was to (a) provide an overview of the weekly externally measured training loads across the AFLW season, which will assist in the preparation of athletes for competition. The second component, part (b) was an analysis of the training undertaken, where the distribution of volume accumulated within training drills relative to the 1-min MM intensity of matches was established. This involved comparing the distribution of intensity of different drill types compared to that obtained within matches and each drill type from training sessions, and further determining if the distribution of intensity changed across the various season phases. Furthermore, the information regarding the intensity distribution of drills will help ensure practitioners are not only exposing athletes to the MM intensity of competition within training, but also are achieving comparable volumes across a range of intensities.

METHODS

Design

To quantify the physical demands of AFLW training across the 2020 season, an observational longitudinal research design was used. Workload data were collected using global navigation

TABLE 1 | Summary of a typical training week during the pre-season and in-season periods.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Pre-season							
Morning(5:30 a.m.–7:00 a.m.)	-	Gym	-	Gym	OFF	Field	OFF
Evening(5:00 p.m.–8:30 p.m.)	Field	-	Field	-	OFF	-	OFF
In-season							
Morning(5:30 a.m.–7:00 a.m.)	-	-	Gym	-	OFF		OFF
Evening(5:00 p.m.–8:30 p.m.)	Recovery (30 min)	Field	-	Field	OFF	Match	OFF

The in-season week is a typical 7-day turnaround.
This table shows a "typical" week therefore some weeks training did not follow this structure. Some weeks included a session the day prior to a match (match−1) rather than 2 days prior (match−2).

satellite system (GNSS) technology during training. Written informed consent was provided prior to the commencement of the study, and institutional ethics approval were obtained from the Australian Catholic University Human Research Ethics Committee (HREC no; 2018-290E).

Subjects

Data were collected from 28 athletes playing for one club competing in the AFLW 2020 season (age: 24.1 ± 4.9 y; mass: 68.3 ± 6.5 kg; height: 171.9 ± 6.7 cm). Although athletes were not separated into positional groups for the analysis, athletes were from all positional groups of the squad, including midfielders ($n = 12$), rucks ($n = 1$), mobile backs ($n = 5$), mobile forwards ($n = 4$), tall backs ($n = 2$), and tall forwards ($n = 4$).

Training Program

A periodized game-specific training program was prescribed and completed at the discretion of coaching and performance staff. An overview of the typical pre-season and in-season weekly schedule is demonstrated in **Table 1**. Some weeks did not follow this structure [i.e., in-season some weeks involved a session the day before a match (match−1) rather than a match−2].

The season was 17 weeks in duration, with the pre-season phase being over a 10-week period. Specifically, general preparation was between weeks 1 and 4, followed by a 1-week Christmas break. Specific preparation was between weeks 6 and 10, with 7 weeks of competition following. Files were removed if an athlete was unable to complete the session due to injury or other reasons, and if the session was modified compared to the remaining group (i.e., load management) as to not affect group loads. As such, there were a total of 1,081 observations (920 training sessions and 161 matches). The mean ± SD and range of observations for each athlete including training sessions and matches was 36 ± 11 (range 3 to 47).

Descriptive Training Loads

During all training sessions and games, microtechnology devices (Optimeye S5, Catapult Sports, VIC, Australia) were used to measure the external workloads of athletes. These devices comprise a 10 Hz GNSS chip, and athletes wore the same device across the season as to minimize inter-unit variability (Buchheit et al., 2014). Prior to the start of training, units were switched on and were fitted into a manufacturer provided garment to tightly secure the device. Data quality was determined by recording the horizontal dilution of position (HDOP; mean ± SD = 0.68 ± 0.09) and satellite count (11.79 ± 0.75). Four files with a HDOP >1.5 were removed. Following training sessions and games, devices were downloaded and trimmed using proprietary software (Openfield, Catapult Sports, VIC, Australia). Numerous movement variables were obtained from the software, including; total distance (m), speed (m·min^{-1}), high-speed distance (>14.4 km·h^{-1}), very high-speed distance (>20 km·h^{-1}), acceleration (m·s^{-2}) and acceleration load (AU). The metrics chosen in this have been demonstrated as reliable in various studies using the same devices as well as previous models (Johnston et al., 2014; Delaney et al., 2017b; Weaving et al., 2017; Thornton et al., 2019).

Intensity Analysis

In addition to using the generic export of the summary metrics as detailed below, following training, raw data (10 Hz) were exported to Microsoft Excel as comma separated value (csv) files. These files included details such as time and speed. Speed was adjusted to mmin^{-1} by multiplying by "60," and acceleration was converted to positive values only, as in its original format it included negative values, reflecting decelerations (Delaney et al., 2017b). Moving averages were calculated over 1-min for speed and acceleration using customized software (RStudio v.1.1.383, RStudio, Boston, MA). A 1-min moving average was selected as this reflects the fluctuating intensity of team sports, although appropriately smooths the data to represent true changes in intensity. Further, as a 1-min MM value is used to represent the peak match intensity, using the same time period to determine the relative intensity of drills is deemed as being most appropriate. Maximal means from the same cohort of athletes has been previously established, where no positional differences were evident for both speed and acceleration, therefore, global values of speed (205 m·min^{-1}) and acceleration (0.70 m·s^{-2}) were used as reference values (Thornton et al., 2020). Following, the volume of speed [distance (m)] and acceleration [impulse (kN·s^{-1})] accumulated in 10% buckets (i.e., 110–100%, 100–90%, all the way to 0) was determined. As the MM value was a mean obtained from the group from all files (not simply an athletes' own within each match file), within matches some athletes were able to accumulate distance and impulse above the MM value.

Figure 1 demonstrates an example of a 1-min moving average for speed across a drill, as well as the raw speed to demonstrate the purpose of applying a moving average to such data. On this

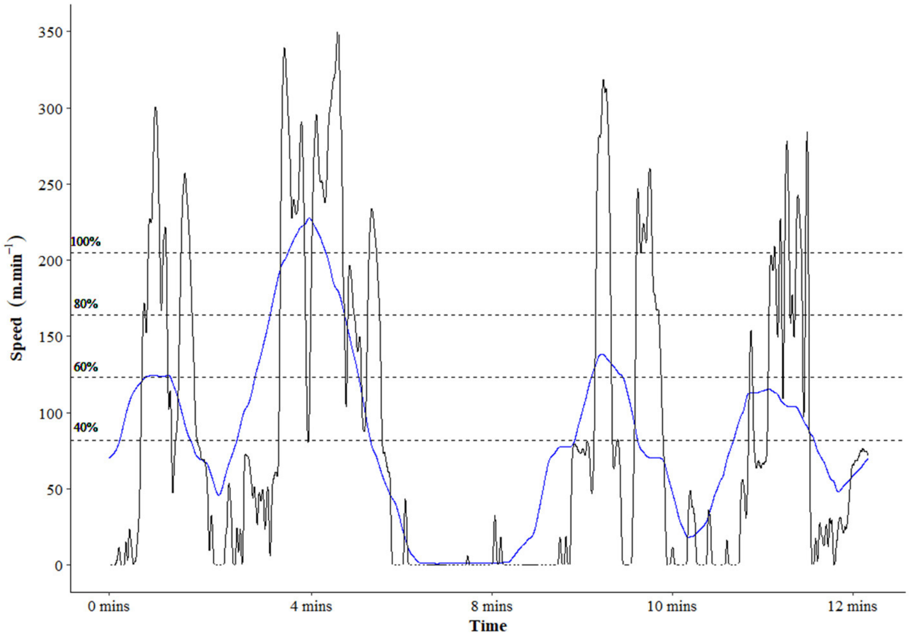

FIGURE 1 | Example 1-min moving average of speed (blue line) and raw speed (black line) across a training game, demonstrating the fluctuating intensity and the purpose of this moving average method. The dotted lines represent values relative to the maximal mean (205 m·min^{-1}) at 20% increments. NB. This file represents one athlete's match file, and in this match could reach speed above the reported maximal mean of 205 m·min^{-1} that is obtained from the squad.

figure, the MM value is demonstrated and 20% buckets (starting at 40%). This figure demonstrates the fluctuating intensity across the drill, and volume can be accumulated at different intensities. For example, based on the 1-min MM speed of 205 m·min^{-1}, 90–100% corresponds to speed between 185 and 205 m·min^{-1}, and the distance accumulated at such intensity was calculated. To account for differing drill lengths, the total volume of distance and impulse covered within drill was calculated, and the volume within each bucket was then divided by the total volume, providing the percentage distribution.

Drill Types

During each training session, drills were labeled according to its primary purpose, categorized as either warm up, skill drill, game (i.e., SSG or high-intensity game), conditioning or matches (official AFLW matches). Matches were also included as a "drill" allowing comparisons to be made with training drills. Specifically, within these categories, warm up represents any drill that is designed to prepare athletes for the session and includes warm up kicking drills. Skill drills include those which are designed to learn or focus on concepts such as kicking, tackling, and handballing. Games include drills used to replicate game scenarios such as match simulation, SSGs and other high-intensity concept drills. Conditioning includes drills solely focused on increasing aerobic power, anaerobic capacity, speed, agility, acceleration, and deceleration movements. Matches included each quarter of AFLW competition. For this analysis, sessions the day prior to the match (match−1) were removed (although most weeks did not have a match−1 session), as they typically involve low intensity craft, or individual skill, as were sessions 2 days post-match (match +2), as this is generally mobility and straight line, low-intensity running. Within the final dataset, there were a total of 800 warm up files, 2,400 skill drills, 1,161 games, 606 conditioning drills, and 523 matches.

Statistical Analysis

Data were assessed for normal distribution using a Shapiro-Wilk test. There were no statistical comparisons made between season phases for the weekly externally measured training loads, as practically this is not deemed as useful. Linear mixed models were used to compare the intensity distribution of each drill type compared to matches within each bucket. In this model, the outcome variables were each intensity bucket, the fixed effect was drill type, and the random effect was the athlete identification. Further, within each drill type, the change in the distribution of intensity across each phase was similarly investigated using linear mixed models. Here, the outcome was each drill type separately (excluding matches as these were only played during competition), the fixed effect was the phase of the season, and the random effect was the athlete identification. Resulting SDs and mean differences were then assessed to establish standardized effect sizes (ES) and 90% confidence limits (CL), and ES were described using the magnitudes; <0.20 trivial; 0.21–0.60 small; 0.61–1.20 moderate; 1.21–2.0 large and >2.01 very large (Hopkins et al., 2009). Effects were deemed to be real if they were 75% greater than the smallest worthwhile difference (SWD; calculated as 0.6 x the between-athlete SD) (Hopkins et al., 2009) based on reasons explained in previous research (Duthie et al., 2019; Johnston et al., 2020). All statistical analyses were performed in R Studio software (version 1.3.959, RStudio Inc.).

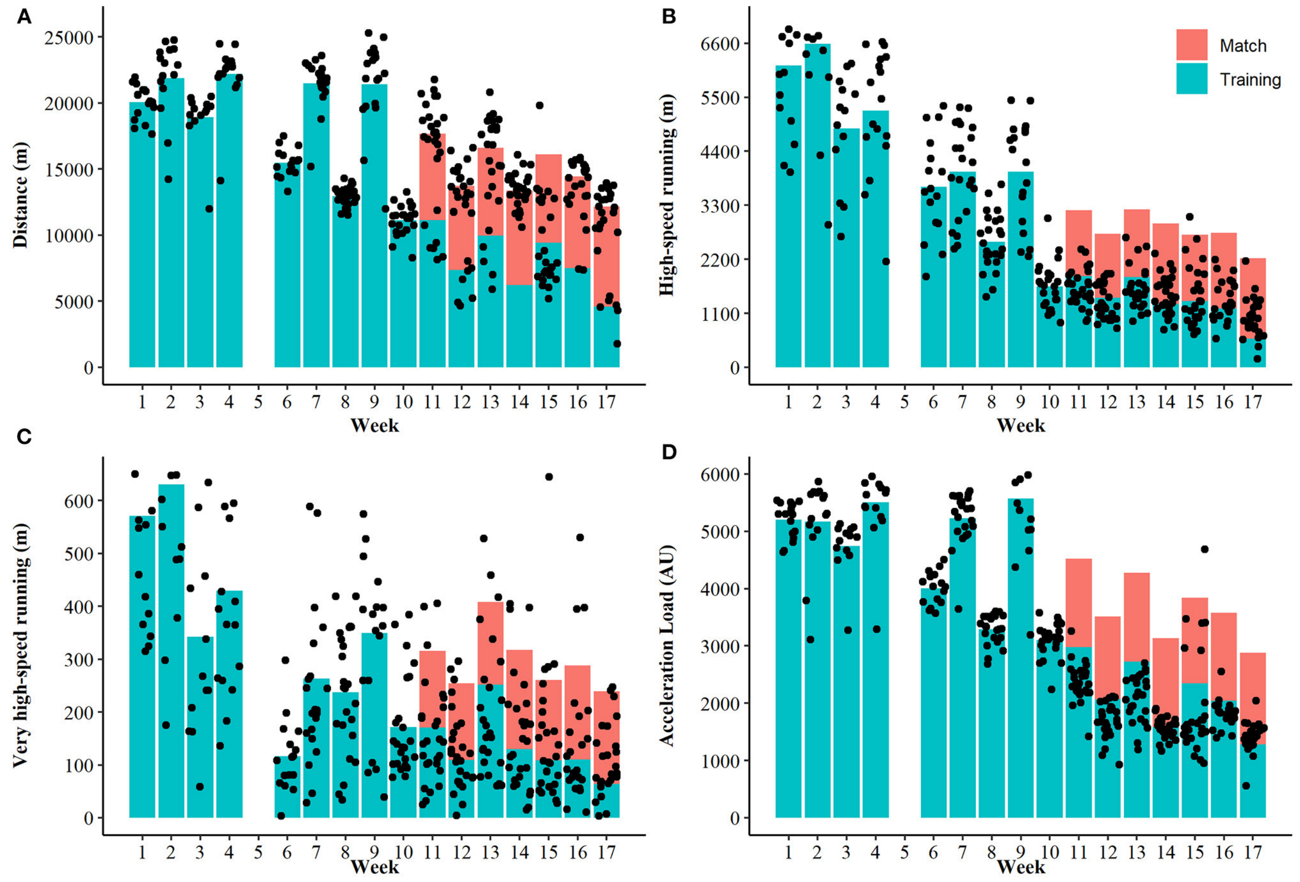

FIGURE 2 | Mean (bars) and individual (dots) weekly physical demands of training and matches across the pre-season and in-season phases. The pre-season phase was week 1–10 (general preparation was weeks 1–4, specific preparation weeks 6–10), and competition was weeks 11–17 for **(A)** distance, **(B)** high-speed running, **(C)** very high speed running, and **(D)** acceleration load. *high-speed running is >14.4 km·h^{-1} and very-high speed running is >20 km·h^{-1}.

RESULTS

Figure 2 depicts the mean and individual weekly externally measured training volumes during training and matches across the pre-season and in-season phases (no statistical comparisons made). **Table 2** provides the descriptive data (mean ± SD) of the volume and percentage of distance and impulse accumulated within each intensity bucket for each drill type. **Figure 3** depicts the percentage distribution of distance (A) and impulse (B) within each intensity bucket for each drill type.

When examining the proportion of distance covered at different intensities, compared to matches, a higher proportion of distance was accumulated at 50% of the MM within matches when compared to conditioning (ES = 0.86; ±90% CL = 0.36), however when compared to warm ups, there was a lower distribution of distance within matches at 50% (1.14; ± 0.48). At 60% of the MM, a higher proportion of distance was accumulated in matches when compared to warm-ups (0.80; ± 0.34), conditioning (1.87; ± 0.79) and skill drills (0.73; ± 0.31). At 70% of MM, a higher proportion of distance was covered in matches compared to both skill drills (1.79; ± 0.76) and warm-ups (2.78; ± 1.18). Similarly, at 80% of MM, a higher proportion of distance was covered in matches compared to both skill drills (2.09; ± 0.88) and warm-ups (3.93; ± 1.66), as it was at 90% for skill drills (1.54; ± 0.65) and warm-ups (2.23; ± 0.94), and at 100% for skill drills (1.05; ± 0.45) and warm-ups (1.43; ± 0.61).

Regarding impulse, at 60% of MM, there was a higher proportion of impulse accumulated within matches compared to conditioning drills (1.06; ± 0.45), similarly at 70% (2.70; ± 1.14) and 80% (0.91; ± 0.38). There were no other substantial differences in the proportion of impulse between matches and drill types at each bucket.

When comparing the distribution of volume covered within each bucket for drill types between each phase, more distance was accumulated at 50% during competition when compared to general preparation (1.08; ± 0.45). There were no other differences between each phase of the season for each drill type.

DISCUSSION

This investigation provided novel evidence of the "field-based" training requirements across an AFLW season. In part (a), the weekly externally measured training loads (including match load)

TABLE 2 | Descriptive data (mean ± standard deviation) of the volume and percentage of distance and impulse accumulated within each intensity bucket for each drill type.

Bucket	Variable	Match		Game		Conditioning		Skill drill		Warm up	
		Volume	**Percentage**	**Volume**	**Percentage**	**Volume**	**Percentage**	**Volume**	**Percentage**	**Volume**	**Percentage**
<50%	Distance	666 ± 85	12 ± 1%	231 ± 43	20 ± 4%	81 ± 21	45 ± 18%	253 ± 57	53 ± 13%	319 ± 52	54 ± 8%
	Impulse	16625 ± 2266	15 ± 2%	5859 ± 1218	23 ± 4%	2710 ± 975	47 ± 15%	3903 ± 1020	26 ± 7%	4694 ± 895	26 ± 5%
50%	Distance	850 ± 334	15 ± 5%	229 ± 141	18 ± 9%	25 ± 29	7 ± 12% *	120 ± 107	20 ± 15%	134 ± 63	24 ± 12% *
	Impulse	18275 ± 6361	16 ± 6%	5652 ± 3878	21 ± 9%	761 ± 831	14 ± 18 *	3054 ± 2579	19 ± 13%	3493 ± 2142	19 ± 10%
60%	Distance	1280 ± 392	22 ± 6%	295 ± 180	22 ± 9%	28 ± 56	6 ± 11% *	106 ± 134	14 ± 14% *	84 ± 57	15 ± 11% *
	Impulse	26721 ± 6862	23 ± 5%	6295 ± 3854	23 ± 8%	546 ± 717	9 ± 16% *	3368 ± 2712	21 ± 13%	3564 ± 2322	20 ± 11%
70%	Distance	1358 ± 370	23 ± 4%	279 ± 196	19 ± 9%	134 ± 250	17 ± 29 *	72 ± 128	8 ± 11% *	31 ± 43	5 ± 8% *
	Impulse	27671 ± 9076	23 ± 5%	5028 ± 3350	19 ± 9%	331 ± 760	3 ± 7% *	2838 ± 2657	16 ± 13%	3144 ± 1908	18 ± 11%
80%	Distance	971 ± 398	16 ± 5%	199 ± 200	13 ± 9%	87 ± 193	11 ± 23% *	36 ± 89	3 ± 7% *	5 ± 23	1 ± 2% *
	Impulse	18426 ± 9230	15 ± 6%	2833 ± 2702	10 ± 9%	918 ± 2793	5 ± 14% *	1862 ± 2357	10 ± 11%	1816 ± 1539	10 ± 9%
90%	Distance	497 ± 335	8 ± 5%	103 ± 152	6 ± 7%	37 ± 112	4 ± 12%	14 ± 49	1 ± 4% *	3 ± 21	0 ± 2% *
	Impulse	8040 ± 6076	6 ± 4%	1046 ± 1617	4 ± 6%	1699 ± 4323	9 ± 22%	984 ± 1795	5 ± 8%	864 ± 1036	5 ± 6%
100%	Distance	165 ± 159	3 ± 3%	36 ± 75	2 ± 4%	29 ± 84	3 ± 7%	4 ± 21	0 ± 2% *	3 ± 21	0 ± 1% *
	Impulse	2424 ± 3094	2 ± 2%	267 ± 677	1 ± 2%	480 ± 1557	2 ± 9%	389 ± 1096	2 ± 6%	236 ± 502	1 ± 3%
110%	Distance	44 ± 83	1 ± 1%	10 ± 36	1 ± 2%	115 ± 344	8 ± 21%	1 ± 8	0 ± 1%	25 ± 170	2 ± 10%
	Impulse	464 ± 982	0 ± 1%	55 ± 293	0 ± 1%	2929 ± 8657	10 ± 26%	132 ± 595	1 ± 3%	65 ± 298	0 ± 1%

*Compared to matches, differences in the distribution of volume that are >0.6 × the smallest worthwhile difference are denoted by *. Only statistical comparisons 50% or above were made.*

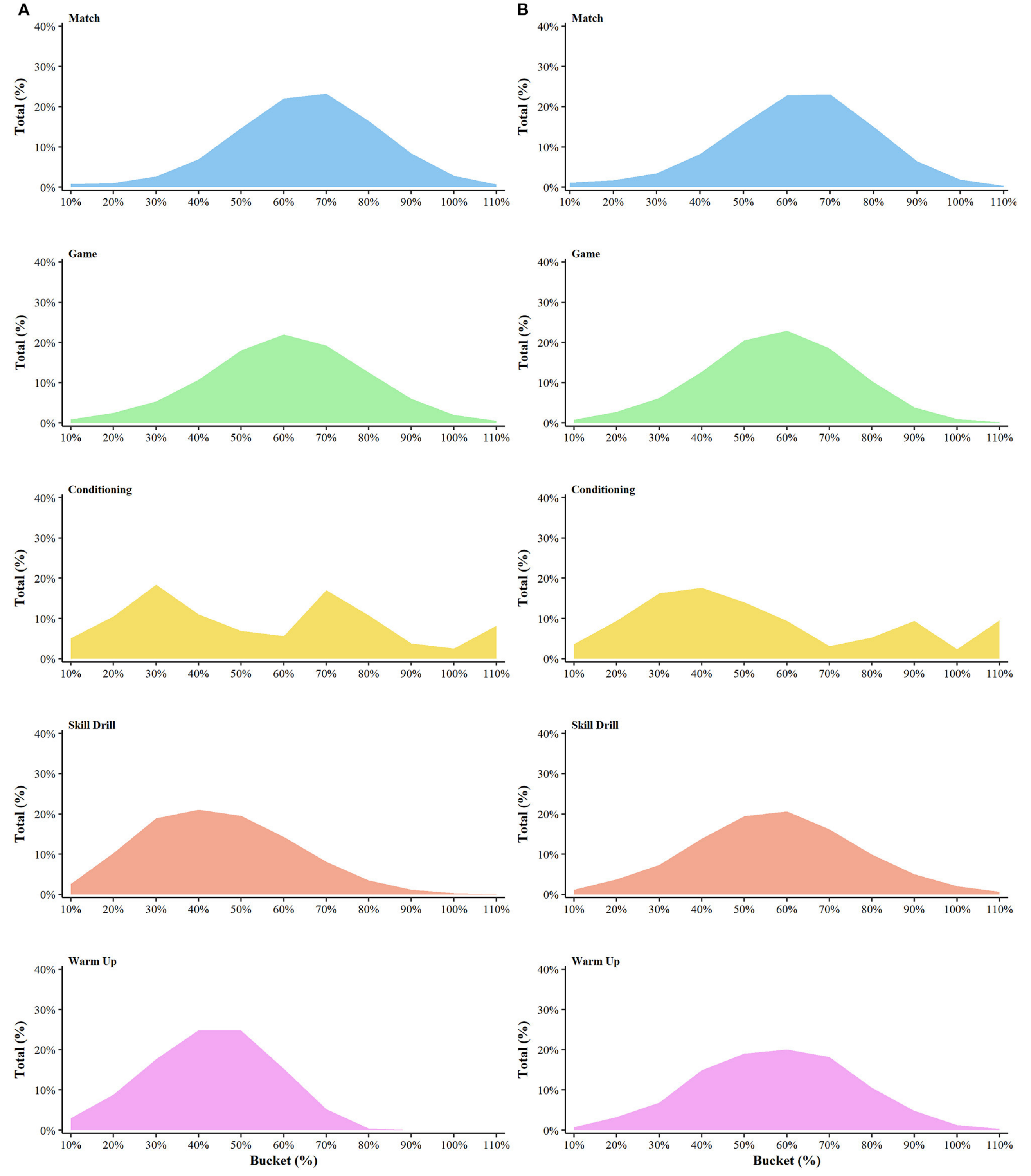

FIGURE 3 | Distribution of distance **(A)** and impulse **(B)** for each drill type.

for various metrics were presented (**Figure 2**), quantifying the periodization of training volume across a season. This analysis demonstrated that AFLW athletes undergo higher training loads during the pre-season phase for most variables that were assessed, a finding that is in agreement with periodization principles of team sports (Bompa and Haff, 2015; Moreira et al., 2020). In part (b), the intensity of training drills and matches relative to previously established MMs was investigated, where the volume of distance and impulse accumulated within intensity buckets (50–110% of MM) for different drill types was determined (**Figure 3**; **Table 2**). This analysis demonstrated that a higher proportion of distance is accumulated at intensities between 70 and 110% of MM within matches compared to each drill type (except conditioning). Further, a higher proportion of impulse is accumulated between 60 and 80% MM within matches compared to conditioning, however no other differences were evident. Additionally, the results of the present study demonstrated that in warm-ups, more proportion of distance was accumulated at 50% of MM during the competition phase compared to general preparation phase of the competition. Together, the findings presented within this study provide practitioners with useful information relating to both the volume and intensity of workloads undertaken across a season. This novel analysis of training drills compared to matches can help ensure athletes are exposed to not only the intensity of matches, but also the volume covered across a range of intensities is comparable. This has important applications for practitioners particularly from a rehabilitation perspective in the return to play process, as ensuring athletes have undertaken high intensity training that is comparable to that within matches.

This is the first study to describe the externally measured weekly workloads undertaken across an AFLW season. As depicted in **Figure 2**, compared to in-season the pre-season phase demonstrated evidently higher (although not statistically compared) field-based training loads for each metric, particularly distance, high-speed running and acceleration load. This findings is in agreement with established training periodization recommendations for team sports (Bompa and Haff, 2015; Moreira et al., 2020). As the primary aim of the pre-season period is to maximize the physical and technical abilities of athletes in preparation for the preceding competition, this finding is common to that of other research (Ritchie et al., 2016; Moreira et al., 2020). Although this study did not examine internal loads, often this pre-season period is also characterized by higher internal load (i.e., session rating of perceived exertion) than the competition period (Rogalski et al., 2012), where emphasis is on recovery and rejuvenation between games to reduce the impact of fatigue on performance. Prior to this research, no such study within AFLW has investigated acceleration load, which is an important metric when considering the global acceleration/deceleration demands of team sports (Delaney et al., 2017b). As such, it is particularly important AFLW athletes are prepared to tolerate the extensive acceleration/deceleration demands of competition (Thornton et al., 2020).

No previous study has investigated the distribution of activity relative to MM within drills (as well as matches). This is a method that may help ensure certain training drills (e.g., match simulation, SSGs) have a comparable distribution of activity across a range of intensities when compared to matches (**Table 2**; **Figure 3**). Previous research has demonstrated the MM values of speed and acceleration across 1–10 min periods within AFL (Delaney et al., 2017a) and AFLW (Johnston et al., 2020), providing important information regarding the most intense periods of competition which is useful in the prescription of training. However, this "peak" of a game only occurs once within the game and fails to consider the volume of work performed at such an intensity (Johnston et al., 2020). A recent study (Johnston et al., 2020) investigated the distribution of activity relative to the 1-min MM intensity within AFL and rugby league, demonstrating that most activity is performed at ∼60% of the MM, and for AFL, just 13% of distance was accumulated above 70% of the MM. Within this study, a higher proportion of distance was covered above 70% (51% and 3.1 km), although this was lower for impulse (46% and 57,025 kN·s^{-1}). Interestingly, above 100% of the MM, there was minimal volume covered for both distance and impulse, reflecting the notion that covering large volumes at these intensities is not necessary to replicate the most demanding periods of competition in training (Johnston et al., 2020). Overall, these findings demonstrate that preparation of AFLW athletes should involve high-intensity skill-based drills (i.e., SSGs, match simulation) periodized within their training program, as these drills can expose athletes to periods of high-intensity work, whilst simultaneously developing the skill component (Weaving et al., 2017; Duthie et al., 2019; Johnston et al., 2019). It can be hypothesized that the capacity to perform at high intensities for sustained periods may have a tactical performance benefit, as this may permit athletes to physically out-perform their opponent, potentially resulting in a greater number of uncontested possessions, thus increased scoring potential.

In addition to investigating the distribution of activity within each drill type, this research compared these distributions to that of matches, to identify if certain drills involve similar physical demands. It was expected that games (i.e., SSG) display a comparable distribution of distance and impulse to that of competition, as games are used by practitioners as a tool to prepare and overload physical and tactical match demands (Duthie et al., 2019). This analysis demonstrated that at 60–100% of the MM, there was a higher proportion of distance within matches compared to conditioning, skill drills and warm-ups (**Table 2**; **Figure 3**). As AFLW is an intermittent sport (Clarke et al., 2018; Thornton et al., 2020), a large portion of activity is completed at lower intensities as demonstrated in this study, where 60% of the MM represents a mean speed of 123 m·min^{-1}. As the intensity increased, for both distance and impulse there were minimal differences between the distribution of activity of drills and matches, showing that the distribution of intensity is alike that of matches. Interestingly, at any intensity bucket, there was no substantial difference in the distribution of distance and impulse within training games to that of matches. From a physical preparation perspective, this finding reflects that games (i.e., SSGs) are a useful tool in exposing athletes to the fluctuating intensities common to that of competition (**Figure 2**), whilst simultaneously developing technical abilities. This study also investigated whether the distribution of intensity within each drill type varied across each phase of the season, to identify if the purpose of each phase influenced the outcome of the intensity distribution within drills. Interestingly, there was only one substantial difference for warm-ups, where at 50% of the MM, a higher distribution was prevalent within competition compared to general preparation (1.08; ± 0.45). This finding may reflect the reduced intensity of warm-ups within competition, where a greater emphasis on recovery and rejuvenation is a key focus. It was expected that games and perhaps skill had a greater distribution of activity at higher intensities (i.e., 80–110%) within specific preparation compared to general preparation, as typically during this phase the aims of training drills is to mimic match scenarios. A likely cause of this not occurring within the present study is that this investigation was conducted within an inaugural season, where training was largely focused on developing tactical skills, where match roles were established and learning key concepts, therefore, drills may not have largely altered as the season progressed.

CONCLUSIONS

Overall, this study aimed to provide an overview of the training undertaken across an AFLW season, where for a range of externally measured metrics, weekly training loads (also included match load) was summarized. This demonstrated the extensive workloads that are completed across a season by AFLW athletes, emphasizing the importance of well–planned, structured training programs. In addition, this study examined the training intensity relative to previously established MM, where the volume and distribution of volume (%) completed within intensity buckets (50–110%) was determined. These findings showed that the highest proportion of volume within matches is performed at ∼60% of the MM for both distance and impulse, a consistent finding with other research. In comparing the distribution within each bucket of matches against different drill types, the distribution of distance is higher between 70 and 100% within matches, compared to each drill type (except conditioning), and a greater proportion of impulse is accumulated between 60 and 80% within matches compared to conditioning. This novel analysis can be used by practitioners to plan and guide training, providing an understanding of the volume of activity performed relative to the 1-min MM. Additionally, when comparing the distribution of activity across season phases, for warm-ups, more distance is accumulated at 50% of MM within competition compared to general preparation, reflecting the differing training aims of these phases.

DATA AVAILABILITY STATEMENT

The datasets used and analyzed during the current study will be made available by the corresponding author upon reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Australian Catholic University Human Research Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

HT had the original idea of the paper, performed statistical analyses, wrote the paper, and prepared the figures. CA collected the data and assisted in editing the manuscript. AR oversaw the planning and prescription of the training program and assisted in editing the manuscript. RJ, GD, and CM contributed to the idea of the paper, assisted in preparing the figures, and editing of the manuscript. All authors contributed to the article and approved the submitted version.

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Movement Patterns and Match Statistics in the National Rugby League Women's (NRLW) Premiership

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As women's rugby league grows, the need for understanding the movement patterns of the sport is essential for coaches and sports scientists. The aims of the present study were to quantify the position-specific demographics, technical match statistics, and movement patterns of the National Rugby League Women's (NRLW) Premiership and to identify whether there was a change in the intensity of play as a function of game time played. A retrospective observational study was conducted utilizing global positioning system, demographic, and match statistics collected from 117 players from all NRLW clubs across the full 2018 and 2019 seasons and were compared between the ten positions using generalized linear mixed models. The GPS data were separated into absolute (i.e., total distance, high-speed running distance, and acceleration load) and relative movement patterns (i.e., mean speed, mean high speed (>12 km·h^{-1}), and mean acceleration). For absolute external outputs, fullbacks covered the greatest distance (5,504 m), greatest high-speed distance (1,081 m), and most ball-carry meters (97 m), while five-eighths recorded the greatest acceleration load (1,697 m·s^{-2}). For relative external outputs, there were no significant differences in mean speed and mean high speed between positions, while mean acceleration only significantly differed between wingers and interchanges. Only interchange players significantly decreased in mean speed as their number of minutes played increased. By understanding the load of NRLW matches, coaches, high-performance staff, and players can better prepare as the NRLW Premiership expands. These movement patterns and match statistics of NRLW matches can lay the foundation for future research as women's rugby league expands. Similarly, coaches, high-performance staff, and players can also refine conditioning practices with a greater understanding of the external output of NRLW players.

Keywords: female, load monitoring, external output, mixed model, match demands, GPS

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INTRODUCTION

The National Rugby League Women's (NRLW) Premiership is the highest level of domestic rugby league competition for women in Australia. The NRLW was introduced in 2018 involving a three-round competition between four teams, culminating in a grand final between the two highest-ranked teams. The NRLW follows the international rugby league rules set by the Rugby League International Federation with the exception that NRLW matches are 60 min comprised of two 30-min halves, half time is 15 min, allow ten interchanges in each match, and observe a 40/30 kick advantage.

Describing the movement patterns of a given sport lays the foundations for future research to examine the intricacies of match play. While female soccer movement patterns have been established as seen in a recent review (Griffin et al., 2020), Clarke et al. have articulated the movement patterns in both Australian-rules football (Clarke et al., 2018, 2019) and rugby sevens (Clarke et al., 2015, 2017). Similarly, a review of movement patterns in field-based sports spanning maximal speed, high-speed thresholds and movement patterns has been conducted in women (Hodun et al., 2016); however, the movement patterns of players competing in elite-level women's rugby league has been rarely explored in the scientific literature (Quinn et al., 2020). With an 18% year-on-year growth in women's rugby league participation (National Rugby League, 2020), the NRLW Premiership is set to expand in the number of teams over the coming years. To ensure that the level of competition does not regress as a function of including more teams, there is a need for emerging players to be sufficiently trained and conditioned to compete at the elite level, such as those described in the present study.

The movements of players in the Australian women's rugby league team during international match-play have previously been recorded using global positioning system (GPS) technology (Quinn et al., 2020). The findings of this initial study reported that players covered 6,500 m in total distance, with ∼500 m covered above 15 $\text{km}\cdot\text{h}^{-1}$. This study also displayed the relative change in the intensity of match play across each half, whereby mean high speed (>12 $\text{km}\cdot\text{h}^{-1}$) was reduced by ∼40% from the start to the end of the first half (Quinn et al., 2020). While backs were shown to exhibit greater absolute distance covered, there were no significant differences in the relative distances between forwards and backs. In female soccer, it was shown that domestic movement patterns were significantly lower than in international-level matches (Andersson et al., 2010); however, it remains to be seen whether this is present in rugby league. As there is a disparity in match duration from the NRLW Premiership to international matches and as there is varying quality of opposition in women's international rugby league (Quinn et al., 2020) which can affect movement patterns (Hulin et al., 2015), the proportional change in movement patterns from domestic to international rugby league may not imitate the change seen in soccer (Andersson et al., 2010).

There is no doubt that the study by Quinn et al. (2020) provides important information regarding the movement patterns of elite, international rugby league players. However, a common critique in the literature when describing player movement patterns is that studies typically only gather data from one or two teams (Glassbrook et al., 2019). By gathering data from only a few teams, team tactics and strategy could obscure the true movement patterns inherent across the entire competition (Glassbrook et al., 2019). As the only previous investigation in women's rugby league was in international rugby league and focused only on a single team (Quinn et al., 2020), this study will examine the GPS data from the four domestic NRLW teams during the 2018 and 2019 seasons to describe the movement patterns of elite, domestic women's rugby league players. Similarly, in studies with only one or two teams, there is usually only enough power to segregate players into three positional groups; however, there have now been studies in men's rugby league that have segregated players into more specific positional groups (Delaney et al., 2015, 2016a). Therefore, in the present study, we expand the comparisons to further quantify the effect of playing position on the match statistics (tackles, runs, etc.) and GPS metrics (distance, velocity, acceleration).

MATERIALS AND METHODS

The present study included 117 players from the four NRLW clubs (age = 26.8 ± 5.4 yr; height = 1.68 ± 0.07 m; body mass = 76.7 ± 11.9 kg). The Griffith University Human Ethics Committee approved this study (GU Ref No: 2019/359). There were 475 match entries as one player did not enter the field during one match. The mean number of matches played by each player was 4.1 ± 2.2 matches.

All match statistics and demographics (i.e., age, height, and body mass) were publicly sourced from NRL.com. The definitions of match statistics were determined by STATS, the National Rugby League's statistics provider. "All runs" were defined as any time the ball carrier went into contact with a defender, "all run metres" was the cumulative distance of all runs, "tackles" were when the defender successfully executed a tackle, "missed tackles" were when the defensive player could not bring the attacking player to the ground or successfully complete the tackle, and "tackle breaks" were when the attacking player was able to continue running after a missed tackle. These five statistics were chosen by the authors to reflect the contact nature of rugby league and, therefore, to highlight the relative position differences in these events.

The movement patterns of all players during NRLW matches were collected using 10 Hz Optimeye S5 GPS units (Catapult Sports, Victoria, Australia). The GPS data were routinely collected at each match by the sport scientists at each club, while the National Rugby League oversaw the collection, amalgamation and provision of the datasets to the authors in ".cpf" form. Of the 475 match entries that had match statistics recorded, 370 were available for GPS analysis. This discrepancy was due to several reasons, with poor satellite coverage within the stadium being the main reason for why files were not provided to the authors for analysis. Regardless of whether an athlete's GPS data was available, the match statistics were still included in the analysis. Match files were segmented into halves within the proprietary software and interchanges were recorded in the software as per the match footage and GPS tracing. Velocity zones (V1-6) were aligned with those previously reported in women's rugby league (Quinn et al., 2020), with V1 set at 0–6 $\text{km}\cdot\text{h}^{-1}$, V2 set at 6.01–9 $\text{km}\cdot\text{h}^{-1}$, V3 set at 9.01–12 $\text{km}\cdot\text{h}^{-1}$, V4 set at 12.01–15 $\text{km}\cdot\text{h}^{-1}$, V5 set at 15.01–18 $\text{km}\cdot\text{h}^{-1}$, and V6 set at >18 $\text{km}\cdot\text{h}^{-1}$. Acceleration load was calculated as the summation of absolute acceleration and deceleration values across the duration of the match. Three absolute output metrics [total distance, distance >12 km·h^{-1} (i.e., high-speed running; HSR), and acceleration load (Delaney et al., 2016a)] were divided by the total time spent on the field to calculate the mean speed (MS), mean speed when traveling >12 km·h^{-1} (MS$_{12}$), and mean acceleration (Andersson et al., 2010), respectively, to represent the relative outputs. The term "absolute" was used to describe the sum of the metric throughout a match, while the term "relative" was used when dividing the absolute metric by time. Twelve kilometers per hour was used as the threshold for high-speed running to draw comparisons to the previous women's rugby league literature (Quinn et al., 2020).

To assess the positional differences for each tactical match statistic, GPS data metric, and the age of each position, GLMM's were employed, with the associated R script is attached as **Appendix 1**. All GLMM's were built using the *lme4* (Bates et al., 2015) package in R version 3.5.2 (R Core Team, 2019), the *afex* package (Singmann et al., 2020) was used to determine significance at $\alpha = 0.05$ for all analyses, the *emmeans* package (Lenth, 2020) was used for pairwise comparisons, while the *sjPlot* package (Lüdecke, 2020) was used for model diagnostics. The dataset was arranged in "long form" with each observation for each player on a new row. After loading in the *lme4* and *afex* packages, the first model was built as seen in line 16. For each model, the dependent variable was the metric we were interested in explaining ("age," "tackles made," "total distance," etc.), a fixed effect of position was inserted, with random effects of "player," "match," and "team" inserted as well to remove the variability attributed to these variables. Finally, the shape of the distribution was identified for each model with most models following a Gaussian distribution except those with count data which followed a Poisson distribution.

Once the full model (i.e., all fixed and random effects included, see Line 16 in Appendix 1) was established for each dependent variable, each random effect was consecutively removed to identify which random effects were required in the model. If the Bayesian Information Criterion (BIC) was lower after removing a random effect (see Line 18 in Appendix 1) and an analysis of variance between the full and the reduced model was significant (see Line 19 in Appendix 1), it was deemed a significant contributor to the model, otherwise it would be subsequently dropped from that model. Once only random effects that significantly contributed to the model were remaining, the reduced model was deemed the most parsimonious. In all models, the match ID was deemed a significant random effect, while the team that each player competed for was not deemed a significant random effect in any of the models. Once the reduced model was identified, the null model was established (i.e., the reduced model without the predictor included, see Line 20 in Appendix 1). If the calculated X^2 statistic from an analysis of variance between the reduced model and the null model was significant ($p < 0.05$), then the predictor variable was deemed to significantly contribute to the model, To check the assumptions, the reduced model's residuals were plotted against its fitted value to determine if there were any patterns emerging (see Line 22 in Appendix 1) (Harrison et al., 2018).

GLMM's were also used to determine whether the duration of play affected the MS (i.e., players who play shorter duration perform at a higher intensity). Due to the nature of interchange in rugby league, some positions were more likely to play the full 60 min than other positions. Consequently, 93% of backs (i.e., fullbacks, wingers, and centers), 80% of halves (i.e., five-eighths and halfbacks), 59% of second-rowers, 46% of hookers, 21% of locks, and 4% of props played the full duration of the match. If the regression coefficient calculated was significantly different ($p < 0.05$) from zero (see Line 42 of Appendix 1), it displayed a relationship between the amount of time played and the relative output of the position. For the positions where there was a significant effect of duration on MS, the slopes were reported alongside the MS.

Finally, GLMM's were used to determine the change in output in different velocity bands across the two 30-min halves. Like the positional analysis, a full model (see Line 63 in Appendix 1) was developed, with non-significant random effects removed in the reduced model (see Line 65 in Appendix 1). An analysis of variance was performed between the reduced model and the null model (i.e., the reduced model with "half" excluded) to calculate a X^2 statistic to determine whether there was a significant difference ($p < 0.05$) in external output measures between the two halves.

RESULTS

The demographics and minutes played across each playing position are displayed in **Table 1**. Second-row players were the tallest, while locks and hookers were the shortest. Props were considerably heavier than all other positions, with fullbacks and hookers the lightest of the positions. There was only one significant difference in age between the positions [$X^2_{(9)} = 17.59$, $p = 0.040$], with hookers significantly older than fullbacks.

Table 1 also displays the tactical match statistics for each playing position. Most of the backs, halves, and second-row players completed the full 60 min of match play. Fullback players recorded the most runs [$X^2_{(9)} = 50.64$, $p < 0.001$], run meters [$X^2_{(9)} = 49.96$, $p < 0.001$], and tackle breaks [$X^2_{(9)} = 32.81$, $p < 0.001$], while hookers recorded the most tackles [$X^2_{(9)} = 153.02$, $p < 0.001$].

As most fullback, wing, center, five-eighth, and halfback players completed the full 60 min, it was not necessary to determine the coefficient for the relationship between MS and minutes played. This relationship was non-significant for hooker, prop, second-row and lock players; however, it was significant for interchange players [$X^2_{(1)} = 24.41$, $p < 0.001$] and therefore needed to be accounted for when calculating MS. For relative outputs, there were no significant differences in MS [$X^2_{(9)} = 14.61$, $p = 0.102$] and MS$_{12}$ [$X^2_{(9)} = 8.04$, $p = 0.530$], between any of the positions, while mean acceleration [$X^2_{(9)} = 21.26$, $p = 0.012$] was significantly different between wingers and interchange. For absolute output, total distance [$X^2_{(9)} = 195.41$, $p < 0.001$], HSR [$X^2_{(9)} = 115.16$, $p < 0.001$], and acceleration load [$X^2_{(9)} = 183.14$, $p < 0.001$] were significantly different between

TABLE 1 | Demographics and technical data of NRLW players by position.

Position	Unique players (*n*)	Match entries (*n*)	Height (cm)	Body mass (kg)	Age (yr)	Game time (min)	All run meters (m)	All runs (*n*)	Tackles (*n*)	Missed tackles (*n*)	Tackle breaks (*n*)
Fullback	8	28	168.4 ± 4.2	66.8 ± 5.2	26.1 (24.9–27.3)	60 (60–60)	97.2 (82.0–112.4)	10.3 (8.5–12.5)	4.8 (1.9–7.7)	1.3 (0.9–2.0)	3.5 (2.4–4.7)
Winger	19	56	168.0 ± 5.5	69.4 ± 5.0	26.6 (25.4–27.7)	60 (60–60)	66.4^{a} (55.9–76.9)	7.5 (6.5–8.8)	4.1 (2.1–6.1)	1.3 (0.9–1.7)	3.1 (2.2–3.9)
Center	17	56	168.3 ± 6.9	71.4 ± 4.4	26.2 (25.1–27.3)	60 (60–60)	82.9 (72.1–93.7)	9.4 (8.2–10.8)	9.4^{b} (7.3–11.5)	2.0 (1.6–2.6)	3.0 (2.2–3.8)
Five-Eighth	10	28	168.1 ± 6.4	70.9 ± 7.8	27.2 (26.2–28.3)	60 (60–60)	38.6^{a,c} (24.4–52.8)	5.2^{a,c} (4.1 – 6.6)	14.3^{a,b} (11.6–16.9)	2.5 (1.8–3.5)	0.9^{a} (–0.2 to 2.0)
Halfback	8	28	168.7 ± 7.1	70.8 ± 11.4	26.6 (25.5–27.7)	60 (59–60)	44.8^{a,c} (29.9–59.8)	6.3^{a} (5.1–7.8)	12.5^{a,b} (9.6–15.3)	3.0^{b} (2.2–4.0)	1.5 (0.4–2.5)
Hooker	6	28	164.5 ± 6.5	67.5 ± 7.0	27.6 (26.5–28.7)	55 (41–60)	42.9^{a,c} (27.3–58.4)	5.3^{a,c} (4.1–6.9)	26.4^{a,b,c,d,e} (23.5–29.4)	3.4^{a,b} (2.5–4.8)	1.1 (-0.2–2.4)
Prop	23	56	171.1 ± 6.2	90.6 ± 8.5	27.0 (26.0–28.0)	35 (30–39)	69.8^{a,d} (59.9–79.7)	7.4 (6.4–8.6)	16.1^{a,b,c,f} (14.3–17.9)	1.6^{f} (1.2–2.1)	1.1^{a,b,c} (0.4–1.9)
Second-Row	15	56	171.6 ± 6.2	81.5 ± 6.8	26.8 (25.8–27.9)	60 (53–60)	65.1^{a} (54.6–75.6)	8.0 (6.9 – 9.3)	17.8^{a,b,c,f} (15.8–19.8)	2.6^{b} (2.0–3.2)	2.6 (1.8–3.3)
Lock	9	28	164.4 ± 8.2	75.4 ± 4.8	27.0 (26.0–28.1)	44 (37–55)	53.2^{a,c} (39.0–67.5)	7.2 (5.9–8.9)	22.9^{a,b,c,d,e,g,h} (20.3–25.5)	3.2^{a,b,g} (2.4–4.4)	2.3 (1.2 – 3.4)
Interchange	48	111	167.5 ± 7.1	80.2 ± 13.4	26.9 (25.9–28.0)	24 (18–33)	47.7^{a,c,g} (40.7–54.6)	5.5^{a,b,c,g,h} (4.9–6.2)	11.9^{a,b,f,g,h,i} (10.6–13.2)	1.6^{e,f,i} (1.3–2.0)	1.7 (1.2–2.3)

N.B. All values are displayed as mean (95% CI) except height and body mass are displayed as mean ± SD and game time which is median (IQR), superscript indicates significantly different from ^{a}fullback, ^{b}winger, ^{c}centre, ^{d}five-eighth, ^{e}halfback, ^{f}hooker, ^{g}prop, ^{h}second-row, ^{i}lock ($p < 0.05$).

positions (**Table 2**). When comparing the first and second halves, there were no significant differences in the relative distances covered in any of the speed zones, as well as the overall MS. The parameter estimates can be seen in **Table 3**.

DISCUSSION

The present study describes the absolute and relative (to time) movement patterns, player demographics, and match statistics of the 2018–2019 NRLW Premiership in Australia. With respect to differing absolute movement patterns, backs covered between 5,100 and 5,500 m with between 850 and 1,100 m above 12 $\text{km}\cdot\text{h}^{-1}$, five-eighths and halfbacks covered ∼5,200 m with 900 m above 12 $\text{km}\cdot\text{h}^{-1}$, while forwards covered between 2,900 and 4,900 m with between 430 and 820 m above 12 $\text{km}\cdot\text{h}^{-1}$. Similar patterns were reflected in acceleration load where there were no significant differences between any back or halves position, while props were significantly lower than all other starting positions. However, when comparing movement patterns expressed relative to time, there were no significant differences in the relative distance metrics (MS and MS_{12}) between any of the positions. The only significant difference in relative movement patterns was mean acceleration between wingers and interchange players. While the absolute movement patterns display a disparity in the typical match profile across positions of elite women's rugby league, the lack of difference in movement patterns relative to time means when designing training and conditioning protocols the intensity of play is matched across all positions and varying levels of total work is required between positions.

When assessing whether the MS changed as a function of the time on field, there were also no significant relationships for any of the starting positions, with a decrease of 0.4 $\text{m}\cdot\text{min}^{-1}$ for each minute played in the interchange players. While this decrease may seem insignificant practically, when comparing an interchange player competing for 10 min compared to 35 min, it equates to a decrease of 10 $\text{m}\cdot\text{min}^{-1}$, which is ∼13% decrease in MS. These results reflect a similar pattern seen in the men's game where transient fatigue was attributed to the decline in intensity as an interchange player's bout was prolonged (Waldron et al., 2013). These results also display a need to further understand the role and requirement of interchange players in women's rugby league, similar to those explored in the men's game (Delaney et al., 2016b).

When comparing relative movement patterns between domestic (i.e., the present study) and international women's rugby league (Quinn et al., 2020) NRLW backs covered between 75.5 and 80.1 $\text{m}\cdot\text{min}^{-1}$ compared to ∼75 $\text{m}\cdot\text{min}^{-1}$ in international matches, NRLW halves covered between 79.8 and 80.5 $\text{m}\cdot\text{min}^{-1}$ compared to ∼78 $\text{m}\cdot\text{min}^{-1}$ in international matches, and NRLW forwards covered between 78.0 and 82.7 $\text{m}\cdot\text{min}^{-1}$ compared to ∼71 $\text{m}\cdot\text{min}^{-1}$ in international matches. This contradicts figures seen in other codes of football played by women, with female soccer players recording a higher intensity when playing at the international level compared to at the domestic level (Andersson et al., 2010). These comparisons show that while the backs and halves roughly display similar MS, it is evident that forwards in the shorter-duration NRLW may maintain their output better than in the longer-duration international level. Conversely, it could be that the international

TABLE 2 | External workload in the NRLW by player position.

Position	Mean speed by minutes	Mean speed ($m\cdot min^{-1}$)	Mean high speed ($m\cdot min^{-1}$)	Total distance (m)	High-speed running (>12 $km\cdot h^{-1}$) (m)	Acceleration load ($m\cdot s^{-2}$)	Mean acceleration ($m\cdot s^{-3}$)
Fullback	–	80.1 (75.4–84.8)	15.3 (12.1–18.6)	5,504 (5,008–6,000)	1,081 (915–1,246)	1,530 (1,374–1,686)	0.37 (0.34–0.40)
Winger	–	75.5 (71.8–79.3)	13.1 (10.4–15.8)	5,134 (4,763–5,504)	916 (780–1,052)	1,549 (1,434–1,664)	0.38 (0.35–0.40)
Center	–	75.9 (72.3–79.6)	13.5 (10.9–16.2)	5,116 (4,760–5,473)	882 (749–1,016)	1,582 (1,472–1,693)	0.39 (0.37–0.42)
Five-Eighth	–	79.8 (75.3–84.3)	13.3 (10.3–16.3)	5,244 (4,754–5,733)	883 (725–1,042)	1,697 (1,545–1,850)	0.42 (0.39–0.45)
Halfback	–	80.5 (76.1–84.9)	14.3 (11.4–17.2)	5,212 (4,741–5,683)	900 (745–1,055)	1,593 (1,446–1,740)	0.41 (0.39–0.44)
Hooker	−0.18 (−0.41 to 0.12)	82.7 (77.5–87.9)	15.2 (11.7–18.7)	4,844.5 (4,289–5,400)	817 (636–999)	1,472 (1,296–1,648)	0.42 (0.39–0.45)
Prop	−0.11 (−0.37 to 0.16)	78.6 (75.1–82.1)	13.4 (11.0–15.8)	2,908^{a,b,c,d,e,f} (2,557–3,259)	432^{a,b,c,d,e,f} (305–559)	887^{a,b,c,d,e,f} (779–994)	0.41 (0.39–0.43)
Second-Row	−0.12 (−0.31 to 0.06)	78.0 (74.3–81.6)	12.7 (10.2–15.1)	4,627^{g} (4,271–4,984)	693^{a,b,g} (563–823)	1,362^{d,g} (1,252–1,472)	0.39 (0.37–0.41)
Lock	−0.22 (−0.53 to 0.16)	78.4 (74.0–82.9)	13.9 (11.1–16.8)	4,044^{a,b,c,d,e,g} (3,562–4,526)	697^{a,g} (543–852)	1,228^{b,c,d,e,g} (1,078–1,378)	0.40 (0.38–0.43)
Interchange	−0.41* (−0.57 to −0.26)	80.1 (77.0–83.1)	14.5 (12.4–16.7)	2,514^{a,b,c,d,e,f,h,i} (2,246–2,782)	439^{a,b,c,d,e,f,h,i} (327–551)	775^{a,b,c,d,e,f,h,i} (695–855)	0.41^{b} (0.40–0.43)

N.B. All figures are presented as mean (95% CI), –indicates insufficient data to determine regression coefficient, * *indicates sig. different from zero, superscript indicates significantly different from* ^{a}*fullback,* ^{b}*winger,* ^{c}*centre,* ^{d}*five-eighth,* ^{e}*halfback,* ^{f}*hooker,* ^{g}*prop,* ^{h}*second-row,* ^{i}*lock* ($p < 0.05$).

players did not require as high output as they were of a higher quality than their opponents (Hulin et al., 2015).

While the values for MS and MS_{12} for the full match were comparable to Quinn et al. (Quinn et al., 2020) (who also found no significant differences in the 80-min players between any of the positions), when comparing half-to-half (**Table 3**), Quinn et al. (2020) found a significant decline in certain velocity bands from the first to second half, where the present study showed no such difference. This could be due to the differing inclusion criteria where Quinn et al. (2020) only included those playing the full 80-min in the half-to-half comparison. The MS in the present study was still lower than those seen in other sports played by women (Hodun et al., 2016), which could be attributed to the energetic demand of the tackling nature of rugby league which is not present in sports such as soccer and hockey. Although, the MS was higher than that recorded in women's rugby union (Suarez-Arrones et al., 2014) which would feasibly be the most similar sport code, which reflects the difference in movement patterns between men's rugby league (Cummins et al., 2018) and rugby union (Jones et al., 2015). However, due to the low threshold for mean high speed (i.e., 12 $km\cdot h^{-1}$), it is difficult to compare high-intensity efforts to other sports (Hodun et al., 2016). While the mean high-speed threshold was chosen to make direct comparisons with international women's rugby league, further investigations could use higher intensity thresholds to further interrogate the differences in movement patterns with other sports.

Another noteworthy finding was the unique characteristics of the lock position. While locks within modern men's rugby league are most commonly paired with second-rowers (i.e., the back row) or with props (i.e., the "middle forwards") (Glassbrook et al., 2019), the present study showed that locks in NRLW were different in their role. NRLW locks were, on average, 8 and 7 cm shorter than second-rowers and props, respectively, weighed 6.1 and 15.2 kg less, respectively, ran for 11.9 and 16.8 m less with the ball, respectively, and made 5.1 and 6.8 more tackles, respectively. Consequently, these findings reinforce the limitations in simply transferring male rugby league conditioning research into the female game (Emmonds et al., 2019).

TABLE 3 | Half-by-half analysis of external outputs obtained during domestic women's rugby league matches.

Metric	1st Half	2nd Half
Relative total distance ($m\cdot min^{-1}$)	79.6 (76.8–82.5)	79.3 (76.5–82.2)
Relative V1 distance ($m\cdot min^{-1}$)	36.7 (33.0–40.4)	36.9 (33.2–40.7)
Relative V2 distance ($m\cdot min^{-1}$)	15.1 (14.4–15.8)	15.0 (14.2–15.7)
Relative V3 distance ($m\cdot min^{-1}$)	14.5 (12.8–16.1)	14.1 (12.5–15.8)
Relative V4 distance ($m\cdot min^{-1}$)	7.7 (4.3–14.1)	7.6 (4.2–13.8)
Relative V5 distance ($m\cdot min^{-1}$)	2.9 (1.6–5.3)	2.9 (1.6–5.2)
Relative V6 distance ($m\cdot min^{-1}$)	2.0 (1.1–3.7)	1.8 (1.0–3.3)

N.B. Values presented as mean (95% CI). $V1 = 0–6$ $km\cdot h^{-1}$, $V2 = 6.01–9$ $km\cdot h^{-1}$, $V3 = 9.01–12$ $km\cdot h^{-1}$, $V4 = 12.01–15$ $km\cdot h^{-1}$, $V5 = 15.01–18$ $km\cdot h^{-1}$, *and* $V6 = >18$ $km\cdot h^{-1}$. *No significant differences* ($p < 0.05$) *were found between halves for any metric.*

The data from the present study is crucial as it is the first week-by-week examination of women's rugby league. Quinn et al.

(Quinn et al., 2020) provided an overview of the movement patterns of the Australian Women's Rugby League team during international competition (Quinn et al., 2020); however, these movement patterns could be adversely affected by cumulative fatigue, as previously seen in male rugby league (Johnston et al., 2013). As the NRLW Premiership expands, it will conceivably shift from a semi-professional to a professional competition enabling players to commit full-time to their career in rugby league. This shift, with players unconstrained by holding secular jobs, may also see the movement patterns of NRLW match play increase above the values seen in this study.

Another notable feature of the present study was the dissemination of knowledge, skills, and awareness around the use of the mixed models for sports science practitioners. As noted in a recent call to sports scientists (Sainani et al., 2020), there is a growing need for sports scientists to be familiar with statistical methods that can properly account for variation within their datasets. While the requirement to account for repeated measures and missing data is pertinent in longitudinal GPS movement pattern studies, it is still lacking within a substantial proportion of the sports science community. For instance, in a recent systematic review of rugby league (Dalton-Barron et al., 2020), only seven of the 15 studies correctly accounted for the repeated observations within GPS datasets. Throughout this study, the authors have highlighted the importance of using appropriate statistical modeling for repeated measures of individuals and teams in longitudinal datasets. We explained the methodology and application of a GLMM as well as provide the relevant computer scripts required to perform a GLMM. We anticipate that this approach will increase the transparency and reproducibility of the findings, as well as encourage statistical literacy for sports scientists.

CONCLUSION

This study was the first study to describe the movement patterns and match statistics in domestic elite-level women's rugby league. Two seasons of the NRLW Premiership (13 matches) were analyzed, with all clubs contributing to the dataset. While backs and halves covered significantly greater absolute distances than forwards, the relative distances covered were not different across any of the positions. The lock position was also a substantially different position to men's rugby league. This study also provided more clarity on the application of mixed models for sports science datasets, with a specific focus on team-sport data with repeated observations.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Griffith University Human Research Ethics Committee. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

TN: project concept, data collection and analysis, and preparation of manuscript. PB and CM: project concept, refining, and synthesizing manuscript. KQ and SB: refining and synthesizing manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2021.618913/full#supplementary-material

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Hormonal Contraceptive Use in Football Codes in Australia

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The recent launch of the new National elite women's football competitions in Australia has seen a 20–50% increase in grassroots female participation. With the growing participation across grassroots to elite competitions, understanding the health of female athletes should be prioritized. In elite level athletes, hormonal contraceptive (HC) use is common (∼50%), however, little is known about the prevalence and reasons for use and disuse of HC in elite female football athletes. As such, the impact of HC use is often not considered when monitoring the health of female footballers. This study involved a subset of data collected as part of a larger questionnaire investigating menstrual cycle function, hormonal contraception use, and the interaction with training load volume and perceived performance in elite female football code athletes. A total of 177 participants completed the questionnaire across three football codes within Australia (rugby league, rugby union/sevens, Australian football). One third ($n = 58$) of athletes were currently using HC, predominately in the form of an oral contraceptive pill (OC, $n = 47$). Reasons for use included: to avoid pregnancy (71%); to control/regulate cycle (38%); and to reduce menstrual pain (36%). However, most athletes using an OC (89%) could not identify the type of pill used (e.g., mono-, bi-, or triphasic). The main reason for disuse was due to the negative side effects ($n = 23$), such as mood swings, weight gain, and depression/anxiety. Comparing HC users and non-users, there were no statistical differences in the number of reported menstrual symptoms, use of medication to relieve menstrual pain, or frequency for needing to adapt training due to their menstrual cycle ($p > 0.05$). Since most athletes were unaware of the type of OC they used, female football athletes require further education about the different types of HC, and specifically OC, available to them. Similarities in the symptoms experienced, pain management, and training adaptation requirements between groups suggests that HC use may not have the intended outcome for certain athletes. As such, greater awareness of athlete's personal experiences with the menstrual cycle, how HC may influence their experience, and acknowledgment of non-pharmacological methods to help manage menstrual cycle related symptoms are warranted.

Keywords: oral contraception, physiology, female athlete, women, elite sport

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INTRODUCTION

Monitoring the menstrual cycle for athlete's optimal health and performance is now recognized as an important aspect of female sport (Harber, 2011). A recent meta-analysis looking at the influence of menstrual cycle phase on exercise performance highlights the challenges in clearly identifying this relationship due to poor quality studies and variation in study design (McNulty et al., 2020). Given these challenges, it is recommended that individualized approaches to managing an athletes' training across their menstrual cycle be taken (McNulty et al., 2020). While research is inconclusive as to whether menstrual cycle phase affects performance, many athletes report negative symptoms and feel that they perform worse at certain phases of their cycle (Armour et al., 2020). To alleviate these symptoms, oral contraceptive (OC) use has been reported as common practice among athletes (Schaumberg et al., 2018).

Understanding the prevalence of hormonal contraceptive (HC) use and their reasons for use/disuse are important for practitioners to develop appropriate monitoring and management practices for female athletes. Approximately 50% of elite British athletes use HC (Martin et al., 2018), while similar values are reported in elite Australian athletes (47%, Larsen et al., 2020). In recreational to elite level Australian athletes, the use of HC use is slightly lower at ∼40% (Armour et al., 2020), likely due to the inclusion of recreational level participants. Despite the advantages of using HC to control their menstrual cycle and potentially reduce menstrual-related symptoms, evidence suggests potential negative outcomes associated with HC use such as a higher risk for depression (Anderl et al., 2020), lower bone mineral density (Allaway et al., 2020), and greater oxidative stress (Cauci et al., 2016), particularly with OC methods. Understanding the reasons why athletes use HC is important to inform athletes' decision to start, stop, or switch between different HC options.

The number of elite women's National-level competitions, specifically within the football codes of Australian football, rugby union, and rugby league has increased over the past 10 years. While these athletes are considered to be playing at the top-level of competition for their sport, given the infancy of these competitions, little research is available on these athletes to inform athlete management practices. Additionally, most research regarding the menstrual cycle and hormonal contraceptive use to date has been conducted on the general population (Schaumberg et al., 2018; Mackay et al., 2019; Freemas et al., 2020) or endurance athletes (Redman and Weatherby, 2004; Solli et al., 2020). Further research is therefore necessary to report the prevalence and reasons for HC use within female football codes to help shape athletes' management and monitoring practices. The aim of this study was to determine the prevalence and reasons for HC use in athletes competing in female football codes in Australia.

MATERIALS AND METHODS

Questionnaire Design

The data used in this study are a subset from a larger questionnaire completed between September 2019 and May 2020, hosted on Qualtrics and adapted from previously used menstrual cycle questionnaires (Armour et al., 2020; Bruinvels et al., 2020). The larger questionnaire gathered data from six areas; sporting background, menstrual cycle function, medical history, hormonal contraceptive use, the interaction between training loads and the menstrual cycle, and education and communication practices regarding the menstrual cycle. This study primarily used data from the HC use section, sporting background (for participant characteristics), and questions regarding menstrual-related symptoms, use of medication to alleviate symptoms, and the need to adapt training. All questions used within this study were multiple choice answers, with some questions allowing an option for "Other, please specify." This project was approved by the La Trobe University Human Ethics committee (HEC19066). Participants provided informed consent and the questionnaire was conducted anonymously.

Recruitment Strategy

Participants were eligible to complete the survey if they were currently competing in a female football code at a representative level and were 16 years of age or over at the time of completing the survey. National sporting bodies were contacted via email and asked to distribute the survey to their player network. The following sporting bodies approved the questionnaire to be disseminated to their state and national representative players: Australian Football League, Rugby Australia, National Rugby League.

Within Australia, there are an estimated 420 elite female Australian football players, 90 elite rugby league players, 100 elite rugby union players, and 150 elite rugby sevens players (although some athletes may play in both rugby union and rugby sevens competitions, and so the total number of elite athletes across both sports is likely lower). To be considered a representative sample, the aim was for a minimum 20% response rate within each sport.

Statistical Analysis

Descriptive statistics are presented as mean (standard deviation) for normally distributed data and counts and proportions (%) for categorical data. Chi-squared analysis was used to compare responses between hormonal contraceptive and non-hormonal contraceptive groups, with statistical significance set at $p \leq 0.05$.

RESULTS

The 20% response rate was achieved for each sport, with 177 athletes responding to the survey. Respondent characteristics are presented in **Table 1**. One third of respondents ($n = 58$) were currently using a HC at the time of survey completion. Most respondents were participating in 4–7 h ($n = 91$, 51%) or 8–12 h ($n = 61$, 34%) of field-based training, and 1–3 h ($n = 82$, 46%) or 4–7 h ($n = 87$, 49%) of gym-based training per week.

The types of HC used and the specific types of OC used are presented in **Figure 1**. The majority of players using OC could not identify the type of pill used (i.e., monophasic, triphasic, $n = 42$, 89% of OC users). Of those who could not identify the type, 10 (21% of OC users) were also unable to identify the brand of OC pill used. HC use for greater than 5 years accounted for the largest group of users ($n = 22$, 38%), while 13 (22%) had used their current HC method for 12 months or less. Reasons for using a hormonal contraceptive included: to avoid pregnancy; to control/regulate their cycle; and to reduce menstrual-related pain (**Figure 2A**). Most users ($n = 23$, 40%) reported experiencing no side effects of using a HC, while light or no periods ($n = 18$), mood fluctuations ($n = 13$), and weight gain ($n = 10$) were the most commonly reported side effects for others.

TABLE 1 | Participant characteristics of HC and non-HC users. Data presented as mean (SD) or number; percentage of total within sport[a] or HC-user group[b].

	HC users ($n = 58$)	**Non-HC users ($n = 119$)**	**Total ($n = 177$)**
Age (y)	24.9 (5.2)	24.3 (7.2)	24.5 (5.2)
Height (m)	1.68 (0.06)	1.71 (0.32)*	1.70 (0.07)
Mass (kg)	71.5 (12.5)	71.0 (15.7)	71.1 (11.6)
Sport (*n*; %)[a]			
Rugby League	17; 35%	32; 65%*	49; 24%
Rugby Union/Sevens	22; 46%	26; 54%	48; 24%
Australian Football	19; 24%	61; 76%*	80; 39%
Age at menarche (*n*; %)[b]			
11 years or younger	9; 16%	13; 11%	22; 12%
12–14 years	34; 59%	77; 65%	111; 63%
15 years or older	15; 26%	26; 22%	41; 23%
Don't remember	0; 0%	3; 3%	3; 2%
Duration competing at current level (*n*, %)[b]			
0–2 years	28; 48%	60; 50%	88; 50%
2–4 years	21; 36%	39; 33%	60; 34%
4–6 years	5; 9%	9; 8%	14; 8%
>6 years	5; 9%	17; 14%*	22; 12%

[a] *Percentage represented from total within each specific sport.*

[b] *Percentage represented from total within hormonal contraceptive use category.*

HC, hormonal contraceptive.

**Significant difference between HC and non-HC groups; $p < 0.05$.*

Previous use of HC was reported in 73 (41%) respondents, across Australian football ($n = 33$), rugby union/sevens ($n = 22$), and rugby league ($n = 18$). Fifty-seven of these respondents no longer use any HC, while 16 replaced their previous HC use with a different HC type. Of those who changed HC, eight changed from one OC to another (often with time between use), three changed from an OC to a hormonal intrauterine device, two from an OC to an implant, two from an implant to an OC, and one from an implant to a hormonal intrauterine device.

The types of HC previously used and the specific types of OC are presented in **Figure 3**. The reasons for no longer using this form of contraception are presented in **Figure 2B**. The 57 respondents who previously used a HC, but no longer do, are made up of athletes from Australian football ($n = 29$), rugby union/sevens ($n = 15$), and rugby league ($n = 13$). Negative side effects ($n = 23$) was the main reason for discontinuation, including mood swings, weight gain, depression/anxiety, and headaches/migraines. Eleven individuals cited that it was no longer needed, however, only five specified the reason why—minimal sexual activity ($n = 2$), acne under control ($n = 2$), and sexual orientation ($n = 1$). Mean duration of previous HC use was 3.5 ± 3.3 years.

Across all respondents, only nine athletes reported not experiencing any pre-menstrual symptoms, of which three were HC users. For the remaining respondents, a mean of 6 ± 4 different symptoms were reported, with the most common

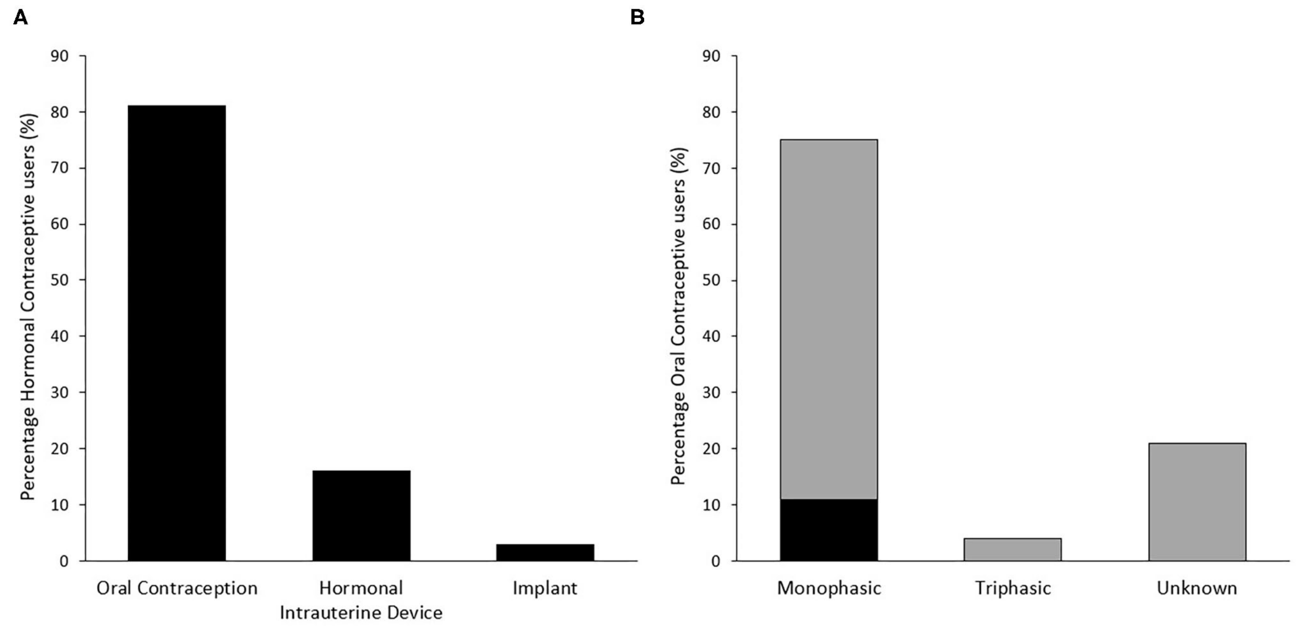

FIGURE 1 | Distribution of type of hormonal contraceptive use ($n = 58$) **(A)** and specific type of oral contraception used ($n = 47$) **(B)** among respondents. Gray bars in panel B indicate an initial response of "Unknown," of which some responses were subsequently able to be classified by researchers based on identification of specific brand used.

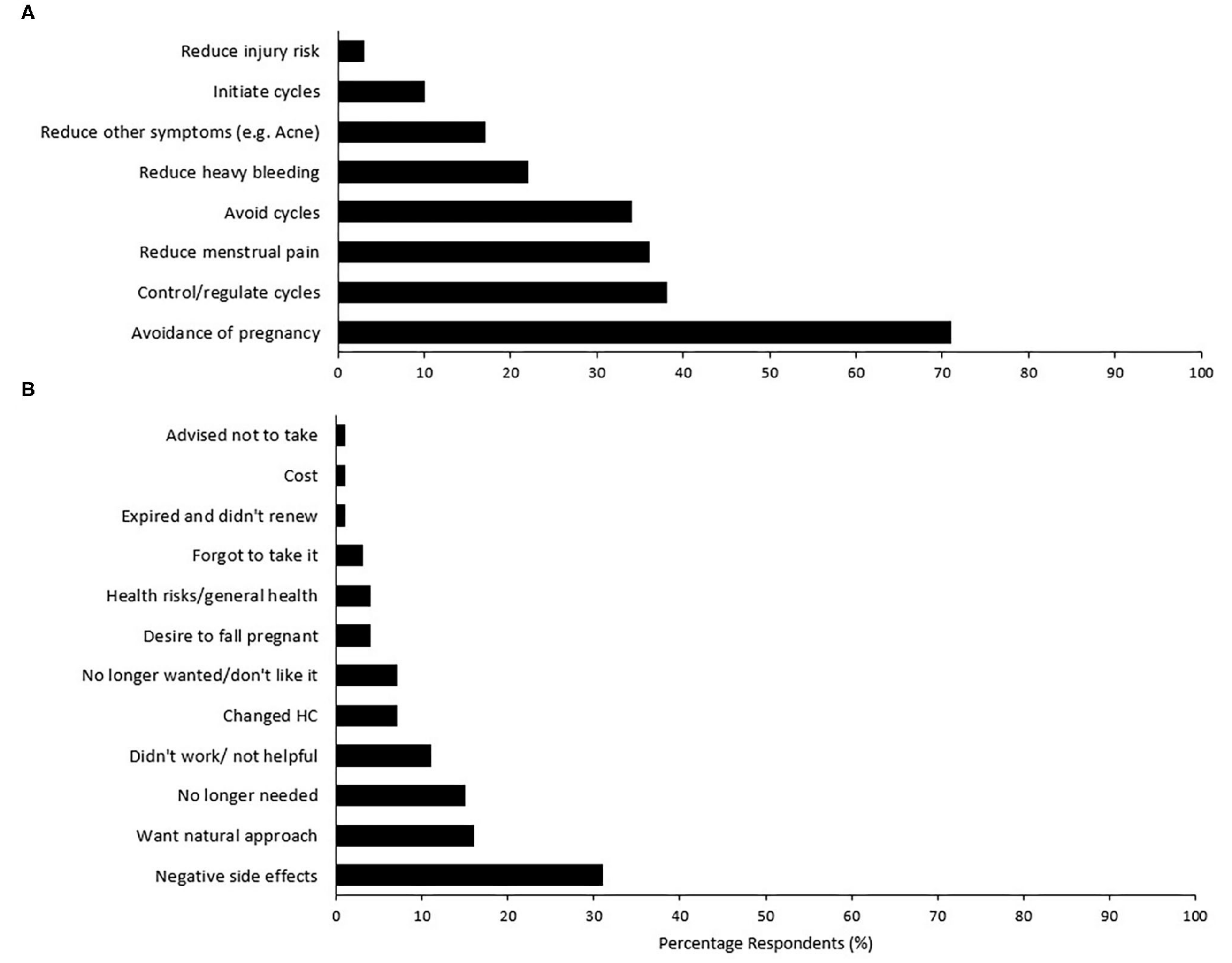

FIGURE 2 | Percentage respondents for **(A)** reasons for hormonal contraception use in current users ($n = 58$), and **(B)** reasons for no longer taking a previous form of hormonal contraception ($n = 73$). Participants were able to select all reasons that apply for current use, while reasons for no longer using was an open-ended question that was subsequently grouped by theme.

symptoms being stomach cramps ($n = 116$) and changes in mood ($n = 100$). There was no statistical difference ($p > 0.05$) in the number of symptoms experienced by HC users and non-users. Overall, use of medication to treat menstrual-related symptoms was reported by 69 athletes (32%), while five athletes chose not to respond. While not statistically different, within hormonal contraceptive users, 20 (34%) required the use of medication to alleviate menstrual-related symptoms, compared to 49 (41%) of non-HC users. Due to menstrual related symptoms, training was missed ($n = 31$, 18%) or had to be adapted ($n = 56$, 32%) by athletes typically 1–5 times per year. The number of athletes who reported missing training or competition due to menstrual related symptoms was similar in HC ($n = 9$, 16%) and non-HC users ($n = 22$, 18%), as was the need to adapt training (HC users, $n = 15$, 26%; non-HC users, $n = 41$, 34%).

DISCUSSION

Approximately one third of athletes from the three codes of football in Australia currently use a form of HC, most commonly a monophasic OC pill. However, almost 90% of OC users could not identify the specific type that they use. The most common reasons for use of HC were (1) to prevent pregnancy, (2) to control their cycle, and (3) to reduce menstrual-related pain. There was no difference between HC users and non-users in relation to menstrual symptoms experienced, use of medication, and the need to adapt or miss training due to their menstrual cycle.

This study observed a lower HC use among elite female football athletes—approximately one third (32.7%)—compared to research conducted in recreational to elite Australian athletes (42%, Armour et al., 2020) and elite Australian (47%, Larsen

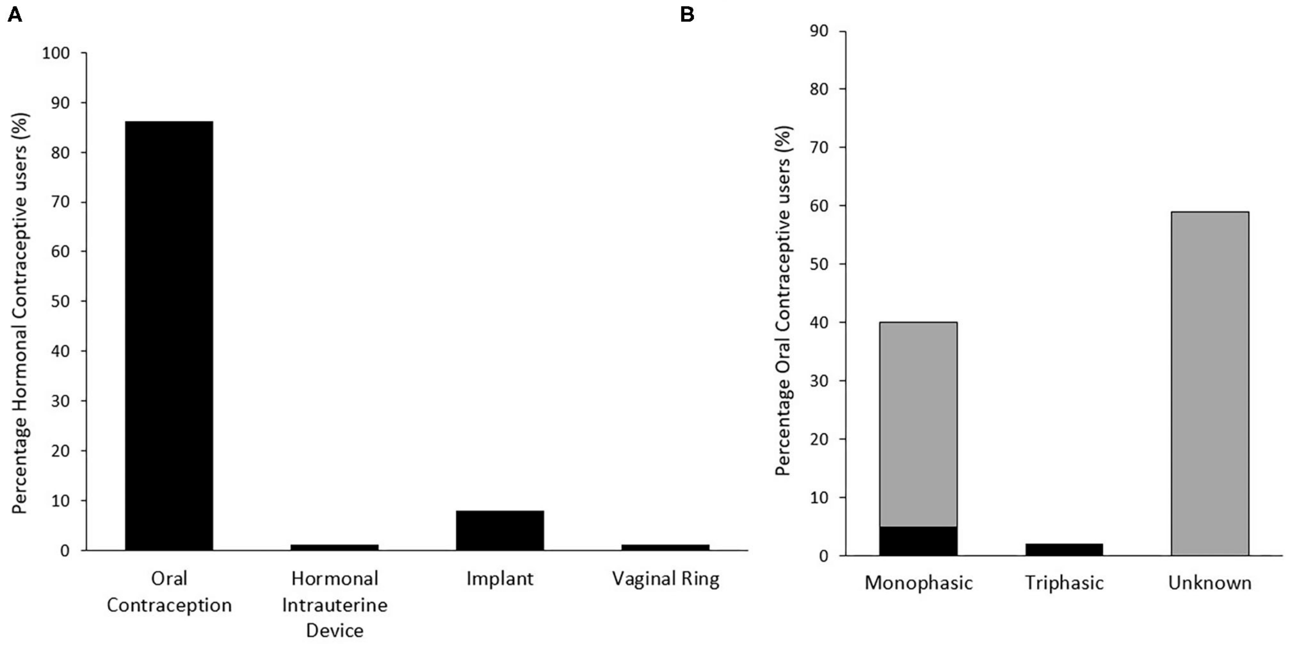

FIGURE 3 | Distribution of previously used hormonal contraceptive type ($n = 73$) **(A)** and specific type of oral contraception used ($n = 63$) (**B**) among respondents. Gray bars in panel B indicate an initial response of "Unknown," of which some responses were subsequently able to be classified by researchers based on identification of specific brand used.

et al., 2020), British (50%, Martin et al., 2018), and Danish (57%, Oxfeldt et al., 2020) athletes across both team and individual sports. Given a limited amount of research has investigated menstrual cycle and HC use in team sport athletes, it is unknown whether the lower prevalence of HC use in the current study is sport related, or a result of sociocultural, geographical, or other influencing factors. Given several athletes in this cohort have previously used an HC, and the second most common reason for discontinuation was that they wanted to take a "natural" approach, understanding the changing attitudes toward the use of HC may be an important consideration. There is a growing body of literature to suggest negative effects such as depression (Anderl et al., 2020), poorer bone mineral density (Allaway et al., 2020), and greater oxidative stress (Cauci et al., 2016) with HC use. However, these effects may be specific to the HC type, with OC the main focus of research looking at these such side effects. The use of HC also masks the natural fluctuations in endogenous hormones, limiting the ability to use the menstrual cycle as an indicator of general health (Harber, 2011). Further, for those athletes who choose to discontinue HC use, it is important for both athletes and their coaching staff to recognize that menstrual disturbances may be present for up to 9 months following cessation (Gnoth et al., 2002). Assessment of athletes' perceptions of HC use for health and performance reasons would be beneficial to understanding the factors contributing to HC use and disuse. Understanding where athlete's source their information regarding this choice and the specific experiences of athletes as they transition away from HC use may also be beneficial to enable the optimal management of female athletes.

Many of the athletes surveyed were unable to specify the type or brand of OC they used, suggesting either a lack of interest in, or awareness of, the different types and/or benefits and risks of OC use. Research in Australian athletes has suggested a poor knowledge in relation to the menstrual cycle and use of HC (Larsen et al., 2020). Greater education may be needed for athletes to make informed choices about their HC use, in conjunction with their medical doctor, to ensure optimal health, well-being, and performance. It is important that athletes understand that an individual approach to choosing a HC is required and they are not guided by other teammates or team coaches, given each has a unique experience with HC and their menstrual cycle.

We did not observe any differences between HC users and non-users in relation to experiencing various menstrual-related symptoms (with both groups reporting stomach cramps and changes in mood as the most common symptoms), the need to use medication, or having to adapt training due to these symptoms. This is despite reasons for using HC including symptom management and reducing menstrual pain. Reported negative symptoms are also similar between HC users and non-users in elite Danish athletes, whereas positive symptoms were reported more frequently in non-HC users (Oxfeldt et al., 2020). However, this research only asked to identify the types of symptoms experienced, rather than rate their severity or duration. We speculate that it is possible that while HC users still experience these symptoms, the severity or duration may be lower than compared to what they would experience if they were not using a HC. Alternatively, HC have been associated with greater inflammation and oxidative stress (Cauci et al., 2016), which may exacerbate pre-menstrual symptoms in some individuals. Further research that looks at both endogenous and exogenous hormones during HC use may help gain further insight in understanding the etiology of symptom manifestation.

This research is the first to look at athletes' experiences and reasons for HC use and disuse in elite football codes in Australia. With the growing professionalism for women's teams within these codes, understanding this information is important to assist with the management of athletes' health and well-being. However, it is important to recognize that these findings are specific to this population group, and other elite women's team sports may have different findings specific to their sport or geographic location, based on different medical advice or personal preferences. The ∼20% response rate (based on the estimated total population size) may also limit the generalizability of these findings, hence further work is required to corroborate these findings. Participants' involvement in this study may also be influenced by self-selection bias. Consequently, participants who completed the study may have already been interested in, or aware of, how menstrual cycle and HC use interacts with their health, training, and performance. Additionally, this research focused on elite players, however, the practices of athletes competing in sub-elite, youth, and recreational competitions may be more diverse due to a different emphasis on general health vs. performance, or based on the resources available to them within their sporting environment. Determining what factors contribute to athletes deciding to use (or stop using) HC, and the specific types and formulations, is an important avenue for future research in female athletes. Understanding the transition between exogenous (HC use) and natural hormones stabilizing following HC discontinuation, and the subsequent influence on menstrual-related symptoms and performance is also an important consideration for practitioners and the need for individualized athlete management. This will ensure sporting bodies and associated medical professionals are able to specifically target the education and management practices for female athletes. Whether an athlete's decision is based on health, practicality, science, or sociological influences (e.g., friend/teammate recommendations or experiences) is yet to be examined. This may be important when it comes to how information is received and acted on by athletes, and how sporting clubs can play their role to optimize the health, performance, and well-being of athletes.

Overall, we make three recommendations from this research. First, there is a need for greater education about the menstrual cycle and HC options for athletes. Second, this education should extend to coaches, support staff, and clinicians to ensure the optimal management of female athletes' health and performance. Given Australian athletes do not often discuss their menstrual cycle or related symptoms with coaching staff (Armour et al., 2020), empowering coaches with this knowledge may help to remove any perceived barriers to having these important conversations. Third, further research is required to understand in greater detail the HC experiences of athletes, how HC use influences the performance and recovery of athletes, and explore alternative methods to HC for the management of MC symptoms without negative side effects.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by La Trobe University Human Ethics Committee. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors were involved in the study design and questionnaire creation. AC recruited the participants and conducted the statistical analysis. All authors contributed to the writing of the manuscript and reviewed and approved the final draft for submission.

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ORIGINAL RESEARCH
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Injury Incidence Across the Menstrual Cycle in International Footballers

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Objectives: This study aimed to assess how menstrual cycle phase and extended menstrual cycle length influence the incidence of injuries in international footballers.

Methods: Over a 4-year period, injuries from England international footballers at training camps or matches were recorded, alongside self-reported information on menstrual cycle characteristics at the point of injury. Injuries in eumenorrheic players were categorized into early follicular, late follicular, or luteal phase. Frequencies were also compared between injuries recorded during the typical cycle and those that occurred after the cycle would be expected to have finished. Injury incidence rates (per 1,000 person days) and injury incidence rate ratios were calculated for each phase for all injuries and injuries stratified by type.

Results: One hundred fifty-six injuries from 113 players were eligible for analysis. Injury incidence rates per 1,000 person-days were 31.9 in the follicular, 46.8 in the late follicular, and 35.4 in the luteal phase, resulting in injury incidence rate ratios of 1.47 (Late follicular:Follicular), 1.11 (Luteal:Follicular), and 0.76 (Luteal:Late follicular). Injury incident rate ratios showed that muscle and tendon injury rates were 88% greater in the late follicular phase compared to the follicular phase, with muscle rupture/tear/strain/cramps and tendon injuries/ruptures occurring over twice as often during the late follicular phase compared to other phases 20% of injuries were reported as occurring when athletes were "overdue" menses.

Conclusion: Muscle and tendon injuries occurred almost twice as often in the late follicular phase compared to the early follicular or luteal phase. Injury risk may be elevated in typically eumenorrheic women in the days after their next menstruation was expected to start.

Keywords: epidemiology, menstrual cycle, injury, soccer, football, female athlete

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INTRODUCTION

With the professionalization of women's football, training, and match demands have significantly increased in recent years (Datson et al., 2014, 2017). The overall injury incidence is similar to male football, although the proportion of severe injuries has been shown to be higher in women's football (Mufty et al., 2015; Roos et al., 2017) which is associated with significant costs (Gebert et al., 2020).

Female football players are reported to have 21% more absence due to injury compared to men, primarily due to greater incidence of severe knee and ankle ligament injuries, with anterior cruciate ligament (ACL) injuries occurring 2–8 times more often in female soccer players (Larruskain et al., 2018; Lin et al., 2018).

The menstrual cycle has been theorized as a factor which could modify injury risk in female athletes, as cyclical fluctuations in reproductive hormones such as estrogen and progesterone can influence musculoskeletal tissues such as muscle, tendon, and ligament (Herzberg et al., 2017; Chidi-Ogbolu and Baar, 2019). Several studies have identified a greater risk of ACL injury occurrence in the late follicular/ovulatory phase when estrogen concentrations are highest (e.g., Wojtys et al., 2002; Beynnon et al., 2006; Adachi et al., 2008; Ruedl et al., 2009), potentially due to increased ACL laxity (Chidi-Ogbolu and Baar, 2019). Although, other studies have shown greater ACL injury incidence during the early follicular or late-luteal phase (Myklebust et al., 1998; Slauterbeck et al., 2002). There is often discrepancy in the way that phases are defined and estimated: for example, some studies have only compared injury incidence in pre and post ovulatory phases (Möller-Nielsen and Hammar, 1989; Beynnon et al., 2006; Ruedl et al., 2009, 2011) which does not consider the ∼10-fold increase in estrogen concentrations from the early to late follicular phase (Stricker et al., 2006). The interpretation of published injury rates is further hampered by the inclusion of hormonal contraceptive users in data sets (Möller-Nielsen and Hammar, 1989; Myklebust et al., 1998; Wojtys et al., 1998; Slauterbeck et al., 2002; Ruedl et al., 2011; Lefevre et al., 2013) despite the downregulation of endogenous reproductive hormones with hormonal contraceptive use (Elliott-Sale et al., 2013). Further issues with existing evidence include a relatively small number of injuries recorded in studies (<40; Myklebust et al., 1998; Wojtys et al., 1998; Arendt et al., 1999; Slauterbeck et al., 2002; Adachi et al., 2008) and a majority focus solely on ACL injuries. Furthermore, much of this research is in skiers (Beynnon et al., 2006; Ruedl et al., 2009, 2011; Lefevre et al., 2013) which may lack application to other sports.

To date, only Möller-Nielsen and Hammar (1989) have reported the distribution of wider injuries across the menstrual cycle in footballers over the course of a season, although only 45 injuries were reported in non-contraceptive users. Injury incidence was greater during the pre-menstrual and menstrual period compared to the rest of the cycle, although phases were not clearly defined. Interestingly, this effect was only apparent in those with dysmenorrhea (menstrual pain symptoms), which may provide an additional mechanism to those already described for differences in injury rates between menstrual cycle phases. Injury risk may also be modified by menstrual cycle effects on recovery from exercise (Markofski and Braun, 2014) or disturbances to postural control, kinaesthesia, and neuromuscular co-ordination (Posthuma et al., 1987; Fridén et al., 2005, 2006).

The Relative Energy Deficiency in Sport (RED-S) model, which includes menstrual dysfunction as one of its characteristics, has suggested that low energy availability may increase injury risk in athletes (Mountjoy et al., 2018). When dietary energy availability is limited, key physiological processes such as the menstrual cycle are sacrificed to conserve energy, resulting in oligomenorrhea or amenorrhea, and greater injury incidence has been observed in athletes and military recruits with extended cycle durations (Rauh et al., 2010; Knapik et al., 2013). Moss et al. (2020) showed that 23% of elite female footballers had low ($\leq$ 30 kcal·kg·FFM^{-1}·day^{-1}) energy availability and menstrual dysfunction has been observed in 9.3–19.3% of elite footballers (Sundgot-Borgen and Torstveit, 2007; Prather et al., 2016). To date, the impact of extended menstrual cycle duration has not been explored in relation to injury risk.

The aim of this study is to assess how menstrual cycle phase and extended menstrual cycle length influence the incidence of injuries in English international footballers using data collected over a 4-year period.

METHODS

Recruitment

Players selected for the England national team Under 15, 16, 17, 18, 19, 20, 23, and Senior level were asked to participate in the study. Informed consent was obtained before data was gathered, and participants were informed that they can withdraw from the study at any time without consequence. Ethical approval was granted by the Nottingham Trent University Non-Invasive Ethical Review Committee (application number: 116V2). In total, the present study includes eight playing squads over 4 years (2012–2016) of data collection. The study and is comprised of 3,947 individual player camp attendances over 160 international camps.

Data Collection

Only data collected in relation to injuries sustained while representing their country (in either match-play or training camps) were included in the study. Data were collected and analyzed in line with the international consensus statement on the process of conducting epidemiological studies in professional football (Fuller et al., 2006) and the International Olympic Committee Consensus Statement (Bahr et al., 2020).

Experimental Design and Protocol Description

Data on injury incidence were collected for the entirety of all international camps from 2012 to 2016 using a case-series design. Any injuries that occurred during the international camps were included in the data analysis. Before the study commenced, all medical support staff for each age group were provided with guidance on why the study was taking place, and information on the definitions of all variables recorded as part of the study.

Injury

An injury was defined as an occurrence which prevented a player from taking part in training or match-play for one or more days following the injury (Fuller et al., 2006). Injuries sustained outside of formal training and match-play were excluded from analysis. Injury information was recorded by each team's medical support staff and a database was created using an electronic medical record system (The Sports Office, Wigan, United Kingdom). Each injury was classified using the Orchard Sports Injury Classification System (Orchard, 2010) by a medical professional within each team.

Menstrual Cycle Categorization

Self-reported information on hormonal contraceptive use, menstrual cycle length and the number of days since the start of their last menstrual cycle (first day of menstruation) was provided by players to Football Association support staff upon injury occurrence. Exclusion criteria were pre-menarchal athletes, hormonal contraceptive use, missing data for last menstrual period or hormonal contraceptive use, and self-reported irregular menstrual cycles. Self-reported typical menstrual cycle length was used to estimate the day of peak luteinizing hormone (LH) concentration using the regression equation of McIntosh et al. (1980), rounded to the nearest whole day. Where a range was given to describe regular cycle length, the midpoint of that range was taken as the cycle length. Based upon data from Stricker et al. (2006), peak estrogen concentrations were estimated to occur on the day of LH peak and the two preceding days; this was labeled the late follicular phase. The follicular phase was defined as the time between the first day of the last menses and the late follicular phase. The luteal phase was defined as any time point following the late follicular phase.

Data Analysis

Descriptive statistics were generated to describe frequencies of total injuries, and different types of injuries, by menstrual cycle phase for eumenorrheic players; defined as those with a regular cycle length between 21 and 35 days (Fehring et al., 2006). Frequencies were also compared between injuries recorded during the reported typical cycle length and those that occurred after the cycle would be expected to have finished ("overdue"). Calculating phase length from cycle length results in variation in follicular and luteal phase lengths across individuals. Therefore, person-days were adopted: the number of days estimated for each phase were summed across injuries, to give a sum for each menstrual cycle phase. These were then used to estimate injury incidence rate per 1,000 person-days for each phase. Injury incident rate ratios were calculated by comparing injury incident rates between phases. Injury incident rates and injury incident rate ratios were not calculated for brain/spinal cord/peripheral nervous system (PNS) or bone injuries due to the limited number of these injuries. Index, subsequent and recurrent injuries were combined for the analysis. Due to the nature of the study design and descriptive aims of the study, null hypothesis testing was not deemed appropriate. Analyses were carried out in Excel (Microsoft Office 365, USA) and RStudio 1.0.153 (R Core Team, 2020).

RESULTS

Players were excluded due to absence of menarche ($n = 2$), hormonal contraceptive use ($n = 19$), self-reported irregular menstrual cycles ($n = 12$), or missing data for key variables (days since last reported menses [$n = 21$]; hormonal contraceptive use [$n = 14$]). There were 156 eligible injuries from 113 players for inclusion in analyses. Twenty-seven players recorded multiple injuries, ranging from 1 to 7 injuries per player. Age at time of injury ranged from 13 to 35 years (median 17 years).

Self-reported regular cycle length ranged from 18 to 64 days (median 28 days). One participant reported a cycle shorter than 21 days; 13 reported long cycles (>35 days). Excluding these participants, the median cycle length remained 28 days ($n = 142$).

For injuries from eumenorrheic players (regular cycle length between 21 and 35 days) estimated follicular phase ranged in length from 8 to 16 days (median 11 days; $n = 142$), and estimated luteal phase ranged from 13 to 16 days (median 14 days). Late follicular phase was 3 days' duration by definition. There were 41 injuries in the follicular phase, 16 injuries in the late follicular, and 57 injuries in the luteal phase.

Twenty eight of 142 (20%) injuries were reported as occurring after the regular cycle was expected to have resumed ("overdue"). Number of days over normal cycle length at time of injury ranged from 0 to 40 days (median 5 days). Thirty-six percent (10 out of 28) of "overdue" injuries were joint/ligament, compared to 21% (24 out of 114) of injuries in the normal menstrual cycle. Of the 114 injuries that were within the regular eumenorrheic cycle length, 65 (57%) were subsequent or recurrent injuries. Of the 28 injuries that were "overdue," 12 (43%) were subsequent or recurrent injuries.

Excluding those injuries which occurred in the "overdue" period, the total person-days was 3,241, of which 1,287 (39.7%) were in the follicular phase, 342 (10.6%) in the late follicular, and 1,612 (49.7%) in the luteal phase. Injury incidence rates per 1,000 person-days were 31.9 in the follicular phase, 46.8 in the late follicular and 35.4 in the luteal (**Table 1**). The injury incidence rate ratio showed the rate of injuries was 47% greater in the late follicular phase compared to the follicular phase and 24% lower in the luteal phase compared to the late follicular phase. Injury incident rate ratios showed that muscle and tendon injury rates were 88% greater in the late follicular phase compared to the follicular phase, with muscle rupture/tear/strain/cramps and tendon injuries/ruptures occurring over twice as often during the late follicular phase compared to other phases. Injury incidence rates for joint and ligament injuries in the luteal phase were approximately double that of the follicular phase and almost treble that of the late follicular phase, although only one injury was recorded for the late follicular phase.

DISCUSSION

The aim of this study was to assess how menstrual cycle phase and extended menstrual cycle length influence the incidence of injuries. Injury incidence rates were 47 and 32% greater in the late follicular phase compared to the follicular phase and luteal phase, with muscle and tendon injury incidence rates in the late follicular phase being almost double that of the other phases. Furthermore, a relatively large proportion of all injuries (20%) occurred after the expected date of menstruation.

Menstrual Cycle Phase

The potentially greater injury rate in the late follicular phase is consistent with some studies showing a greater incidence of ACL

TABLE 1 | Number of injuries, injury incidence rates, and injury incidence rate ratios for all injuries and injuries separated by type and sub-type (italics) for eumenorrheic participants.

	Total number of injures			Injury Incidence Rate (per 1000 person-days)			Injury Incidence Rate Ratios		
	Follicular	**Late Follicular**	**Luteal**	**Follicular**	**Late Follicular**	**Luteal**	**Late follicular: Follicular**	**Luteal: Follicular**	**Luteal: Late Follicular**
All Injuries	41	16	57	31.9	46.8	35.4	1.47	1.11	0.76
Muscle and tendon	28	14	35	21.8	40.9	21.7	1.88	1.00	0.53
Muscle rupture/tear/ strain/cramp	14	8	17	10.9	23.4	10.5	2.15	0.96	0.45
Tendon injuries/ruptures	4	3	7	3.1	8.8	4.3	2.84	1.39	0.49
Joint and Ligament	7	1	16	5.4	2.9	9.9	0.54	1.83	3.41
Brain/Spinal cord/PNS	3	1	2						
Bone	3	0	4						

PNS, Peripheral nervous system.

injuries during this phase (Adachi et al., 2008; Ruedl et al., 2009), although we did not limit injury observations to ACL injuries as in previous research. In fact, throughout the observation period, only one ACL rupture occurred during international matches or training in this population, and this in an OC user, so is not included in the analysis. It has been suggested that higher ACL injury rates in the late follicular phase may be a result of reduced ligament stiffness which compromises joint stability (Shultz et al., 2005; Myer et al., 2008; Chidi-Ogbolu and Baar, 2019). In contrast, tendon stiffness may increase injury risk as eccentric load is increased in the muscle with less compliant tendons (Chidi-Ogbolu and Baar, 2019). We showed that, compared to the follicular and luteal phases, muscle and tendon injuries were approximately twice as common during the late follicular phase, when estrogen concentrations are highest (Stricker et al., 2006). This is despite some studies showing that estrogen is negatively associated with tendon stiffness (Bell et al., 2012) and tendon stiffness is lowest in the late follicular phase (Eiling et al., 2007; Casey et al., 2014), although other studies show no change in tendon stiffness across the menstrual cycle (Burgess et al., 2009; Kubo et al., 2009). Therefore, it is not possible to relate muscle and tendon injury rate in the late follicular phase to changes in musculotendinous stiffness. This current study is also in contrast to the only prior study to assess menstrual cycle phase effects on all injuries (Möller-Nielsen and Hammar, 1989), which reported an increased risk of injury during the premenstrual and menstrual period. Möller-Nielsen and Hammar (1989) observed a limited number of injuries ($n = 45$) and did not stratify injury by type or clearly define phases, so direct comparisons are difficult. In the current study, injury incidence rates were lowest in the follicular (31.9 per 1,000 person days) and luteal (35.4 per 1,000 person days) phases, which does not suggest an increase in injury risk pre-menstruation or during menstruation.

Extended Menstrual Cycles

The proportion of injury in athletes when "overdue" (20%) is relatively high compared to the 9.3–19.3% prevalence of menstrual dysfunction in footballers (Sundgot-Borgen and Torstveit, 2007; Prather et al., 2016), given that time "overdue" will account for a small proportion of these athletes' overall training/match exposure time. However, as menstrual cycle details were only collected upon the occurrence of an injury, it is not possible to identify whether there is an increased risk of injury when menstrual cycle length was extended as there is no "exposure" data for comparative assessment. The range (0–40 days) and median (5 days) time "overdue" at injury, suggest clustering of injury occurrence in the initial days following the expected date of menstruation, potentially highlighting this as a timeframe where injury incidence is relatively high. Previous research has shown that injuries are more common in those with oligomenorrhea and amenorrhea (Rauh et al., 2010; Knapik et al., 2013); however this is the first study to assess injuries in "overdue" athletes in a prospective assessment by cycle date. It is also worth noting that the type of injury was seemingly different when cycle length was extended as 36% (10 out of 28) of "overdue" injuries were joint/ligament, compared to 21% (24 out of 114) of injuries occurring during the typical time frame of the athletes' menstrual cycles This evidence adds to existing data showing the potential negative impacts of menstrual dysfunction on athlete health and performance (Mountjoy et al., 2018).

Limitations

There are several limitations to this study which should be noted when interpreting these data. Whilst the reported number of injuries in this analysis is substantially greater than previously published research in team sports, numbers are still relatively small, especially when breaking incidence down by injury type which may be differentially affected by the menstrual cycle. However, collecting data of this type on a greater number of international footballers would be impractical without multicentre research teams. The data also include observations which are not independent (e.g., recurrent injuries) and therefore should be interpreted with caution. Self-reported menstrual cycle length was used to predict the time within the menstrual cycle that the injury occurred which can be inaccurate (Jukic et al., 2007) and may vary over time or seasonally with the demands of training (Sundgot-Borgen and Torstveit, 2007). Data quality would be greatly enhanced by players using menstrual cycle tracking applications. Ideally, blood samples would be collected upon injury to confirm hormone concentrations and menstrual cycle phase, although this is less feasible in the type of large-scale project required to assess injuries in team sports. A regression equation was used (McIntosh et al., 1980) to allocate a menstrual cycle phase given the relatively fixed luteal phase duration, although there is some interindividual variation in cycle length (Fehring et al., 2006). By counting days to determine phases, sub-clinical menstrual dysfunctions such as luteal phase defects cannot be identified which could affect interpretation (Schaumberg et al., 2017). We excluded athletes that reported typically irregular menstrual cycles (i.e., oligomenorrhea, amenorrhea, polymenorrhea) as we had no way to estimate cycle phase or whether they were "overdue," but this should be explored in future research. A more accurate assessment of risk could also be determined by knowing the exposure to training/matches within each menstrual cycle phase as an assumption of the data is that this exposure was even although this could not be determined. Despite these cautionary notes, these data provide an important insight into the pattern of injuries sustained at an elite level of women's football, spanning across a large age range of international competitors.

Practical Application

This study shows that the incidence of injuries may vary across the eumenorrheic menstrual cycle and that the impact of the menstrual cycle may be dependent upon type of injury or the tissue affected. As this research is in its infancy, we do not recommend that this data is used to inform exercise practice or participation as further work is needed before clear guidelines on the menstrual cycle phase and injury risk mitigation can be generated. This study can, however, serve as basis for future research to develop knowledge in this important area. We showed that a relatively large proportion (20%) of all injuries occurred after the expected date of menstruation. In line with other recommendations (Martin et al., 2018; Armour et al., 2020), we suggest that athletes/practitioners should monitor menstrual cycle length using tracking systems/applications as an "overdue" cycle is easily identified and may present with increased risk for the athlete. Identification of extended cycles can facilitate discussions with appropriate support staff (e.g., medical staff, nutritionist, psychologist) to promote the health and well-being of the athlete.

Conclusion

This is the first study to assess the injury rate of all injuries by menstrual cycle phase whilst stratifying by injury type and the first study to report the data on the injury rate when "overdue." These data suggest that muscle and tendon injuries may occur approximately twice as often in the days preceding ovulation. Furthermore, this study has provided initial evidence that injury risk may be elevated in typically eumenorrheic women in the days after their next menstrual cycle was expected to start. This research provides further evidence of the need to consider the menstrual cycle and menstrual dysfunction in athletic populations.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Nottingham Trent University Ethics Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

CC, JA, RM, and AT conceptualized and designed the study and acquired the data. KT and DM conducted data analysis. DM and IV drafted the manuscript. DM, KT, IV, and CC revised the manuscript. All authors contributed to the content and approved the final version.

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Acceleration and High-Speed Running Profiles of Women's International and Domestic Football Matches

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Acceleration and deceleration are important given football is an intermittent sport with constant changes in velocity and direction. It is unclear, however, if the accelerations and decelerations performed by players differ between competition levels. The aim of the present study was to compare the acceleration, deceleration, and high-speed running profiles of players during international and domestic matches and to determine if differences were apparent across playing positions (defenders, midfielders, and attackers). GPS data from 21 Australian women's domestic football league matches over 2 seasons (2016–2018) and 15 Australian women's international matches (2017–2018) were collected and analyzed. Movement pattern data was collected using VX Sport and GPSports 10 Hz GPS receivers. Variables analyzed included: total distance, distance covered high-speed running (16–20 $km{\cdot}h^{-1}$) distance covered sprinting ($> 20\ km{\cdot}h^{-1}$) and time spent accelerating and decelerating in four predetermined bands (1–2 $m{\cdot}s^{-2}$, 2–3 $m{\cdot}s^{-2}$, 3–4 $m{\cdot}s^{-2}$, and $> 4\ m{\cdot}s^{-2}$). Results revealed that players competing in international matches covered significantly greater total distances, greater high-speed running distances and greater sprinting distances as well as spending a greater duration accelerating in band 4 compared to players in domestic competitions ($p < 0.05$). Players competing in international matches spent significantly less duration decelerating in bands 2 and 3, compared to players in domestic competitions. International defenders and midfielders recorded significantly higher total distances and high-speed running distance compared to players in domestic matches. Our findings suggest that preparing players for international-level competition should include progressive exposure to high-speed running and sprinting distances, as well as high magnitude accelerations. Furthermore, the higher running speeds experienced by players during international matches appears to be a result of less time spent decelerating. The optimal deceleration necessary for specific situations appears important and emphasizes the need for specific deceleration training. The increased effort of high-intensity activity that is required for players competing in international matches affects defenders and midfielders to the

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greatest degree. Gradual exposure to the increased running demands for midfielders and defenders competing in international matches is needed to improve performance and reduce the potential risk of injury.

Keywords: female athlete, soccer, movement patterns, match demands, GPS

INTRODUCTION

Evidence from time-motion analysis studies demonstrates that total distance covered during match-play is similar between international and domestic women's football matches (Gabbett and Mulvey, 2008; Andersson et al., 2010; Gabbett et al., 2013). Nonetheless, players competing in international women's football matches achieve higher running velocities (Gabbett and Mulvey, 2008; Andersson et al., 2010; Gabbett et al., 2013) and cover greater distances at high-speed running (13%) and sprinting (14%) intensities compared to players in domestic competitions (Andersson et al., 2010). International matches also require players to perform longer-duration sprint efforts with shorter recovery periods compared to domestic matches (Gabbett et al., 2013). Since these pioneering time-motion analysis studies (Gabbett and Mulvey, 2008; Andersson et al., 2010; Gabbett et al., 2013), no investigation has utilized the Global Navigation Satellite System (GNSS) to compare acceleration and high-speed running profiles of women's international and domestic football matches. Approval for the utilization of GNSS, specifically Global Positioning System (GPS) technology, within football, has allowed for a greater number of match files and data to be collected and analyzed more time-efficiently (Griffin et al., 2020b). Such comparisons between international and domestic competition levels offer important insights into key differences that can be used to inform talent identification programs and training interventions which may ultimately lead to improved athletic development and performance of female football players.

An important locomotive movement observed during football match-play that has received increasing attention in the literature is acceleration (and deceleration). Maximal acceleration and deceleration are considered "high-intensity" efforts as they impose the greatest physiological and mechanical loading demands on players of any running metric (Bloomfield et al., 2007; Osgnach et al., 2010; Dalen et al., 2016). The metabolic cost of acceleration is higher compared to running at a constant velocity, and as the intensity or number of accelerations increase, so too do the metabolic demands of the movement and also of the match (Osgnach et al., 2010). Likewise, maximal decelerations also produce higher mechanical loads (up to 65% higher) compared to other running metrics such as constant velocity running, due to the eccentric nature of the muscle contractions (McHugh et al., 1999; Dalen et al., 2016; Harper and Kiely, 2018). Accelerations and decelerations contribute significantly to the total high-intensity running distances and sprinting distances of women's football matches and occur more frequently during a match than any other running metric (Mara et al., 2017a; Ramos et al., 2017; Trewin et al., 2018). During women's domestic football competition players have been reported to perform 420 and 430 acceleration and deceleration efforts, respectively (Mara et al., 2017a). Data was collected using 25 Hz Optical Player Tracking and defined acceleration and deceleration as >2 m·s^{-2} and <-2 m·s^{-2}, respectively. In contrast, during international competition, players were reported to perform ∼200 accelerations (Meylan et al., 2017; Ramos et al., 2017; Trewin et al., 2018) and 170 decelerations (Ramos et al., 2017), with data collection utilizing 10 Hz GPS with an acceleration criteria including >1 m·s^{-2}, >2.3 m·s^{-2}, and deceleration <-1 m·s^{-2}. Direct comparisons between studies may be inappropriate due to the methodological differences in technology used for data collection and criteria to define an acceleration and deceleration. The methodological differences outlined may explain the discrepancies observed.

The analysis of accelerations and decelerations is a key consideration to player load and performance in women's football, given the physiological and mechanical loading and frequency of movements during a match. Comparing accelerations and decelerations during international and domestic women's football matches will determine if a difference exists and if indeed accelerations and decelerations are a distinguishing factor between competition levels. A review of the physical characteristics of female football players has demonstrated that the ability to accelerate and decelerate as measured during field-testing are differentiating factors between international, domestic and sub-elite players (Griffin et al., 2020a). Whether these differences in physical characteristics are also evident in player movement patterns during women's football matches is unknown, conclusive evidence is yet to exist regarding the acceleration and deceleration of players during international and domestic matches. Therefore, the aim of the present study was to examine acceleration, deceleration and high-speed running profiles of players during women's international and domestic football matches. A secondary aim was to examine the effect of playing position on acceleration, deceleration, and high-speed running profiles of players during international and domestic matches.

METHODS

Subjects

Fifteen female football players (age: 25.7 ± 3.1 years, height: 167.5 ± 7.7 cm, body mass: 61.3 ± 6.2 kg) from the same club team in the Australian women's domestic football league and eighteen female football players (age: 25.6 ± 3.7 years, height: 166.7 ± 8.4 cm, body mass: 59.7 ± 6.8 kg) from the Australian women's national football team participated in the present study. Players were analyzed based on three playing positions from domestic (defenders: $n = 7$, midfielders: $n = 5$, and attackers: $n = 3$) and international matches (defenders: $n = 8$, midfielders: $n = 9$, and attackers: $n = 6$). Data for goalkeepers were excluded given the unique running profile and technical skills of that position.

Data from twenty-one matches (eighty-five individual player match files) over two seasons (2016-2018) were collected from the domestic competition. International matches included data from a total of fifteen games (ninety-seven individual player match files) that were collected from the 2017 Algarve Cup in Portugal, the 2017 Tournament of Nations in the United States of America, the 2018 Asian Cup in Jordan and international "friendlies" in Australia. Only data where a player completed the full match (i.e., 90-min) was included in the study. This study was approved by the Griffith University Human Ethics Committee and Football Federation Australia.

Procedures

Domestic competition movement data were collected during match-play using VX Sport technology (VX live log, Visuallex Sport International, Wellington, New Zealand) whereas GPSports technology (SPI HPU, GPSports, Canberra, Australia) was utilized during international competitions. Individual players positional and time data was collected by attaching the GPS receivers (VX Sport or GPSports), sampling at 10 Hz, between the scapulae of each player using manufacturer designed elastic vests. Both GPS technology used in the present study have been reported to have acceptable accuracy and both between- and within-manufacturer reliability for quantifying movement patterns during team sport (Varley et al., 2012; Delaney et al., 2018). To ensure that we could confidently compare data collected from two different manufacturers, we performed an inter-manufacturer comparison of the raw data as recommended by Malone et al. (2017). This procedure has been demonstrated to be a valid method for analyzing data from different GPS manufacturers (Thornton et al., 2019; Johnston et al., 2020). The inter-manufacturer comparison comprised of nine elite team sport athletes simultaneously wearing the two different GPS receivers during a 30-m sprint testing session with varying distances of deceleration at the end, determining the smallest worthwhile change. The smallest worthwhile change was determined by dividing the standard deviation of all trials by 0.3 as outlined by Hopkins (2004). The highest variability has shown to occur within acceleration and deceleration variables, so the smallest worthwhile change between GPS manufacturers has been reported for the acceleration and deceleration variables (**Table 1**).

Approximately 30 min before the start of the pre-match warm-up, all receivers were switched on to ensure sufficient time for connection with satellites. The same receivers were worn by the same player for each match to reduce the potential of any inter-unit variability. All players were familiar with the data collection procedures and had experience with wearing GPS receivers during training sessions and matches. Data collection started on the referee's whistle, to commence each half and only included the first 45 min of each half. Data for injury time was excluded so that the match duration was standardized across all games for both domestic and international matches. After each match, data from the GPS receivers were downloaded using VX Sport software (VX View v5.0.3) and GPSports software (Team AMS, R1_2016_7). To minimize the effect of filtering and data processing differences that occur between the manufacturer's software, the raw data was exported to Microsoft Excel and analyzed using R programming language (Version 3.6.1, Vienna, Austria) (Malone et al., 2017; Thornton et al., 2019). Both the VX Sport and GPSports raw exports were analyzed using the same lines of R script. During data analysis, four acceleration and deceleration zones were created, where band 1 was set between 1 and 2 $\text{m}\cdot\text{s}^{-2}$, band 2 between 2 and 3 $\text{m}\cdot\text{s}^{-2}$, band 3 between 3 and 4 $\text{m}\cdot\text{s}^{-2}$, and band 4 above 4 $\text{m}\cdot\text{s}^{-2}$ based on previous research (Akenhead et al., 2013; Curtis et al., 2018; Harper et al., 2019). The four deceleration zones were identical to their respective acceleration zones, with the difference being these values were negative e.g., between -1 and -2 $\text{m}\cdot\text{s}^{-2}$. The present study utilized duration accelerating or decelerating (as opposed to frequency or distance) as the primary outcome measure for accelerations and decelerations. It has been demonstrated that the total cumulative distance covered decelerating may not be a true representation of deceleration, given that a player is aiming to cover less distance while decelerating as opposed to more (Harper and Kiely, 2018; Newans et al., 2019). To be valid, all acceleration and deceleration efforts required a minimum duration of 0.2 s with only one acceleration or deceleration effort permitted within a single 1 s period. Sprint analysis research has demonstrated that peak acceleration occurs within the first 0.2 s immediately after the start of a sprint effort from a static starting position (Di Prampero et al., 2005). Furthermore, a minimum duration of 0.2 s has been used in acceleration based research during team-based sports (Coutts et al., 2015; Buchheit and Simpson, 2017). Analysis of high-speed running and sprinting data was based on the pre-defined cut-offs of 16–20 $\text{km}\cdot\text{h}^{-1}$ and > 20 $\text{km}\cdot\text{h}^{-1}$, respectively. These thresholds are in agreement with previous investigations of women's football (Griffin et al., 2020b).

Statistical Analysis

Statistical analysis involved the use of linear mixed models, with significance set at an alpha level of 0.05. Each GPS metric was set as the outcome variable, competition level, and playing position set as a fixed effect, and the player and match were set as random effects. Linear mixed models were conducted in R programming language using the *lme4* package, while the *afex* package was used to calculate confidence intervals and *p*-values.

RESULTS

The results of the linear mixed models comparing running metrics of players during domestic vs. international football matches are shown in **Table 1**. Players in international-level matches covered greater distances for all three locomotive metrics (i.e., total distance, high-speed running, and sprinting) compared to players in domestic matches. For accelerations, players competing in international matches spent less duration in band 1, 2, and 3, but a greater duration in band 4. For decelerations, players in international matches spent less duration in bands 2 and 3, compared to players in domestic matches.

TABLE 1 | Comparison of player movement patterns between domestic and international women's football.

Variable	Domestic	International	SWC
Total distance (m)	8727.5 ± 282.5	9432.5 ± 262.9***	
HSR (16-20 km·h^{-1}) (m)	608.5 ± 68.8	766.4 ± 64.0***	
Sprinting (> 20 km·h^{-1}) (m)	306.3 ± 56.3	363.7 ± 53.0*	
Acceleration Duration (s)			
Band 1 (1 to 2 m·s^{-2})	553.9 ± 26.3	523.7 ± 24.6*	5.6
Band 2 (2 to 3 m·s^{-2})	187.8 ± 14.6	164.3 ± 13.7**	3.5
Band 3 (3 to 4 m·s^{-2})	71.8 ± 5.7	50.5 ± 5.3***	2.3
Band 4 (> 4 m·s^{-2})	31.6 ± 3.8	39.4 ± 3.5***	3.5
Deceleration Duration (s)			
Band 1 (−1 to −2 m·s^{-2})	529.9 ± 29.7	544.2 ± 27.9	6.5
Band 2 (−2 to −3 m·s^{-2})	180.9 ± 13.6	162.1 ± 12.7**	3.8
Band 3 (−3 to −4 m·s^{-2})	73.6 ± 5.3	53.8 ± 4.9**	2.3
Band 4 (< −4 m·s^{-2})	39.2 ± 4.0	42.4 ± 3.7	3.3

*All values are presented as mean ± 95% CI. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. HSR, High-speed running; SWC, Smallest worthwhile change.*

The percent difference between competition levels for total distance, high-speed running, and sprinting across playing positions are displayed in **Figure 1**. Players competing in international matches (defenders and midfielders) recorded higher total distances and high-speed running distance compared to players during domestic competitions.

The positional differences in acceleration and deceleration between competition level are displayed in **Figures 2**, **3** respectively. Defenders performed greater duration accelerating in band 1 and 2 during domestic matches compared to international matches. All playing positions during international matches recorded lower durations in acceleration band 3 and spent longer durations accelerating in band 4 compared to domestic matches.

Defenders spent a higher duration in deceleration band 2 during domestic matches compared to international matches. Duration spent decelerating in band 3 was also lower across all positions for international matches.

DISCUSSION

To the author's knowledge, this is the first study to utilize GPS to make comparisons between international and domestic competition levels and among playing positions as well as to analyze all data outside of the manufactures software to allow for the same analysis and future comparisons to the present study. The present study demonstrated that during international women's football matches, players cover greater distances at faster speeds compared to players in domestic-level competitions. Overall, players competing in international-level matches spent a greater duration accelerating in band 4, covered greater distances at high-speed running and sprinting intensities, and covered greater total distances.

Maximal or near-maximal acceleration is an important precursor to high-speed running and sprinting during football matches, particularly given that the majority of sprinting distance is covered over distances of <10 m (Akenhead et al., 2013; Mara et al., 2017a,b). The present study found that players competing in international matches spent 25% greater duration in acceleration band 4 compared to players competing in domestic competitions. While it could be perceived that an actual difference of ∼8 s between players during domestic and international competition might be of no practical significance in isolation, put into context of only 30–40 s currently occurring in the entire match, an increase of 25% is substantial and likely to physiologically impact a player especially in conjunction with additional running demands of a match. Furthermore, the increase between competition levels is for the highest intensity of accelerations and as highlighted in the literature, higher magnitude accelerations impose higher mechanical and physiological load on players (Osgnach et al., 2010, Dalen et al., 2016).

The increased acceleration capacity of players competing in international matches is supported through sprint testing, with players competing in international matches faster over 10 and 20 m compared to players in domestic competitions (Gabbett, 2010; Haugen et al., 2012; Griffin et al., 2020a). The faster 10 and 20 m sprint times of players competing in international matches indicate they have a higher acceleration capacity from a standing start. Further research, is needed to conclusively determine if players competing in international competitions also have a greater acceleration ability when performing accelerations from a "rolling start." It is clear from our results, that acceleration ability is a key characteristic of female football players competing in international matches, and that coaching and high-performance staff might focus on exposing players to high acceleration activities.

Deceleration is also a critical component of football and is most commonly performed by a player before they undertake a change of direction (COD). Decelerations account for ∼15% of total game duration for players competing in both domestic and international matches, suggesting substantial cumulative loads are placed on the lower-body musculoskeletal system during a match and over a season (McHugh et al., 1999).

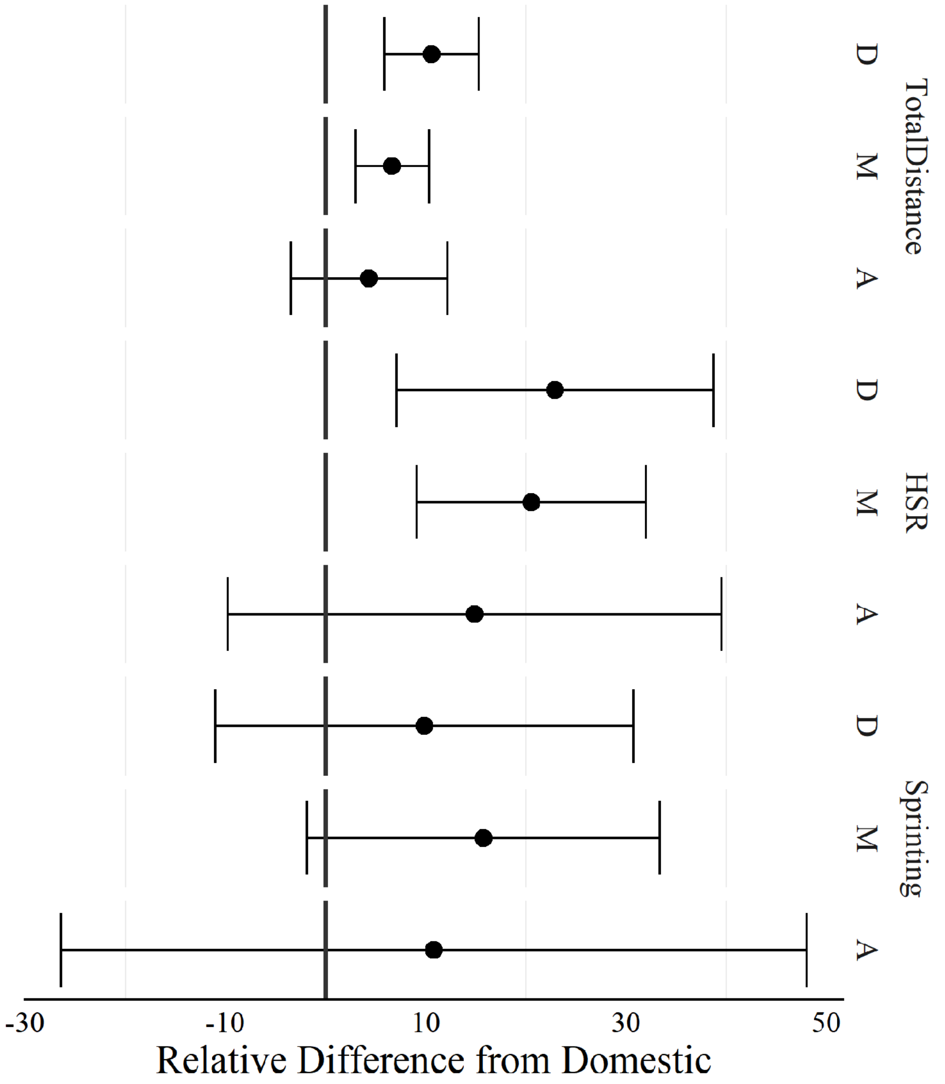

FIGURE 1 | Positional comparison of total distance, high-speed running, and sprinting between players competing in domestic and international women's football matches. HSR, High-speed running (16–20 km·h^{-1}); sprinting (>20 km·h^{-1}); D, Defenders; M, Midfielders; A, Attackers. A negative difference indicated, domestic was greater than international, a positive difference indicated international was greater than domestic.

With deceleration ability being a critical mediator of load-related injuries (Harper and Kiely, 2018), it is important that players are adequately prepared for the demands of competition (particularly at an international-level) through the appropriate level of exposure to high deceleration activities before and during the season. An interesting observation from our results was that players competing in international matches spent less duration decelerating in band 2 (12%) and band 3 (32%) compared to players in domestic competitions. The faster intermittent running speeds of players during international matches appears to be a result of less time spent decelerating, which is intuitive given that a high duration of decelerations would cause reductions in speed. The ability to decelerate maximally and come to a stop or reduce velocity faster than your opponent will always be important in team-sport (Hagerman, 2005), it appears though that the ability to decelerate specific to the situation is more important and allows for the preservation of greater speed.

In agreement with previous research (Gabbett and Mulvey, 2008; Andersson et al., 2010), our findings revealed that players competing in international matches performed greater high-speed running and sprinting distances compared to players in domestic competitions. Players competing in international matches performed 26% more distance at high-speed, which is consistent with the 28% difference previously reported for players competing in international matches compared to players in domestic competitions (Mohr et al., 2008). The distance covered at high-speed running and sprinting during international matches presented in the current study was similar to previously reported distances of 755 m of high-speed running and 306 m of sprinting (Ramos et al., 2017). We observed that

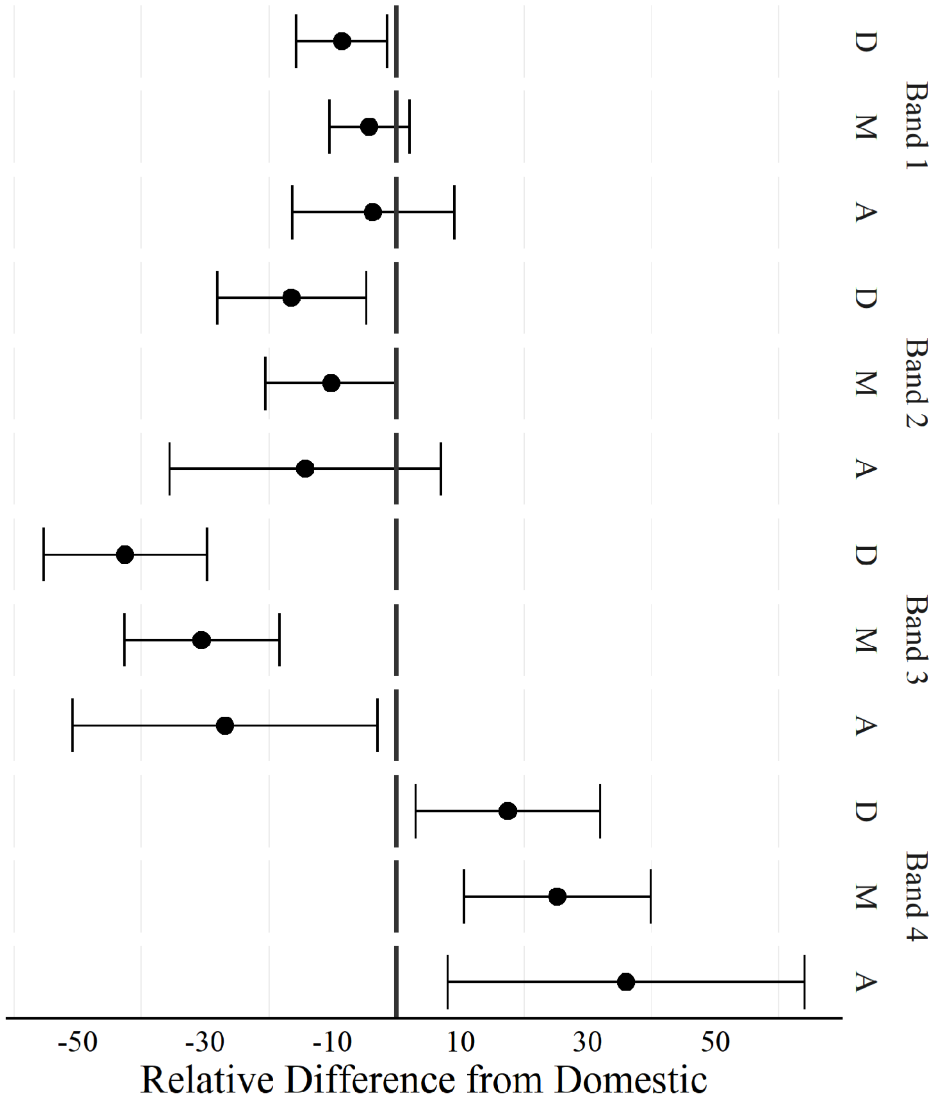

FIGURE 2 | Positional comparison of duration spent accelerating at different intensities between players competing in domestic and international women's football matches. Band 1 (1–2 m·s^{-2}), band 2 (2–3 m·s^{-2}), band 3 (3–4 m·s^{-2}), band 4 (>4 m·s^{-2}·). D, Defenders; M, Midfielders; A, Attackers. A negative difference indicated, domestic was greater than international, a positive difference indicated international was greater than domestic.

total distance covered by players was greater during international matches compared to domestic matches. While previous studies have reported no differences in total running distance of players competing in international and domestic women's football matches (Gabbett and Mulvey, 2008; Andersson et al., 2010), a possible explanation may be the differences in technology utilized, with the present study being the first to use GPS to quantify the running profiles of players during domestic and international matches. It is imperative that players are conditioned for the increased demands of international matches. This may require players increasing their aerobic capacity to cope with the higher total distances and increasing their anaerobic capacity to produce the greater high-speed running and sprinting distances.

Positional differences and requirements have been demonstrated to exist in women's football matches (Griffin et al., 2020b). Comparisons between playing positions demonstrate that attacker's movement patterns, except for the duration spent accelerating and decelerating in band 4, were similar or higher during domestic matches. Attackers often perform more high-speed running and sprinting than other positions (DeWitt et al., 2018; Griffin et al., 2020b) however, both of these metrics demonstrate the greatest between-game variability (CV = 33%, 53%, respectively) (Trewin et al., 2018). Our results are also consistent with previous literature, where attackers demonstrated the highest variability between competition levels for all movement patterns. The results found suggest that with increased high intensity accelerations (band 4), attackers may

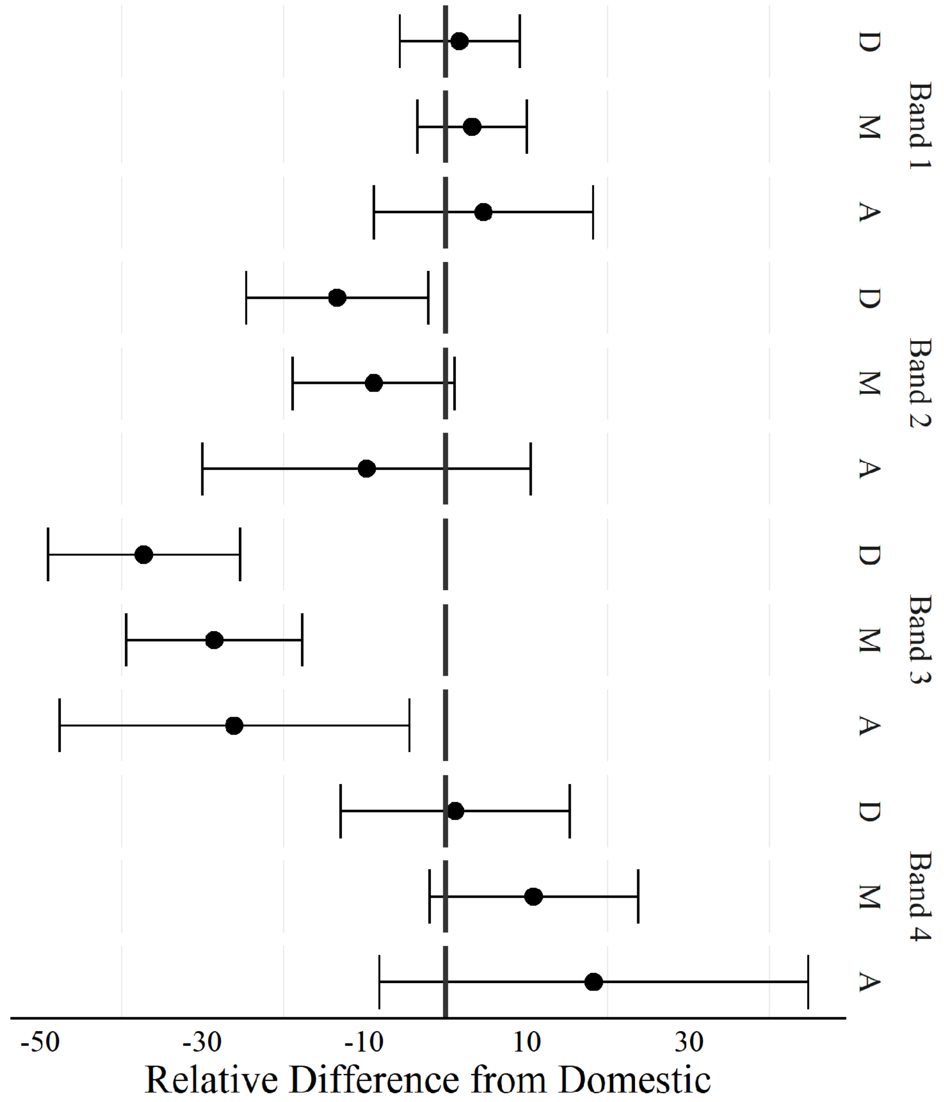

FIGURE 3 | Positional comparison of duration spent decelerating at different intensities between players competing in domestic and international women's football matches. Band 1 (–1 to –2 m·s^{-2}), band 2 (–2 to –3 m·s^{-2}), band 3 (–3 to –4 m·s^{-2}), band 4 (<–4 m·s^{-2}·). D, Defenders; M, Midfielders; A, Attackers. A negative difference indicated, domestic was greater than international, a positive difference indicated international was greater than domestic.

be more prepared for the transition from domestic matches to international matches.

The largest differences in playing positions between competition levels were apparent for defenders and midfielders. When international matches are compared to domestic matches, defenders and midfielders are required to perform more high-speed running, total distance, and greater time spent accelerating in band 4. The increased speed of players competing in international matches, therefore, requires greater movement patterns of defenders and midfielders. Additionally, defenders were the only position to demonstrated greater duration accelerating in band 1 and 2 and decelerating in band 2 during domestic matches compared to international matches. The lower magnitude of accelerations and decelerations highlight the reduced intensity of domestic matches compared to international matches for defenders. The lower intensity of decelerations for defenders may be a direct result of a lack of opportunity to decelerate, given the dependent nature of decelerations on prior velocity and accelerations (Newans et al., 2019). The increase in intensity observed during international matches affects defenders and midfielders to the greatest degree, therefore, it is important if players are to transition to a higher competition level these playing positions specifically are capable of and exposed to the increased intensity required for international matches.

Some inherent limitations warrant acknowledgment in the current study. The collection of GPS data using two different manufacturer GPS receivers is an important limitation, however, collecting data from a domestic and international team meant it was not possible to use receivers from the same manufacturer given each team's contractual obligations and preferences. Despite this, we undertook important steps to ensure standardization of data by implementing measures to minimize the effects of filtering and processing differences between manufacturers, as well as performing an inter-manufacturer comparison to determine the smallest worthwhile change for the variables of interest. The collection of GPS consisted of a small number of subjects, limiting the generalizability of the findings. Despite this limitation, data was based on elite female football players and given the limited number of female players involved in elite football and within a team, this was an unavoidable compromise in order to obtain data applicable to elite female football players.

PRACTICAL APPLICATIONS

Players competing in international matches should be exposed to a greater volume of high-speed running, sprinting and high magnitude (band 4) accelerations during training to prepare them for the increased demands of an international match. In the current study, players covered 26% more distance high-speed running during international matches compared to domestic matches. This is an important consideration in preparing players for international matches. Specifically, acceleration ability needs to focus on producing higher magnitude (band 4) accelerations, by applying greater force to the ground over a shorter ground contact time. Given acceleration or prior speed are needed for deceleration training, it is recommended that speed and deceleration are trained simultaneously as it may offer the most time-efficient approach to integrating both of these important elements into a time-restricted training program.

CONCLUSION

Results from the present study demonstrate that players competing in international matches perform more explosive, faster efforts, with greater outputs of high magnitude (band 4) accelerations, high-speed running, and sprinting. To prepare players for these increased running demands, players need to be progressively exposed to high-intensity activities during training. To maintain the faster speeds that are required during international matches, it appears that the ability to decelerate specific to the situation is important. The use of magnitude bands in the current study provides novel insights into differences between players movement patterns during international and domestic matches, highlighting the need for deeper understanding around the distribution of specific magnitudes of acceleration and deceleration efforts. The increased effort of high-intensity activity that is required for international matches in comparison to domestic matches, affects defenders and midfielders to the greatest degree. Therefore, it is important that these playing positions are gradually exposed to the increased stimulus to improve performance and reduce the potential risk of injury.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Griffith University Human Ethics Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

JG: project concept, data collection and analysis, and preparation of manuscript. CM: project concept, refining, and synthesizing manuscript. SH: data preparation, refining, and synthesizing manuscript. JK: refining and synthesizing manuscript. TN: data analysis and preparation of results (tables and figures). MA: project concept and provision of data collection. All authors contributed to the article and approved the submitted version.

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Physical Demands of Women's Soccer Matches: A Perspective Across the Developmental Spectrum

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Female soccer players are exposed to specific physical demands during matches, which vary according to the standard of play. Existing studies have largely focused on quantifying the distances covered for professional and international level players. This approach is limited in scope regarding the broader aspects around physical demands and is detached from development pathway models. An understanding of the demands across all standards will provide valuable insights about appropriate player development and help ensure physical readiness for the demands of the sport. The aim of this perspective paper is to describe the physical demands experienced during women's soccer matches across the developmental spectrum. A combination of evidence from the literature and data from the author's research (JDV) is presented. Specifically highlighted are the trends for locomotor distances, acceleration and deceleration frequency, and metabolic power metrics for youth (≤U17), college (NCAA/U20), professional (domestic) and international standards of women's soccer. In addition, the changes in match demands between levels of play are used to help illustrate gaps that must be overcome in order to successfully achieve physical readiness to compete at higher levels. The evidence demonstrates the importance of training appropriate attributes to prepare female soccer players who are striving to play at progressively higher standards.

Keywords: women's soccer, match demands, running distance, metabolic power, acceleration

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INTRODUCTION

Female soccer players are exposed to specific physical demands during matches, which vary according to the level/standard of play. To date, researchers and sport scientists have generally focused on the highest-level teams (i.e., elite) in order to develop strategies aimed at optimizing the physical readiness of these players and ultimately winning League titles, World Championships, or Olympic medals. Solely focusing match analysis at this level certainly has benefits for broadening our knowledge of the demands experienced by the best players (and teams), but is simultaneously disconnected from player development models, where gaps in technical, tactical, and fitness capabilities are routinely evaluated. Therefore, a comprehensive understanding of the physical demands of women's soccer matches across a wider range of standards is an essential element for enhancing player development pathways. There has been increased attention at some lower levels (i.e., U21, college), but there is still a paucity of research available describing the physical demands of youth matches.

Despite the recent interest and popularity in describing the physical demands of women's soccer matches, there are two substantial challenges to overcome for organizations, coaches, and sport science practitioners when examining published studies. First, outcomes between (i.e., video, GPS) and within (e.g., GPS 1, 5, and 10 Hz) systems are not interchangeable (Buchheit and Simpson, 2017), so some latitude is warranted when attempting to compare studies. Second, there is currently no consensus regarding the thresholds used for establishing discrete bands for key performance indicators (e.g., locomotor distances) (Bradley and Vescovi, 2015; Park et al., 2019). As a result, it is difficult to make direct comparisons within the published literature and subsequently create a cohesive view across the entire developmental spectrum for match demands. Recognizing these limitations, the aim of the current perspective paper is to describe match demands of women's soccer across the developmental spectrum in two ways. First, by presenting and comparing (when possible) published studies and second, by including data from the author (JDV) that uniquely spans youth, college, professional, and international women's soccer matches. The benefit of including these data is that they were collected using identical technology (5 Hz GPS) and applied the same thresholds for all reported variables–thus, direct comparisons can be made across all standards of play within this dataset.

METHODS

A literature search of Pubmed and Google Scholar was conducted using a combination of the following terms: women's soccer, match demands, running distance, metabolic power, acceleration, deceleration, youth soccer, college soccer, professional soccer, elite soccer, and international soccer. Additionally, the references of identified studies were searched for other citations not found in the electronic search. Both studies and reports were included that described the locomotor distances, acceleration and deceleration profiles, and/or metabolic power metrics for women's soccer matches at any standard of play. Despite the limitations of comparing various data collection technologies, papers were selected regardless of the methodology used to quantify match demands (i.e., video, GPS, etc.). To simplify and help facilitate comparisons of locomotor metrics between published studies, we focused on total distance, movement rate (distance per minute), and high-intensity distances (inclusive of sprinting) since the latter has been identified as a key indicator that differentiates between levels of play in women's soccer (Mohr et al., 2008; Andersson et al., 2010). We recognize that positional differences in physical demands exist; however, an examination of this component was beyond the scope of the current perspective.

Data from the author's (JDV) previous research is included, which contains locomotor distance, acceleration and deceleration frequencies, and metabolic power metrics. These particular data are presented for descriptive purposes only and do not represent an experimental study; therefore, statistical analyses were not applied. Players competed across four standards: youth (U15 to U17), college, professional (PRO), and elite international (INT). All matches were played on regulation sized soccer fields with referees. Youth players (U15 = 21, player-matches = 21; U16 = 69, player-matches = 85; U17 = 32, player-matches = 32) were involved in a high-level tournaments or talent identification camps with varying match durations (35–45 min halves) depending on the specific age-group. Matches at the other three standards had 45 min halves. College players (n = 51, player-matches = 71) competed in regular season NCAA Division I matches. Professional players (n = 83, player-matches = 205) competed in regular season (domestic) matches for a professional league. In addition to domestic players, each team included several international players from their respective national teams. Elite international players (n = 12, player-matches = 39) were from a top ranked FIFA women's national team and competed in "friendly" matches against other ranked FIFA women's national teams.

Players wore a GPS unit (SPI Pro 5-Hz, GPSports, Canberra, Australia) that is valid and reliable for measuring sprint distance and speed (Petersen et al., 2009; Waldron et al., 2011). Between 8 and 12 satellites were available for signal transmission (Jennings et al., 2010). Horizontal-dilution-of-precision values > 4 were automatically removed by the Team AMS software, which is below the maximum value (50) reported to result in inaccurate outcomes (Witte and Wilson, 2004). A digital watch that received satellite time identified the start and end of each half, as signaled by the referee's whistle. Data were extracted using the manufacturer software (GPSports, Team AMS R1 2015.10J) for analysis. The outcomes are presented in the current paper using the following thresholds for locomotor distance (Bradley and Vescovi, 2015), metabolic power (Osgnach et al., 2010), and acceleration/deceleration (manufacturer default setting):

- Locomotor distance: $\leq$ 6.0 kph (Zone 1), 6.1–8.0 kph (Zone 2), 8.1–12.0 kph (Zone 3), 12.1–16.0 kph (Zone 4), 16.1–20.0 kph (Zone 5), and > 20.0 kph (Zone 6)
- Metabolic power: $\leq$ 10.0 W/kg (Zone 1), 10.1–20.0 W/kg (Zone 2), 20.1–35.0 W/kg (Zone 3), 35.1–55.0 W/kg (Zone 4), and >55 W/kg (Zone 5)
- Acceleration and deceleration: 1.80–3.60 m/s^2 (Zone 1), 3.61–5.40 m/s^2 (Zone 2), and 5.41–7.20 m/s^2 (Zone 3)

LOCOMOTOR DEMANDS

Locomotor demands are the most popular metrics in soccer and have been widely reported for several decades. Some of the pioneering work in this space included manually coding video of recorded games (Bangsbo et al., 1991), whereas today there are automated video systems permanently installed in stadiums as well as GPS technology that afford teams a mobile option that can be used almost anywhere. These technological advances have enabled the continued expansion of data collection, which ultimately allow practitioners to capture data more easily and report the distances covered within various velocity bands.

Youth

To date, there are five studies describe the demands of female youth soccer matches (Barbero-Alvarez et al., 2008; Vescovi, 2014; Orntoft et al., 2016; Ramos et al., 2019; Harkness-Armstrong et al., 2020). The youngest age groups to be reported is U11-U12; however, the modified structure (see **Table 1**) makes direct comparisons to the literature impossible (Barbero-Alvarez et al., 2008; Orntoft et al., 2016). Still, the 20 and 50-min games resulted in ∼1,600 and 3,963 m of total distance, respectively, and a corresponding movement rate of about 80 m/min (Barbero-Alvarez et al., 2008; Orntoft et al., 2016), which is expectedly lower than movement rates for older age groups. A study during a youth national championship tournament (domestic) reported the demands of U15 to U17 players competing in typical match configurations (11v11 for 80–90 min) (Vescovi, 2014). The U15 players covered 6,961, 458, and 76 m for total, high-intensity (15.6–20.0 kph) and sprinting (>20 kph) distances, respectively, which were lower than the distances reported for U16 (8,024, 611, 185 m) and U17 (8,558, 658, and 235 m) age-group matches. These age-group differences persisted even after accounting for match duration with lower movement rates for U15 (86 m/min) compared to U16 and U17 (93–95 m/min) players. Talent pathway league matches for U14 and U16 teams showed average total distances of 7,148 and 7,679 m, respectively, with 217 and 247 m of high-intensity running (>19.0 kph) (Harkness-Armstrong et al., 2020). During the women's U17 South American championships (international), the players for Brazil covered 8,270, 485, and 191 m for total, high-intensity (15.6–20 kph), and sprint distances (>20 kph), respectively (Ramos et al., 2019). In general, there seems to be comparable total distances and movement rates for the same age groups, but the two studies using the same velocity thresholds showed high-intensity distances were about 24% lower during the international event (676 m) (Ramos et al., 2019) than the domestic event (893 m) (Vescovi, 2014). This difference could be attributable to the GPS technology used (5 vs. 10 Hz), environmental conditions, as well as game tactics (e.g., formation, style of play, etc.). Overall, it seems progressively greater movement rates occur across age-group youth soccer matches and is likely a reflection of improved physical capacities of players (Mujika et al., 2009) while holding match contextual factors constant.

College

Research examining the demands of women's college soccer matches has gained attention during the past few years. An important distinction to note about NCAA matches is that they do not follow international standards for substitutions. So, researchers tend to either include players that competed in full matches (which limits the sample size) or "create" 90-min matches from multiple players (which tends to alter movement rates). This is evident from a study comparing Division I regular season and post-season matches, which showed a 10% increase in total distance with a corresponding 6.5% decrease in movement rate (Wells et al., 2015). Nevertheless, total distances reported for NCAA Division I (∼9,000–9,900 m) (McCormack et al., 2014; Vescovi and Favero, 2014; Sausaman et al., 2019), Division II (∼10,000) (Gentles et al., 2018), Division III (∼9,600–9,800 m) (Jagim et al., 2020) as well as Canadian University matches (∼8,800–9,600 m) (Turczyn, 2018) are fairly similar, with subsequent movement rates of ∼100–110 m/min. Despite slightly different velocity thresholds used to define high-intensity running, it seems that when the velocity band spans only 3–4 kph the amount of distance covered is within a range of ∼600–800 m (Vescovi and Favero, 2014; Wells et al., 2015; Ramos et al., 2017; Turczyn, 2018; Jagim et al., 2020) with a notable exception reaching ∼1,000 m (Sausaman et al., 2019). For sprint distances, increasing the lower limit velocity threshold from 18 to 19 kph (∼280–420 m) (Alexander, 2014; Sausaman et al., 2019; Jagim et al., 2020; McFadden et al., 2020) to 20 kph (∼200–250 m) (Vescovi and Favero, 2014; Ramos et al., 2017) and 22 kph (<100 m) (Wells et al., 2015) has the expected reduction of reported distances.

Investigators have also examined the impact of contextual factors (e.g., altitude, match frequency, etc.) on locomotor demands in college matches. Moderate altitude (1,839 m) had a negative effect on total (121 vs. 106 m/min) and high-intensity (28 vs. 25 m/min) movement rates (Bohner et al., 2015), suggestive that hypoxic conditions adversely impacted locomotor activity. When college soccer matches end in a draw, the teams play two 10-min extra-time periods. The additional 20 min result in a 22–23% increase in total distances for extra-time matches compared with 90-min matches (Williams et al., 2019). Surprisingly, the total distances covered during extra-time were equivalent (∼1,100 m) between players who competed in the entire match or only a portion of the match. The NCAA soccer match schedule can be considered congested, where multiple games are oftentimes played with minimal days off in between. One study demonstrated that regular Friday and Sunday matches throughout the season resulted in lower total (120 vs. 106 m/min) and high-intensity (25 vs. 22 m/min) movement rates during the second game (McCormack et al., 2015). Similarly, Canadian women's soccer matches showed a ∼13% reduction in high-intensity (16–20 kph) and sprint (>20 kph) distance when games were on back-to-back days (Turczyn, 2018). Interestingly, there was no impact of poor sleep on match demands in these players (Turczyn, 2018). In contrast to the impact of match schedule, no differences were observed for high-speed or sprint distances between NCAA Division I regular-season and playoff matches (Wells et al., 2015), suggestive that players were able to continue playing with similar intensity throughout an entire season. Overall, these studies highlight how contextual factors might impact game demands for female college soccer players and the need to monitor these metrics in order to manage the physical demands players experience during the season.

Professional and International

There is substantially more evidence describing the locomotor demands of elite female soccer with a fairly even distribution between professional (domestic) (Krustrup et al., 2005; Mohr et al., 2008; Andersson et al., 2010; Bradley et al., 2014; Martínez-Lagunas et al., 2016; Datson et al., 2017; Mara et al., 2017b; Nakamura et al., 2017; DeWitt et al., 2018; Vescovi and Falenchuk, 2019; Julian et al., 2020; Scott et al., 2020a; Moraleda et al., 2021; Principe et al., 2021) and international matches (Mohr et al., 2008; Andersson et al., 2010; Ritschard and Tschopp, 2012; Hewitt et al., 2014; Martínez-Lagunas and Scott, 2016;

TABLE 1 | Velocity thresholds and distances for high-intensity running and sprinting across standards.

			High-intensity		Sprint	
References	**Competition standard**	**Method**	**Velocity (kph)**	**Distance (m)**	**Velocity (kph)**	**Distance (m)**
Youth						
Barbero-Alvarez et al. (2008)	U12 (7v7, 50 min game)	GPS (1 Hz)	13.1–18.0	228	>18.0	21
Harkness-Armstrong et al. (2020)	U14 (35 min half)	GPS (10 Hz)	> 19.0	1,530	>22.5	29
	U16 (40 min half)			1,695		53
Orntoft et al. (2016)	U11 (7v7 & 8v8, 20 min game)	GPS (5 Hz)	16.0–20.0	34–63	> 20.0	0
Ramos et al. (2019)*	U17 International	GPS (10 Hz)	15.6–20.0	485	> 20.0	178
Vescovi (2014)	U15 (40 min half)	GPS (5 Hz)	15.6–20.0	458	> 20.0	76
	U16 (40 min half)			611		185
	U17 (45 min half)			658		235
College						
Alexander (2014)*	Division I	GPS (10 Hz)	15.1–18.0	527	> 18.0	362
Gentles et al. (2018)	Division II	GPS (5 Hz)	15.1–25.0	∼1,140	> 25.0	∼80
Jagim et al. (2020)	Division III	GPS (10 Hz)	15.0–19.0	739	> 19.0	282
McCormack et al. (2015)	Division I	GPS (10 Hz)	13.0–22.0	∼2,283	> 22.0	NR
McCormack et al. (2014)	Division I	GPS (10 Hz)	13.0–22.0	1,586	> 22.0	NR
McFadden et al. (2020)	Division I	GPS (10 Hz)	15.0–19.0	∼800	> 19.0	∼400
Ramos et al. (2019)*‡	U20 International	GPS (10 Hz)	15.6–20.0	660	> 20.0	202
Sausaman et al. (2019)	Division I	GPS (10 Hz)	15.0–18.0	1,014	> 18.0	428
Strauss et al. (2019)	University	GPS (10 Hz)	> 15.5	∼336		
Turczyn (2018)	University	GPS (15 Hz)	16.0–19.9	∼680	> 20.0	∼250
Vescovi and Favero (2014)*	Division I	GPS (5 Hz)	15.5–20.0	776	> 20.0	250
Wells et al. (2015)	Division I-Reg season	GPS (10 Hz)	16.0–22.0	557	> 22.0	86
	Division I-Post season			603		85
Professional and elite						
Andersson et al. (2010)	Professional	Video-S	15.0–18.0	1,330	18.0–25.0	221
	Elite International			1,530		256
Bradley et al. (2014)	Professional	Video-M (25 Hz)	12.0–18.0	2,374	> 18.0	777
Bradley and Scott (2020)	Elite International (2015)	Video-M (20 Hz)	13.0–23.0	∼2,493	> 23.0	∼140
	Elite International (2019)	Video-M (20 Hz)		∼2,563		∼181
Datson et al. (2017)	Professional	Video-M	19.8–25.1	608	> 25.1	168
DeWitt et al. (2018)	Professional	GPS (10 Hz)	> 17.8	570	> 22.7	NR
Hewitt et al. (2014)	Elite International	GPS (5 Hz)	12.0–19.0	2,407	> 19.0	338
Julian et al. (2020)	Professional (1st/2nd Div)	GPS (5 Hz)	16.7–19.9	∼567	>19.9	∼342
Krustrup et al. (2005)	Professional	Video-S	15.0–18.0	1,310	18.0–25.0	160
Mara et al. (2017b)	Professional	Video-M (25 Hz)	12.2–19.0	2,452	> 19.0	615
Martínez-Lagunas and Scott (2016)	Elite International (2011)	Video-M (25 Hz)	16.0–20.0	846	>20.0	485
	Elite International (2015)	Video-M (20 Hz)		868		472
Martínez-Lagunas et al. (2016)	Professional (2nd Div)	GPS (5 Hz)	16.0–20.0	671	>20.0	290
	Professional (4th Div)			515		162
Meylan et al. (2017)	Elite International	GPS (10 Hz)	16.5–20.0	∼542	> 20.0	∼250
Mohr et al. (2008)	Professional	Video-S	15.0–18.0	1,300	18.0–25.0	380
	Elite International			1,680		460

(Continued)

TABLE 1 | Continued

References	Competition standard	Method	High-intensity		Sprint	
			Velocity (kph)	**Distance (m)**	**Velocity (kph)**	**Distance (m)**
Moraleda et al. (2021)	Professional	GPS (5 Hz)	>15.0	1,108		
Nakamura et al. (2017)	Professional	GPS (5 Hz)		NR	> 20.0	284
Principe et al. (2021)	Professional	GPS (10 Hz)	16.0–20.0	∼599	>20.0	∼303
Ramos et al. (2017)	Elite International	GPS (10 Hz)	15.6–20.0	744	> 20.0	304
Ritschard and Tschopp (2012)	Elite International (2011)	Video-M (25 Hz)	18.1–21.0	395	>21.0	290
Scott et al. (2020a)*	Professional (domestic)	GPS (10 Hz)	12.5–22.5	2,746	> 22.5	119
	Professional (internat)			2,834		150
Scott et al. (2020b)	Professional	GPS (10 Hz)	12.5–22.5	2,799	> 22.5	122
Trewin et al. (2018a)	Elite International	GPS (10 Hz)	> 16.5	∼873	> 20.0	NR
Trewin et al. (2018b)	Elite International	GPS (10 Hz)	> 16.5	∼855	> 20.0	NR
Vescovi and Falenchuk (2019)	Professional	GPS (5 Hz)	16.1–20.0	∼756	> 20.0	∼351

*weighted average across positions using mean values; ‡same sample used in 2019 paper; NR, not reported.
Video-S (single camera); Video-M (multi-camera).

Trewin et al., 2018a,b; Ramos et al., 2019; Bradley and Scott, 2020; Scott et al., 2020a,b).

The average total distances reported among professional (∼8,200–11,000 m) and international (∼9,300–11,000 m) level matches are generally similar. The majority of studies have demonstrated movement rates between 100 and 120 m/min (Krustrup et al., 2005; Mohr et al., 2008; Andersson et al., 2010; Bradley et al., 2014; Hewitt et al., 2014; Datson et al., 2017; Mara et al., 2017b; Trewin et al., 2018a,b; Julian et al., 2020; Scott et al., 2020b) with only a few showing movement rates below 100 m/min (Martínez-Lagunas et al., 2016; DeWitt et al., 2018; Moraleda et al., 2021; Principe et al., 2021) and one above 120 m/min (Datson et al., 2017). Interestingly, only the top finishing teams in the 2015 and 2019 FIFA Women's World Cups had movement rates that were aligned (105–113 m/min) with the general consensus from the literature, whereas the bottom finishing teams were between 86 and 94 m/min (Bradley and Scott, 2020). Additionally, there was a sizeable gap in movement rate between German teams in the 2nd division (∼104 m/min) and 4th division (∼91 m/min) (Martínez-Lagunas et al., 2016). The differences between top and bottom teams within a given standard of play (i.e., divisions in a professional league or international events like the World Cup) could be the result of contextual factors (e.g., lower-level teams making tactical decision to largely play defense). It is also possible these outcomes highlight supportive evidence for the link between fitness levels and distances covered during women's soccer matches (Krustrup et al., 2005).

There is a substantial range describing the high-speed running and sprinting distances in elite women's matches, which is directly attributable to the wide variety of thresholds used to define these particular metrics (see **Table 1**). For example, some studies have used 12.0–12.5 kph as the lower limit for a given threshold (e.g., high-intensity running) (Bradley et al., 2014; Hewitt et al., 2014; Mara et al., 2017b; Scott et al., 2020a,b), but the upper limit has ranged between 18.0 and 22.5 kph. Subsequently, the reported distances vary from ∼2,300–2,450 m (Bradley et al., 2014; Hewitt et al., 2014; Mara et al., 2017b) when using 18.0 kph, compared with ∼2,800 m being captured as a result of using 22.5 kph (Scott et al., 2020a,b). Three studies have examined both professional and international women's matches; despite similar total distances between standards (within their respective studies) (Mohr et al., 2008; Andersson et al., 2010; Scott et al., 2020a), two studies reported 15–29% more high-intensity running during international matches (Mohr et al., 2008; Andersson et al., 2010), whereas the other found only a 3% difference (Scott et al., 2020a). The wider velocity zone (12.5–22.5 kph) (Scott et al., 2020a) may have impacted the outcomes because smaller differences in distance are seen between standards at slower speeds (e.g., 6–16 kph), thus potentially washing out an effect that was observed when using a smaller velocity zone (15–18 kph) (Mohr et al., 2008; Andersson et al., 2010). On the other hand, it is possible that differences between international and professional matches dissipate when players at both levels compete together. Thus, elevated international match demands may be the result of contextual factors inherent to the competition itself (i.e., higher stakes, greater motivation), rather than as unique physiological characteristics of international level players. Lastly, the influence of natural (∼660 m) and synthetic (∼770 m) turf on high-intensity running during women's matches has also been reported (Vescovi and Falenchuk, 2019) and demonstrates how this contextual factor might impact match demands at this standard of play.

Sprinting distances between studies also varies widely because of the different velocity thresholds. Several studies have used >20 kph and found sprint distances between ∼250 and ∼350 m per match (Martínez-Lagunas et al., 2016; Meylan et al., 2017; Nakamura et al., 2017; Trewin et al., 2018a,b; Ramos et al., 2019; Vescovi and Falenchuk, 2019; Julian et al., 2020; Principe et al., 2021), with substantially smaller distances shown (120–180 m) when higher thresholds are used (22.5–25.1 kph) (Datson et al., 2017; Bradley and Scott, 2020; Scott et al.,

TABLE 2 | Locomotor distances and movement rate across standards.

	Match	<6 kph	6–8 kph	8–12 kph	12–16 kph	16–20 kph	>20 kph	>16 kph	Total	Rate
	Duration (min)	Zone 1 (m)	Zone 2 (m)	Zone 3 (m)	Zone 4 (m)	Zone 5 (m)	Zone 6 (m)	Zone 5+6 (m)	Distance (m)	(m/min)
U15	80 (2)	2,597 (368)	838 (193)	1,996 (395)	958 (226)	465 (111)	79 (61)	545 (141)	6,936 (335)	87 (4)
U16	84 (1)	2,957 (358)	896 (179)	2,168 (469)	1,211 (365)	562 (179)	150 (115)	713 (206)	7,946 (869)	94 (11)
U17	90 (0)	3,124 (328)	1,031 (162)	2,461 (610)	1,306 (456)	609 (163)	213 (174)	823 (281)	8,746 (928)	97 (10)
NCAA	97 (4)	3,178 (279)	1,251 (185)	2,898 (487)	1,455 (307)	744 (205)	237 (121)	981 (309)	9,762 (774)	101 (8)
PRO	94 (2)	3,363 (369)	1,276 (258)	2,851 (484)	1,728 (471)	752 (184)	361 (191)	1,113 (288)	10,332 (877)	109 (9)
INT	91 (2)	2,846 (247)	1,242 (114)	2,977 (308)	1,827 (318)	837 (172)	414 (170)	1,251 (276)	10,144 (546)	111 (6)

Values are mean (SD). Data from author (JDV).

2020a,b). These differences between studies are expected since the impact of implementing various high-velocity thresholds on these locomotor distances has been previously demonstrated in professional women's matches (Vescovi, 2012; Bradley et al., 2014). Nevertheless, players competing in international matches have 16–26% more sprint distances than during professional matches (Mohr et al., 2008; Andersson et al., 2010; Scott et al., 2020a). An examination of the previous three FIFA Women's World Cups indicates nearly identical sprint distances between 2011 and 2015 (485 vs. 472 m; using >20 kph) (Martínez-Lagunas and Scott, 2016), but a 21% increase from 2015 to 2019 (∼558 vs. ∼677 m; using >19 kph) (Bradley and Scott, 2020). Taken together and despite the difficulty of making direct comparisons between published studies, greater high-intensity demands are evident at the highest standard.

Developmental Perspective

Table 2 displays the total distance, movement rate and distances in each velocity band across the developmental spectrum. In general, total match distances are aligned with data from the literature for the respective cohorts and shows a strong linear increase from youth (∼7.0–8.7 km) to professional and international matches (∼10 km) (**Figure 1**). This relationship remained even after taking match duration into account, although after the NCAA a plateau of movement rate occurred for professional (domestic) and international matches. The movement rates for professional and international matches are similar to the top teams that competed in the 2011 (106–120 m/min) (Ritschard and Tschopp, 2012), 2015 (108–113 m/min) (Martínez-Lagunas and Scott, 2016), and 2019 (105-110 m/min) FIFA Women's World Cup (Bradley and Scott, 2020) tournaments. As a proportion of total distance, Zone 2 (∼12–13%) and Zone 3 (∼27.5–29.5%) remained fairly constant between all standards of play. However, there was a larger change in the relative distances for lower (Zone 1) and higher (Zone 5+6) speed movements, demonstrating that younger players perform greater proportions of walking and smaller proportions of high-intensity movement compared to higher standards (**Figure 2**). So, young players will be exposed to greater demands progressing through age-groups and then again if they progress to play at the college level. The greater demands through youth and into college will be somewhat connected to increased match duration, but more important, also linked with higher match tempos. College athletes seeking to compete at even higher standards will be required to have ∼10% faster movement rates in order to match the tempo of professional and international players. This will result from a substantially greater percent change for high-intensity distances (Zones 5+6) compared with total distance. For example, the relative changes between U17 and NCAA Division I is 12% for total distance and 19% for high-intensity running. Similarly, 6% and 13% increases are evident when transitioning between Division I and professional matches for total and high-intensity distance, respectively. These are critical pieces to understand when designing the physical preparation component of player development models.

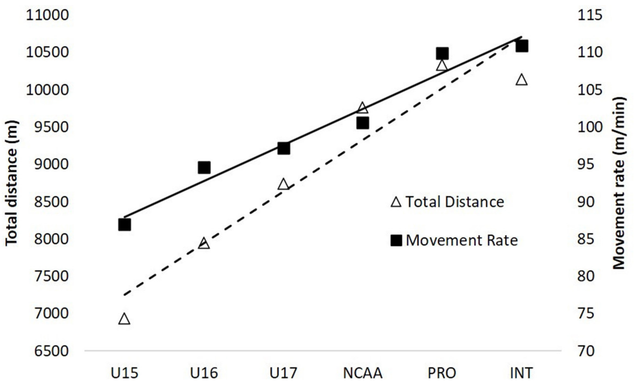

FIGURE 1 | Average total distance and movement rate across standards. Data from author (JDV).

ACCELERATION AND DECELERATION DEMANDS

Quantifying the distance covered and movement rate of soccer matches only describes a portion of the demands experienced by players since the intermittent nature of the game requires frequent changes of speed. The positive (acceleration) and negative (deceleration) changes in speed impose additional demands on the body than when moving at a constant velocity (Osgnach et al., 2010). These changes in speed may be brief and not meet the duration (e.g., >1 s) or speed (e.g.,

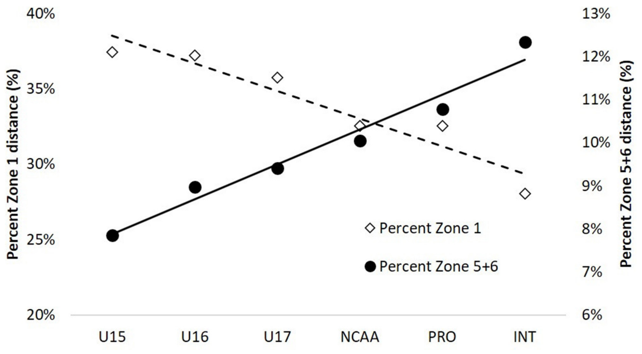

FIGURE 2 | Average percent distance of Zone 1 and Zone 5+6 across standards. Data from author (JDV).

>20 kph) requirements that would result in the activities being labeled as high-velocity running activities within GPS systems. Nevertheless, they are still high-intensity actions based on acceleration (Akenhead et al., 2013; Mara et al., 2016; Nakamura et al., 2017). Therefore, it is important for practitioners to give consideration to the quantity and intensity of accelerations and decelerations when examining match demands of women's soccer.

Youth

There is a single study describing the acceleration profile for youth women's soccer matches (Ramos et al., 2019). The physical demands of seven matches from the U17 National Brazilian team demonstrated that, on average, players performed 150–200 accelerations (>1 m/s^2) and 85–122 decelerations (> -1 m/s^2) during an international event.

College

Several research groups have described acceleration profiles (Ramos et al., 2017, 2019; Jagim et al., 2020) as well as accelerometer derivative metrics (e.g., player load) (Wells et al., 2015; Gentles et al., 2018; Strauss et al., 2019) for college age-group matches. The accelerometer derivatives might be useful metrics because they can account for movements such as jumping; however, these do not directly reflect changes in horizonal speed and thus are not considered here.

Categorizing movements into specific bins demonstrated the vast majority of accelerations and decelerations were low intensity (± 0.5–1.99 m/s^2, 953 vs. 1,010, respectively), when compared with moderate (± 2.00–2.99 m/s^2, 64 vs. 69, respectively), and high-intensity (± 3.00–50.0 m/s^2, 10 vs. 17, respectively), counts for Division III NCAA matches (Jagim et al., 2020). During a U20 international tournament players performed 172–196 accelerations and 108–145 decelerations (>1 m/s^2) (Ramos et al., 2019); however, these values were substantially reduced when the threshold was increased to >2 m/s^2 (13–17 and 11–25, respectively), in the same group (Ramos et al., 2017).

Professional and International

Several studies have reported acceleration (Meylan et al., 2017; Trewin et al., 2018a,b; Principe et al., 2021) and deceleration profiles (Mara et al., 2017a; Ramos et al., 2019; Principe et al., 2021) for elite female soccer players. Three studies were conducted by the same group and implemented the same definition (>2.26 m/s^2) to quantify the frequency of accelerations that occurred during matches (Meylan et al., 2017; Trewin et al., 2018a,b). In general, the number of accelerations performed was about 1.8/min (∼162 for 90 min match) (Meylan et al., 2017; Trewin et al., 2018b). They also demonstrated contextual factors (hot environment had lowest count = 1.73/min or ∼156; draws vs. lower teams had highest count = 2.07/min or ∼186) influenced the number of accelerations performed (Trewin et al., 2018a,b).

A few studies described both acceleration and deceleration profiles (Ramos et al., 2019; Moraleda et al., 2021; Principe et al., 2021). The Brazilian women's national team was monitored during the Rio 2016 Olympic Games and had average acceleration and deceleration counts ranging from 201–218 to 161–182 per match, respectively (Ramos et al., 2019). These outcomes demonstrate acceleration counts are about 16–38% higher when using a substantially lower threshold (1 m/s^2) (Ramos et al., 2019) than reported above. Professional Brazilian players had substantially lower acceleration and deceleration frequencies (also used >1 m/s^2 - ∼155 and ∼157, respectively) (Principe et al., 2021) than their national team counterparts, highlighting the distinction between these two standards of play. Another study implemented a threshold of 2 m/s^2 but uniquely described accelerations and decelerations by the starting and finishing speed associated with the movement and classified the frequency counts in six different zones (Mara et al., 2017a). They reported a total of 423 and 430 accelerations and decelerations, respectively, with the majority of them (∼250 each) having a low starting and ending speed ($<$ 3.4 m/min). Interestingly, this study found substantially greater counts of accelerations and decelerations in elite women's matches (about double) despite using a threshold that was between other research groups (1.0 vs. 2.0 vs. 2.26 m/s^2). Perhaps the video system (25 Hz) is more sensitive than GPS technology (10 Hz) for quantifying these match demands. When monitoring acceleration counts for elite matches practitioners need to consider match-to-match variation (12–21%) (Meylan et al., 2017; Trewin et al., 2018a).

Developmental Perspective

The acceleration and deceleration profiles shown in **Table 3** highlight several key features across the developmental spectrum. First, more than 95% of accelerations and 85% of decelerations occurred between 1.8 and 3.6 m/s^2. These thresholds are the manufacturer defaults, nevertheless the skewed distribution suggests that alternative values are likely needed if practitioners want to qualify these metrics as low, moderate and high-intensity. Improved quantification of frequency counts might require assessment of acceleration ability across the developmental spectrum to identify appropriate thresholds. Second, the total accelerations for professional and international matches (145–158 or 1.6–1.8/min) appear somewhat aligned with previous

TABLE 3 | Acceleration and deceleration frequencies across standards.

	Match	1.8–3.6 m/s^2	3.6–5.4 m/s^2	5.4–7.2 m/s^2	Accel	1.8–3.6 m/s^2	3.6–5.4 m/s^2	5.4–7.2 m/s^2	Decel
	Duration (min)	Accel 1 (n)	Accel 2 (n)	Accel 3 (n)	Total (n)	Decel 1 (n)	Decel 2 (n)	Decel 3 (n)	Total (n)
U15	80 (2)	98 (19)	2 (2)	0	101 (20)	103 (17)	9 (6)	1 (1)	113 (18)
U16	84 (1)	109 (33)	3 (2)	0	112 (34)	112 (21)	12 (5)	1 (2)	125 (26)
U17	90 (0)	109 (31)	2 (2)	0	112 (31)	114 (24)	13 (6)	1 (1)	129 (29)
NCAA	97 (4)	144 (29)	5 (3)	0	149 (31)	141 (32)	20 (8)	2 (2)	163 (38)
PRO	94 (2)	145 (26)	5 (3)	0	151 (27)	144 (28)	21 (8)	2 (2)	167 (32)
INT	91 (2)	158 (23)	6 (4)	0	164 (25)	146 (22)	23 (8)	3 (2)	172 (27)

Values are mean (SD). Data from author (JDV).

studies using GPS technology, despite implementing different thresholds (1 and 2.26 m/s^2) (Meylan et al., 2017; Trewin et al., 2018a,b; Ramos et al., 2019). It is unclear what could cause this but is likely a result of subtle differences in vendor software calculations. Lastly, the largest change in acceleration (∼34%) and deceleration (∼26%) frequency occurs between youth and NCAA matches. This highlights a substantial component for player development pathways aimed at athletes making the transition from high school to college.

METABOLIC POWER DEMANDS

The introduction of metabolic power (di Prampero et al., 2005) and subsequent application to soccer match analysis (Osgnach et al., 2010) has integrated acceleration and deceleration data to define additional metrics. This method has been suggested to better represent match demands than relying upon velocity based demands alone, especially for high-intensity work (Gaudino et al., 2013). The outcomes include distances within various metabolic power bands (similar to establishing velocity bands for locomotor distances) as well as the energetic cost (internal load metric). An important note, unlike velocity thresholds, the originally proposed metabolic power thresholds (Osgnach et al., 2010) have been consistently applied in the literature, which are: <10 (low), 10–20 (moderate), 20–35 (high), 35–55 (elevated), and > 55 (maximal) W/kg. Although updated algorithms have been developed to improve the accuracy of this method (di Prampero and Osgnach, 2018; Osgnach and di Prampero, 2018), it should be noted that studies reporting on metabolic power in women's soccer are scarce and have applied the original approach (di Prampero et al., 2005).

Youth

As of this writing, there are no published studies examining the metabolic power demands of youth female soccer matches.

College

Two studies have examined metabolic power in women's college soccer matches (Wells et al., 2015; Williams et al., 2019) but described limited outcome variables despite the ability to quantify several more (Osgnach et al., 2010). In one study, the mean high-metabolic power distance (>20 W/kg) in NCAA Division I matches was 1,839 and 440 m for regulation and extra-time, respectively (Williams et al., 2019). The total for that study (2,279 m total) is similar to unpublished data from NCAA matches (2,126 m–**Table 3**) that also includes stoppage-time (mean match duration, 97 min). An important consideration for practitioners is that stoppage and extra-time can substantially elevate the amount of high-metabolic power distance (Williams et al., 2019), therefore recovery strategies from those matches become more important, especially if there is little time before the next match as often is the case with the NCAA soccer schedule.

Using this method (Osgnach et al., 2010) also allows for an estimation of energetic demands. One study reported a 10% increase in energy expenditure between regular season (34 kj/kg) and post-season (38 kj/kg) college matches which was linked to an additional 700 m of total distance (Wells et al., 2015). The energetic demands were greater (48 kj/kg) in another group of Division I players (Williams et al., 2019) and even higher for NCAA teams in **Table 4** (53 kj/kg). Although all were NCAA Division I teams, the ones included in **Table 4** had a high national ranking (e.g., six of nine teams ranked top 30 and three ranked top 10). Similar to the differences described for locomotor movement rates between top and bottom teams in FIFA Women's World Cup (Bradley and Scott, 2020) there are likely variations in the tempo of play across NCAA Division I that could subsequently impact energetic demands of these matches. Furthermore, the implementation of the metabolic power methodology could be modified by commercially available GPS systems (Williams et al., 2019) in order to have a proprietary competitive advantage, which could have also influenced the reported outcomes between studies (Terziotti et al., 2018). Additionally, when converting the relative energetic demands from these studies into calorie expenditure (520–770 kcal) (Wells et al., 2015; Williams et al., 2019), they are substantially lower than values obtained using heart rate derived equivalents (∼1,100–1,400 kcal) (Jagim et al., 2020; McFadden et al., 2020), thus it does not appear the outcomes from various methods can be used interchangeably.

Professional and International

To date there are two published studies that include metabolic power demands for female players. Both studies evaluated professional domestic match play and included the same cohort of players from the WPS league (Vescovi, 2016; Vescovi and Falenchuk, 2019). Playoff matches showed greater mean

TABLE 4 | Metabolic power distances and load across standards.

	Match	<10 W/kg	10–20 W/kg	20–35 W/kg	35–55 W/kg	>55 W/kg	>20 W/kg	Equivalent	Metabolic
	Duration (min)	**Zone 1 (m)**	**Zone 2 (m)**	**Zone 3 (m)**	**Zone 4 (m)**	**Zone 5 (m)**	**Zone 3+ (m)**	**Distance (m)**	**Load (kj/kg)**
U15	80 (2)	3,926 (312)	1,555 (274)	881 (133)	342 (60)	147 (47)	1,370 (178)	8,411 (452)	39.1 (2)
U16	84 (1)	4,402 (277)	1,853 (492)	1,026 (260)	395 (107)	179 (97)	1,600 (400)	9,349 (1,136)	43.4 (5)
U17	90 (0)	4,789 (231)	2,021 (528)	1,197 (289)	461 (99)	178 (86)	1,835 (416)	10,170 (1,195)	47.2 (6)
NCAA	97 (4)	5,124 (276)	2,415 (466)	1,378 (257)	522 (100)	225 (66)	2,126 (372)	11,569 (997)	53.7 (5)
PRO	94 (2)	5,144 (293)	2,435 (436)	1,460 (279)	573 (103)	274 (80)	2,307 (392)	11,617 (1,507)	53.9 (7)
INT	91 (2)	4,935 (170)	2,681 (303)	1,595 (209)	624 (81)	306 (73)	2,527 (299)	11,745 (1,121)	51.9 (11)

Values are mean (SD). Data from author (JDV).

metabolic power (10.2 W/kg) than regular season matches (9.2 W/kg), which corresponded to ∼23, 26, and 29% more relative distance covered in high (19.4 vs. 15.8 m/min), elevated (7.2 vs. 5.7 m/min) and maximal (2.2 vs. 1.7 m/min) metabolic power categories, respectively (Vescovi, 2016). There was little impact on metabolic power metrics when examining various contextual factors (i.e., home vs. away, natural vs. artificial turf, and match outcome) (Vescovi and Falenchuk, 2019). The only notable difference was greater high-metabolic power distance when matches were played on artificial turf (16.3 m/min) than on natural turf (14.4 m/min). When the top three categories are taken together (>20 W/kg) the distances covered on natural and artificial turf were ∼2,070 and 2,313 m (Vescovi and Falenchuk, 2019), which are greater than the value previously described for college matches (regulation-time 1,839 m) (Wells et al., 2015).

The energetic demands of players competing at higher standards have also been described. During a modified match structure (3 × 20 min), female players had a relative energetic load of 37 kj/kg (∼2,400 kj) (Mara et al., 2015a). Even higher values have been reported from professional regular-season and post-season matches (51–58 kj/kg) (Vescovi, 2016; Moss et al., 2020). This equates to ∼900 kcal expenditure during professional women's soccer matches, which is greater than measured values (∼744 kcal) reported for professional German players during a 90-min training game (Martínez-Lagunas, 2013). However, the overall movement demands were lower (total distance ∼ 7,230 m and distance >16 kph ∼631 m) than values typically observed during regulation matches and so lower energy expenditure values would be expected. Nonetheless, these data highlight the overall energetic needs for female players is likely between 750 and 900 kcal per match.

Developmental Perspective

The data provided in **Table 4** fills some of the gaps identified in the literature surrounding metabolic power and also includes a derived metric, equivalent distance. The equivalent distance is a way to express the distance an athlete would have traveled at a steady pace on grass by using the total energy expended during the entire match (Osgnach et al., 2010). The ratio of equivalent distance to total distance (called equivalent distance index–EDI) has been previously defined for convenience to be ∼1.20 (Osgnach et al., 2010). The equivalent distance and its index may be metrics of interest because they represent the overall volume and metabolic intensity a player experiences during a match, respectively (di Prampero and Osgnach, 2018; Osgnach and di Prampero, 2018). It is evident that there are steadily increasing values for several metrics such as metabolic load, movement rate, and equivalent distance from youth and into the NCAA matches, which then seem to plateau at higher standards. Similar to **Table 2**, the percent change among standards for high-metabolic power distance (Zone 3+ >20 W/kg) is substantially larger than the corresponding percent change between levels for equivalent distance (9–17 vs. 1–14%, respectively). The reason this occurred is unknown, but since these metrics take into account acceleration/deceleration, their distribution might offer insights into potential links. Currently, the skewed distribution of this dataset obstructs an understanding on this topic - perhaps applying different acceleration/deceleration thresholds would be better suited to investigate this in the future. Nonetheless, metabolic power outcomes provide supportive evidence for giving attention to developing the ability to perform greater amounts of high-intensity effort across the developmental spectrum.

PRACTICAL CONSIDERATIONS AND APPLICATIONS

The data presented highlights the physical demands of women's soccer matches across the developmental spectrum. This information can be used by clubs, leagues and federations for player development within and between levels of play. It could also be used for return to play protocols for injured players during the rehabilitation process. It is beyond the scope of this paper to detail the specific ways to go about incorporating this into the daily training environment and rehabilitation settings. However, coaches and fitness practitioners can likely focus on two overarching objectives with respect to effectively using information on the physical demands of women's matches. The first way is to help players achieve the match demands within their current standard. For example, players on a particular team or teams within a given level (e.g., U15, NCAA Division III) will demonstrate a range of physical match demands for any of the metrics described above. Improving the physical fitness qualities of players/teams that are at the lower end of the range can subsequently have a positive impact on performance during matches. The second focus for coaches and practitioners is to prepare athletes/teams who are looking to transition to the next higher standard (i.e., a player going from college to professional, or a team being promoted from a lower to higher professional division). In these circumstances, the physical preparation must be targeted at the demands for the higher level with care taken to implement a periodized plan over a sufficient amount of time to elicit the desired (beneficial) physiological adaptations.

A general heuristic often followed in endurance training is for athletes to perform ∼2.0–2.5 times the competition distance as total weekly training volume. Translated to women's soccer, that would mean if total distances during matches were ∼7 km (youth), ∼9 km (college), or ∼11 km (professional/elite), then total weekly volume should roughly be 14–18, 18–22, and 22–28 km, respectively. These theoretical targets for total weekly training distance seem to be somewhat aligned with what has been reported for professional teams (∼16–22 km, exclusive of matches) (Mara et al., 2015b; Moraleda et al., 2021). Please note, the ratio (2.0–2.5X) would only be applied to total volume since evidence-based recommendations on other metrics (i.e., sprint distance, volume of accelerations, metabolic power) do not currently exist. These distances could be programmed into the weekly training sessions and incorporated directly into practice with soccer-specific drills and small-sided games that target particular attributes of interest (e.g., very short maximal accelerations [<5 m], achievement of maximal velocity [15–20 m], etc.). This type of approach enables technical, tactical and physical components to be developed simultaneously and reduces the need for additional (off-field) work.

MOVING FORWARD

There has been a steady increase in the number of published studies describing the physical demands of women's soccer matches. The advancements in video capture systems and GPS technology have enabled the expansion of insights about a broad spectrum of movement demands. Still, there are gaps specific to women's soccer that have been noted by others (Martínez-Lagunas et al., 2014) and need to be addressed. First, there is a lack of standardized thresholds for quantifying locomotor distances as well as acceleration and deceleration profiles. This prevents a unified understanding of match demands across the developmental spectrum. The use of physiological (Bradley and Vescovi, 2015; Trewin et al., 2018a) and mathematical (Park et al., 2019) approaches have been suggested but still have not been embraced (e.g., different thresholds implemented in previous three Women's World Cup events) (Ritschard and Tschopp, 2012; Martínez-Lagunas and Scott, 2016; Bradley and Scott, 2020). Second, there is a tremendous gap in research describing the physical demands of youth soccer matches (≤U17). In order to provide comprehensive training recommendations for developmental pathways additional attention is required. Work has been initiated in this area (Harkness-Armstrong et al., 2020), but needs to continue through National Sport Organizations and professional academies that have the necessary resources to monitor players within their ecosystem, but effort is also required by researchers to partner with women's youth domestic leagues in order to broaden the scope of understanding. Lastly, there is limited data about the metabolic power metrics in women's soccer, which now exist in most commercially available GPS systems. Therefore, if metabolic power provides insights beyond velocity-based movement demands, then researchers should begin to include these outcomes in published studies. Overall, the direction of research in women's soccer is very promising and continued advancements to fill these gaps will ensure that better, evidence-based recommendations are applied to the physical developmental component of female player pathway models.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because of pre-existing legal agreements. Requests to access the datasets should be directed to Dr. Jason Vescovi.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by York University, Office of Research Ethics. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

JDV was responsible for manuscript concept, data collection, writing, and revision of the paper. EF and AK were responsible for conducting the literature search, writing, and revision of the paper. All authors contributed to the article and approved the submitted version.

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The Efficacy of Heat Acclimatization Pre-World Cup in Female Soccer Players

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The efficacy of a 14-day field-based heat acclimatization (HA) training camp in 16 international female soccer players was investigated over three phases: phase 1: 8 days moderate HA (22. 1°C); phase 2: 6 days high HA (34.5°C); and phase 3: 11 days of post-HA (18.2°C), with heart rate (HR), training load, core temp (T_c), and perceptual ratings recorded throughout. The changes from baseline (day−16) in (i) plasma volume (PV), (ii) HR during a submaximal running test (HRex) and HR recovery (HRR), and (iii) pre-to-post phase 2 (days 8–13) in a 4v4 small-sided soccer game (4V4SSG) performance were assessed. Due to high variability, PV non-significantly increased by 7.4% ± 3.6% [standardized effect (SE) = 0.63; $p = 0.130$] from the start of phase 1 to the end of phase 2. Resting T_c dropped significantly [$p < 0.001$ by −0.47 ± 0.29°C (SE = −2.45)], from day 1 to day 14. Submaximal running HRR increased over phase 2 (HRR; SE = 0.53) after having decreased significantly from baseline ($p = 0.03$). While not significant ($p > 0.05$), the greatest HR improvements from baseline were delayed, occurring 11 days into phase 3 (HRex, SE = −0.42; HRR, SE = 0.37). The 4v4SSG revealed a moderate reduction in HRex (SE = −0.32; $p = 0.007$) and a large increase in HRR (SE = 1.27; $p < 0.001$) from pre-to-post phase 2. Field-based HA can induce physiological changes beneficial to soccer performance in temperate and hot conditions in elite females, and the submaximal running test appears to show HRex responses induced by HA up to 2 weeks following heat exposure.

Keywords: plasma volume, submaximal, football, heart rate, monitoring, training

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INTRODUCTION

Athletes are often required to compete in hot and humid environmental conditions, which, if sufficiently hot and coupled with high exercise intensities, can lead to heat stress and, eventually, hyperthermia. Hyperthermia is characterized by an elevation in core (T_c) and skin temperature; an increase in sub-maximal exercise heart rate (HR); and with subsequent dehydration, a reduction in peripheral blood flow and an eventual reduction in sweat rate, resulting in a decline in performance (Chalmers et al., 2014; Racinais et al., 2015; Pryor et al., 2019). Soccer is a sport with high physiological intensities that has the potential to result in greater heat-induced metabolic stress compared to other team sports (Chalmers et al., 2014; Datson et al., 2014).

Previous research in high-level soccer players has shown how playing in temperature above 21°C and associated hyperthermia (Buchheit et al., 2011; Carling et al., 2011; Mohr et al., 2012; Mara et al., 2015; Trewin et al., 2018) are negatively correlated to match performance in terms of decreasing the total running distance covered, reductions in high-intensity running speed, and the number of fast directional movements (acceleration and deceleration). Therefore, enhancing environmental preparation is required to optimize soccer performance in the heat.

Repeated training exposures in a hot environment have the potential to induce positive physiological adaptations that can attenuate the negative effects of heat stress by regulating cardiovascular strain while enhancing thermoregulation [e.g., increased plasma volumes (PV) and sweat rates] (Racinais et al., 2015). While isothermically controlled, lab-based heat acclimation protocols have demonstrated improvements in both team and endurance sport performance (Pethick et al., 2018; Benjamin et al., 2019), the resources required to execute an effective acclimation protocol can be expensive (core temperature monitoring), involve extensive equipment (heat chamber), and usually involve non-soccer-specific training (typically cycling) (Buchheit et al., 2011; Racinais et al., 2012; Chalmers et al., 2014). Therefore, the implementation of a field-based, sport-specific heat acclimatization protocol is more ecologically valid and practical for soccer players, while also minimizing time away from training often required for lab-based protocols. Indeed, field-based protocols, such as those utilized by Buchheit et al. (2011, 2013, 2016) and Racinais et al. (2012) previously in male soccer players, have highlighted the potential of repeated heat training exposures to elicit adaptations and offset the impedance of cardiovascular strain during exercise in the heat. This type of training also has the potential to improve sport performance in more temperate conditions (∼14–20°C) (Lorenzo et al., 2010; Corbett et al., 2014; Buchheit et al., 2016). Specifically, an enhanced sweat and skin blood flow response, as well as plasma volume (PV) expansion, provides greater cardiac output contributing to the ergogenic response (Lorenzo et al., 2010). This improved cardiac efficiency post-heat acclimatization was evident by reductions in heart rate (HR) during a submaximal running test (Buchheit et al., 2013, 2016). Therefore, it is important to understand how to utilize an effective field-based heat acclimatization protocol in order to preserve, or enhance, soccer performance in both extreme temperatures, as well as during more temperate conditions (Corbett et al., 2014).

While heat acclimatization (via natural environment) has proven to be effective to prepare male soccer players to perform in the heat (Buchheit et al., 2011, 2013, 2016; Mohr et al., 2012; Racinais et al., 2012), other than in female recreational team sport (Sunderland et al., 2008), there has been no research investigating this type of intervention with elite female players. Therefore, the primary purpose of this study was to investigate the response to a natural heat acclimatization camp in a top 10 globally ranked women's national team ahead of the Women's World Cup. This study implemented extensive training load and heat monitoring, as well as various blood measures and practical field-based performance tests.

MATERIALS AND METHODS

Athletes and Experimental Design

Nineteen international-level female soccer players (age: 27.0 ± 5.0 years, body mass: 65.7 ± 5.3 kg, height: 170 ± 6.0 cm, $\dot{V}O_{2Max}$: 53.1 ± 3.1 ml kg^{-1} min^{-1}) participated in the heat acclimatization (HA) protocol. Three players missed at least one session (injury/scheduling) and were excluded from the final analysis. The study was approved by the University of British Columbia Clinical Ethics Board and conformed to the Declaration of Helsinki. All athletes provided their written consent to participate in all training, monitoring, and testing protocols.

Players were not heat adapted prior to initial testing in April in Vancouver, Canada [mean $T_{ambient}$ ∼13°C, 72% relative humidity (RH)]. **Figure 1** highlights the full testing intervention, training, match, and rest days, over the 25-day period, including the 14-day HA period:

(i) Phase 1: 8 days in Los Angeles (22.1 ± 3.3°C; 45 ± 9% RH)
(ii) Phase 2: 6 days in Cancun (34.5 ± 1.2°C; 53 ± 4% RH)
(iii) Phase 3: 11 days in Toronto (18.2 ± 4.6°C; 51 ± 20% RH).

Hematological Parameter Assessments

The training program was adapted, and the athletes were asked to refrain from strenuous exercise and alcoholic and caffeinated drinks in the 12 h prior and to be well-hydrated on all testing days. Body mass was assessed upon arrival; after which, athletes rested in a seated position for 15 min prior to antecubital vein blood sampling. On the first testing occasion (baseline day−16), the optimized carbon monoxide rebreathing protocol was used to determine all hematological parameters (Schmidt and Prommer, 2005) (measured via blood gas analyzer: Radiometer ABL80 FLEX CO-OX analyzer, Denmark), as previously described by our laboratory (Pethick et al., 2019). The Dill and Costill equation (Dill and Costill, 1974) was then subsequently used to determine plasma volumes (PV) as a percent change from the absolute baseline measure.

Training Load and Player Monitoring

Morning urine specific gravity (USG; Atago PAL 10S refractometer) was monitored throughout (with baseline USG Z-scores being calculated from 26 samples for each player over 5 months). T_c was monitored throughout phases 1 and 2 using a VitalSense Telemetric Monitoring System (Mini Mitter, Philips Respironics, Eindhoven, Netherlands) and thermal sensor (Jonah™ Ingestible Core Temperature Capsule). All T_c data data were recorded for each athlete ∼4–6 times (every ∼15 min) throughout the training sessions. Verbal T_c feedback was provided to the players and coaches in phase, 1 but there was no specific target T_c. In phase 2, T_c feedback was provided to players and coaches with the goal to maintain a targeted T_c threshold (i.e., 38.5°C) during training sessions, as generally ∼38.5°C appears optimal for HA (Racinais et al., 2015; Periard et al., 2016; Pethick et al., 2018, 2019; Pryor et al., 2019). Area under the T_c curve or total heat load (AUC) and average ΔT_c were calculated as previously described by our laboratory (Pethick et al., 2019).

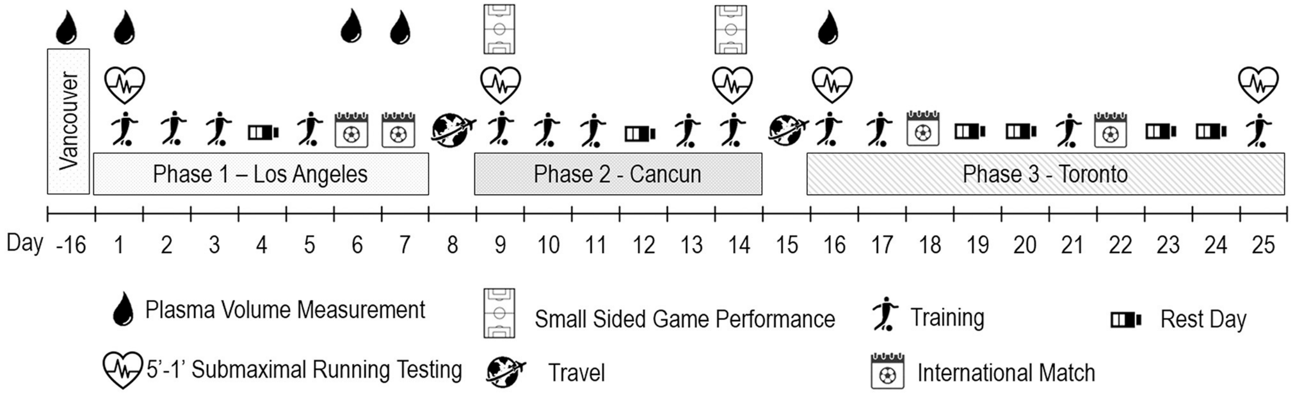

FIGURE 1 | Overview of the study design. Between day−16 and the start of the study, players return home in different places in Canada for a regeneration phase and remote training.

HR responses were gathered using a Polar Team2 System (1.4.1, Polar Electro Oy, Kempele, Finland), while ratings of perceived exertion (RPE; Borg Scale 1–10) were collected immediately post-session. Session RPE (sRPE) was calculated as a measure of session duration (minutes) multiplied by the RPE value (1–10), as validated for soccer (Impellizzeri et al., 2004). Ratings of thermal comfort (TC: scale of 1–5) and thermal sensation (TS: scale 0–9) were also collected (Young et al., 1987). Players wore a GPS unit incorporating a 100-Hz triaxial accelerometer (Catapult, MinimaxX S4 and Sprint 5.1 software, Australia) to record external training load (Varley et al., 2012). Player movement was categorized as total distance, and any efforts at speeds >16.5 km h^{-1} were recorded as high-speed efforts (Meylan et al., 2017). High Inertial Movement Analysis (High IMA) was categorized as accelerations, decelerations, or changes of direction that exceeded the threshold of 2.5 m s^{-2} (Meylan et al., 2017). As heat-induced blood volume expansion response can also be impacted by training load (Garvican-Lewis et al., 2014), sRPE was also recorded for 5 weeks prior to the HA intervention to establish normal training loads (**Figure 2**). However, between this 5-week block and the start of the HA (phase 1), players had a 12-day recovery phase, including 10 days at home, where they completed prescribed workouts. Actual training load was not recorded during that time, but sRPE was estimated based on historical responses to the session prescribed. Reported compliance of athletes while training at home was >95% of prescribed.

The 5-Min Running/1-Min Recovery Submaximal Running Test

A 5-min running/1-min recovery (5′-1′) submaximal test was performed during warm-up on five testing occasions (see **Figure 1**). Players were tested simultaneously at 12 km h^{-1} over a 40-m shuttle (Mohr et al., 2012). Mean exercise HR (HRex) during the last 30 s of the 5-min running period was recorded with HR recovery index (HRR; %) being calculated by taking the absolute difference between the HRex and the HR in the final 5 s of the recovery period as a percent of HRex. The reliability of the 5′-1′ submaximal running test was assessed on 13 members of the women's national team prior to the HA period on the same athletes across five occasions. Typical error was 2.5 bpm for HRex [confidence limits (CL): 2.03, 3.29], 8% for HRR (CL: 7, 10%), and 0.44 AU for RPE (CL: 0.37, 0.56).

Small-Sided Game Assessment

A total of four 2-min four-aside small-sided soccer games (4V4SSG) were performed on a reduced pitch (40 × 35 m) with a 2-min rest between games immediately following warm-up on the first (day 9) and last training day (day 14) of phase 2 (**Figure 1**). Athletes were familiarized with the 4v4SSG prior to the camps. HRex in the small-sided soccer game (SSG) was calculated as the average HR during each of the four SSG (excluding the 2-min rest period). HRR in the SSG was calculated by taking the absolute difference between (i) average HRex during each SSG and (ii) average HR 30 s prior to the next SSG during the 2-min recovery. This value was then divided by the average HRex from each SSG and multiplied by 100 to be expressed as a percentage. The total high IMA and distance were normalized to the 2-min SSG duration and averaged from game one to four to obtain an average game intensity (i.e., meters per minute and high IMA per minute).

Statistical Analysis

The effect of the HA was analyzed using one-way repeated measures analysis of variance (ANOVA) for the repeated metrics (absolute PV, submax HRR, HRex, RPE, and T_c pre-training) in R (version 3.4.2, Vienna, Austria). The Tukey honestly significant difference (HSD) *post hoc* procedure was used to control for type I error in making multiple comparisons, to identify the significance difference between conditions. The investigation of residual plots showed a random scatter of points, and the normality plots showed that the residuals fall on a straight line, indicating the normality assumption as appropriate for all metrics. Paired sample *T*-test was conducted with all SSG metrics as well as training variables between phases 1 and 2. The probability of a null effect was set at an alpha level of 0.05.

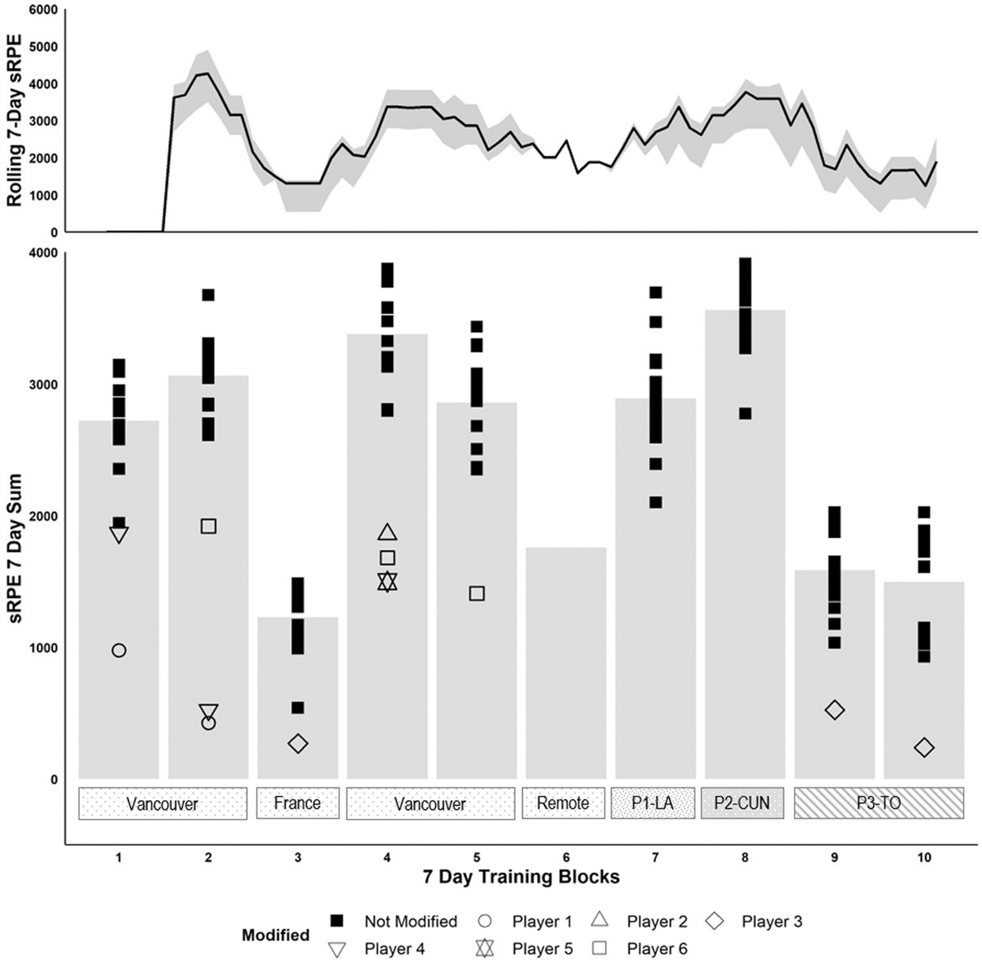

FIGURE 2 | Seven-day RPE rolling sum average (top) and RPE 7-day sum (bottom) across the 10-week world cup preparation. The shaded area in the top graph represents the maximum and minimum for the rolling 7-day sum average. Heat acclimatization occurred during phase 1 in Los Angeles (P1—LA) and phase 2 in Cancun (P2—CUN). Phase 3 was in Toronto in moderate climate (P3—TO).

The effect of the intervention was also provided as standardized effects (Hopkins et al., 2009). Uncertainty in the estimates of effects on laboratory and performance metrics was expressed as 90% confidence limits. Threshold values for assessing magnitudes of standardized effects (changes as a fraction or multiple of baseline SD) were 0.20, 0.60, 1.20, and 2.00 for small, moderate, large, and very large, respectively (Hopkins et al., 2009). These probabilities are not presented quantitatively but were used to make a qualitative probabilistic clinical inference about the effect in preference to a statistical inference based on a null hypothesis test (Hopkins et al., 2009). The effect was deemed unclear when the chance of benefit (a standardized improvement in performance of >0.20) was sufficiently high to warrant use of the intervention, but the risk of impairment was unacceptable (Hopkins et al., 2009). Such unclear effects were identified as those with an odds ratio of benefit to impairment of <66, a ratio that corresponds to an effect that is borderline possibly beneficial (25.0% chance of benefit) and borderline most unlikely detrimental (0.5% risk of harm) (Hopkins et al., 2009).

RESULTS

Training Load

Data in text and figures are presented as means (±SD) with 90% confidence limits (CL). **Figure 2** illustrates the 7-day rolling sum and 7-day weekly block sum of sRPE across 5 weeks prior to, during, and after the HA phases. The peak in 7-day moving average occurred during week 2 of training (4,202 ± 408 AU) and was nearly equivalent to the peak during the HA phase 2 (week 7: 3,630 ± 380 AU). Weeks 3, 9, and 10 were tapering weeks toward international matches and the World Cup. Week 6 was the remote training and sRPE weekly sum was estimated at 1,760 AU, which can be considered a de-loading/recovery week. **Table 1** and **Figure 3** outline the mean and daily variation in training for the phases 1 and 2. There was a small-to-moderate decrease in external load (e.g., total distance) from phase 1 to phase 2 ($p < 0.05$); however, there was a small-to-very large increase in internal load and thermoregulation from phase 1 to phase 2 ($p < 0.05$) (**Table 1**). It is important to denote that on

TABLE 1 | Descriptive (mean ± SD) and standardized differences in weather conditions, thermoregulation responses, and training load for the two phases of heat acclimatization.

	Phase 1—Los Angeles days 1–7	Phase 2—Cancun days 9–14	Standardized difference (90% ± CL)	*P*-value
Dry bulb temperature (°C)	22.1 ± 3.3	34.5 ± 1.2		
Wind speed (km/h)	2.8 ± 1.4	3.5 ± 0.9		
Relative humidity (%)	47.0 ± 13.0	53.2 ± 4.7		
Average across sessions				
Session end T_c (°C)	38.5 ± 0.2	38.6 ± 0.2†	0.59 ± 0.46*	0.040
Session ΔT_c (°C)	1.2 ± 0.3	1.5 ± 0.2†	0.80 ± 0.48**	0.007
Time $\Delta T_c > 1$°C (min)	33.1 ± 15.6	34.8 ± 13.7	0.19 ± 0.35	0.565
AUC heat load (AU)	82.2 ± 20.1	105.2 ± 22.3†	0.96 ± 0.43**	0.001
Thermal comfort (AU)	1.6 ± 0.4	3.3 ± 0.5†	2.25 ± 0.33****	< 0.001
Thermal sensation (AU)	5.5 ± 0.9	7.5 ± 0.6†	1.71 ± 0.30***	< 0.001
RPE (AU)	5.2 ± 0.6	7.0 ± 0.5†	2.21 ± 0.31****	< 0.001
Meters per minute	76 ± 7	71 ± 4†	−0.64 ± 0.41**	0.013
Sum across sessions				
Training duration (min)	492 ± 35	512 ± 21	0.53 ± 0.47*	0.069
Session RPE (AU)	2,407 ± 310	3,561 ± 293†	2.31 ± 0.40****	< 0.001
80–89% HRmax (min)	93 ± 22	115 ± 15†	0.88 ± 0.39**	< 0.001
90–100% HRmax (min)	61 ± 25	118 ± 17†	1.13 ± 0.39**	< 0.001
Total distance (km)	31.3 ± 3.5	24.8 ± 1.9†	−1.80 ± 0.42***	< 0.001
High-intensity efforts (count)	174 ± 43	145 ± 30†	−0.65 ± 0.27**	< 0.001
High IMA (m s^{-2})	557 ± 110	408 ± 95†	−1.47 ± 0.38***	< 0.001

*T_c, core temperature; AUC, area under the curve; HRmax, maximal heart rate; AU, arbitrary units; high-intensity efforts: >16.5 km h^{-1}; IMA, inertial movement analysis; high IMA, >2.5 m s^{-2}. Standarized effect: *small; **moderate; ***large; ****very large. †Significant difference between phase 1 and phase 2.*

days 6 and 7, international games were played, during which meters per minute were much higher because there were very limited stoppages compared to training sessions and players were disregarded if they were subbed out. However, in training sessions, all players were considered and training intensity varied based on coaching within a drill.

Plasma Volume

The mean team USG pre-HA on baseline PV testing (day−16) was 1.020 ± 0.005 (team *z*-score: +1.5 ± 2.0). The mean USG on PV testing on day 1 and day 6 or 7 were 1.014 ± 0.005 (mean *z*-score: +0.1 ± 1.2) and 1.011 ± 0.005 (mean *z*-score: −0.2 ± 0.7), respectively. The mean USG post-HA (day 16) was 1.013 ± 0.005 (mean *z*-score: +0.1 ± 0.8). **Figure 4** outlines the change in PV from the absolute average baseline measure via CO re-breathing methodology at day−16 in Canada [PV: 3,935 ± 440 ml (63.5 ± 4.9 ml/kg); BV: 6,561 ± 663 ml; HBmass: 774 ± 88 g (11.8 ± 1.3 g/kg)]. Absolute ($p = 0.351$) and relative ($p = 0.130$) PV changes were non-significant (*F* value = 1.114 and 1.965, respectively). However, there was a small decrease in PV from day−16 (baseline) to day 1 (phase 1 start) (SE = −0.43; CL: −0.66, 0.20). From day 1 to days 6 and 7 (end of phase 1), there was a large increase in PV (SE = 0.64; CL: 0.99, 0.29). From day 1 to day 16 (end of phase 2), there was a large positive increase in PV (SE = 0.63; CL: 0.34, 0.93), and this expansion occurred primarily in phase 1, as the change in PV from days 6 and 7 to day 16 was trivial.

Core Temperature

Changes in resting T_c at the start of training were used to further quantify thermoregulation adaptations during the HA phase (*F* value = 17.97). Resting T_c in day 1 was 37.5 ± 0.18 in Los Angeles and dropped by 0.47 ± 0.13°C (SE = −2.45; −1.24 ± 0.34%; CL: −3.11, −1.78; $p < 0.001$) by day 14 in Cancun. Over the 5 days in Cancun, resting T_c dropped by 0.22 ± 0.10°C (SE = −1.13; −0.58 ± 0.25%; CL: −1.64, 0.50; $p = 0.003$).

Submaximal Exercise Performance

Figure 5 outlines the change in 5′-1′ submaximal running performance from day 1 to assess the change in HRex (170 ± 11 bpm), HRR (39 ± 6%), and RPE (3.5 ± 1.3 AU) during HA. HRex did not show any significant changes across the testing occasion (*F* value = 0.95) while HRR and RPE did (*F* value = 2.72 and 7.94, respectively). From day 1 to day 9 (phase 2 start), there was a small increase in HRex (SE = 0.45; CL: 0.32, 0.57; $p = 0.442$), a moderate decrease in HRR (SE = −1.02; CL: −1.38, −0.67; $p = 0.037$), and a moderate increase in RPE (SE = 1.00; CL: 0.53, 1.47; $p = 0.003$). Following five HA sessions over 6 days in phase 2 (days 9 to 14), there were no significant changes in the variables of interest ($p > 0.05$), but the standardized effect indicated a small decrease in HRex (SE = −0.49; CL: −0.67, −0.31) and a small increase in HRR (SE = 0.53; CL: 0.04, 1.02) while RPE remained consistent (AU = 4.7 ± 0.9 to 4.9 ± 0.9). From the end of phase 2 on day 14 to day 16 (start of phase 3), there were no significant changes in the various metrics ($p >$

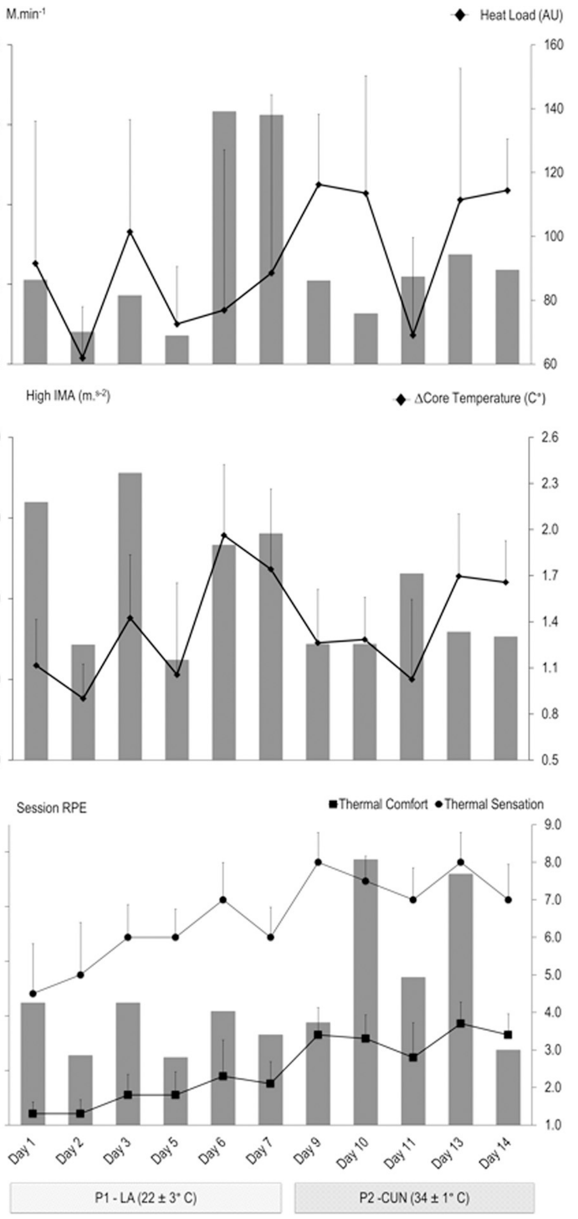

FIGURE 3 | Daily variations in training load and heat stress response during phase 1 in Los Angeles (P1—Los Angeles) and phase 2 in Cancun (P2—Cancun). There was no training on days 4, 8, and 12. Days 6 and 7 were international friendlies.

0.05) and SE analysis only revealed a small decrease in RPE (SE = −0.41; CL: −0.65, −0.18). There was also a moderate increase, yet not significant ($p = 0.486$), in RPE (SE = 0.45; CL: 0.03, 0.88) from day 1 to day 16. From day 1 to day 25 (end of phase 3), even though not significant, there was a moderate decrease in HRex (SE = −0.42; CL: −0.52, −0.3; $p = 0.442$) and a moderate increase in HRR (SE = 0.37; CL: −0.17, 0.92; $p = 0.999$), while RPE was similar to what was observed on day 1 during initial testing (SE = −0.04; CL: −0.41, 0.33; $p = 0.004$).

Small-Sided Games

Figure 6 outlines the standardized differences between the 4v4SSG at the start (day 9) and end (day 14) of phase 2. HRex and HRR were both different from days 9 to 14 with HRex decreased (−3.5 bpm; CL: −5.5, −1.6; $p = 0.007$) and HRR increased (5.7 ± 1.6%; CL: 4.1, 7.4; $p < 0.001$). Additionally, there was an increase in high IMA activity (20.1%; CL: 6.6, 35.2; $p = 0.015$) but not in meters per minute (−4.7%; CL: −9.6 to 0.7; $p = 0.144$), although both changes were small.

DISCUSSION

Our study is the first to investigate the effect of a field-based heat acclimatization protocol on PV, submaximal HR responses (as a marker of cardiovascular adaptations), and core temperature monitoring within soccer-specific, performance-based testing protocols in international female soccer players. The key finding was that a practical real-world HA camp induced relevant improvements in sport-specific performance metrics (**Figure 6**), although some of these positive adaptive responses were delayed coming out of the HA camp (**Figure 5**). These changes occurred along with a non-significant trend for PV expansion, which may be associated with high inter-athlete variability.

Previous findings in male soccer players (Buchheit et al., 2011, 2013, 2016; Racinais et al., 2012) show that heat acclimatization can lead to an increase in PV and were corroborated in elite female soccer athletes in the current study, although the PV change failed to reach significance (**Figure 4**). Laboratory studies utilizing controlled hyperthermia acclimation protocols have reported PV increases of 4–15%, improving cardiovascular stability via maintenance of cardiac output and reductions in HRex, leading to performance enhancement (Chalmers et al., 2014; Periard et al., 2015, 2016; Racinais et al., 2015; Casadio et al., 2017; Benjamin et al., 2019; Pryor et al., 2019). While laboratory HA protocols are more controlled, they are less practical and potentially less effective than field-based HA, which has been shown to induce better peripheral adaptations from sport-specific training and better maintenance of skills (Pryor et al., 2019). Collectively, four field-based HA protocols utilizing team sport players demonstrated a mean PV expansion of 5.4% (Buchheit et al., 2011, 2013, 2016; Racinais et al., 2012), similar to the current study's trend of 7.4 ± 3.6% across phase 1 (LA) and phase 2 (Cancun; **Figure 4**). This would be a similar PV expansion to what we found during an indoor heat acclimation study in some of the same athletes, where we demonstrated ∼9% PV increase (Pethick et al., 2018). Additionally, some soccer-specific, field-based HA protocols have previously demonstrated improved sport performance following HA (Sunderland et al., 2008; Buchheit et al., 2011, 2013). In two different studies featuring natural heat acclimatization, Buchheit et al. (2011, 2013) reported increases in PV following both 1 week (7%) and 2 weeks (5.6%) of HA, which translated into substantial improvements in athletic performance with the greater improvement seen with the longer HA protocol (+7 vs. 44% in YOYOIR2, respectively). It should be noted that beyond sex-based differences (male vs. female players

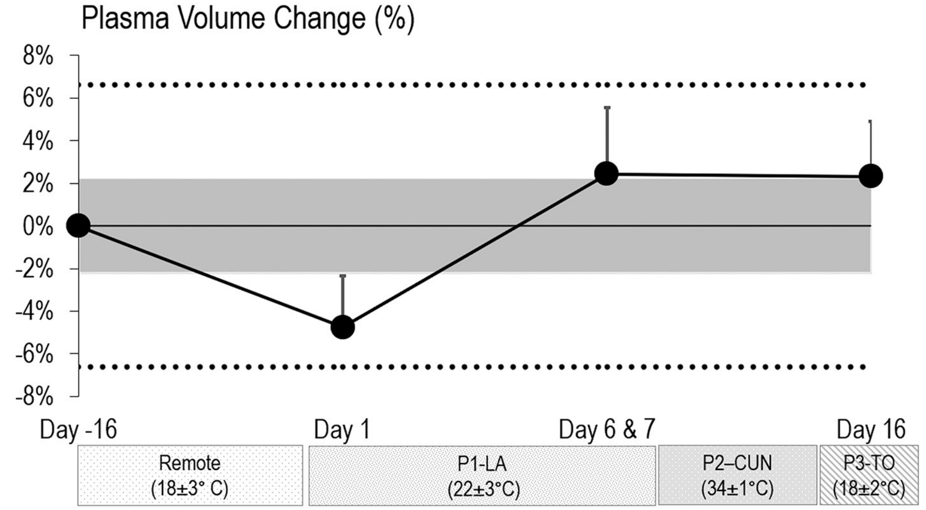

FIGURE 4 | Plasma volume change from baseline testing (day−16) to each follow-up test occasion on day 1 and day 6/7 in Los Angeles (P1—LA) and day 16 in Toronto (P3—TO). No blood draw occurred during phase 2 in Cancun (P2—CUN). The shaded area represents trivial changes, and the dash line represents the lower limit for moderate changes [<0.20, >0.60, and >1.20 of baseline between-subject standard deviation (SD)]. Bars are SDs of changes from baseline to day 6/7 and baseline to day 16. None of the changes were significant ($p > 0.05$).

in the current study), the significant findings of the prior heat acclimatization studies (Buchheit et al., 2011, 2013, 2016; Racinais et al., 2012) all featured longer durations in high heat (7–14 days) and higher heat stress (up to 43°C) compared to the current study.

The present findings suggest a meaningful 7.4 ± 3.6% increase in PV from the start of phase 1 to the end of day 16 (Cancun; **Figure 4**). Indeed, this potential shift in PV was probably caused by a combination of increases in training load after the 10 days recovery remote phase and throughout the 7 days of phase 1, as there is evidence that physical training alone induces PV expansion in elite endurance athletes (Garvican-Lewis et al., 2014; Bejder et al., 2017). However, exercise alone is certainly not solely responsible for this PV expansion, as there was significant heat stress throughout phase 1 in LA, as demonstrated by the various elevated T_c metrics during phase 1 (**Table 1**) as well as the drop in resting T_c, a key indicator of HA (Periard et al., 2015, 2016; Racinais et al., 2015). Interestingly, despite phase 2 being significantly warmer than phase 1, there did not appear to be further PV expansion, probably due to the fact that the players were already at the peak of their aerobic fitness and had endured a large training load in preparation for the World Cup (**Figure 2**). Indeed, the athletes' ability to expand PV to an even greater extent may have been limited by a potential ceiling effect, as it has been previously demonstrated that a low baseline PV was a significant predictor of HA-induced increases in PV (Pethick et al., 2019). While further studies are needed to more clearly establish the effects of PV expansion and the ergogenic potential of HA in field-sport/team athletes, even minor physiological improvements are likely to benefit athletic performance at the international level (Malcata and Hopkins, 2014).

The literature has consistently demonstrated improvements in submaximal exercise performance following HA characterized by a reduced HRex and an increased VO_{2max} (Periard et al., 2016). However, the evidence for observed improvements specifically in HR response during submaximal field sport testing in elite athletes is more limited (Buchheit et al., 2011; Racinais et al., 2014, 2015). In line with previous literature in elite male soccer players (Buchheit et al., 2011), our data also demonstrated meaningful improvements in HR response (**Figure 5**) in international female soccer players during submaximal running pre-post HA; however, this same study found no improvement in HRR (Buchheit et al., 2011). This limited response in HRR was suggested to be the result of using low running speeds during the test (9 km h^{-1} instead of 12 km h^{-1}) and by extension lower HRs, for the elite-level players (Buchheit et al., 2011). By contrast, the current study implemented the higher running speed of 12 km h^{-1} and did find an improvement in HRR. Thus, the 5′-1′ submaximal running test used in the current study was effective in tracking both HRR and HRex to monitor HA-induced cardiovascular adaptations throughout the various phases. As outlined in **Figure 5**, initial submaximal performance during phase 2 (day 9 ∼34°C) was more stressful than during the mild conditions in phase 1 (day 1 ∼22.1°C). Likewise, Buchheit et al. (2016) observed an increase in RPE during HA (34.9°C) when athletes underwent a 12-°C increase in temperature over 2 days. After six days, players in the current study acclimatized aerobically to the heat as evidenced by the internal response (HR and HRR) to submaximal running by the end of phase 2 (day 14) returning to similar levels as at the start of phase 1 (**Figure 5**). Therefore, in support of previous findings, both cardiovascular and perceptual adaptation can be

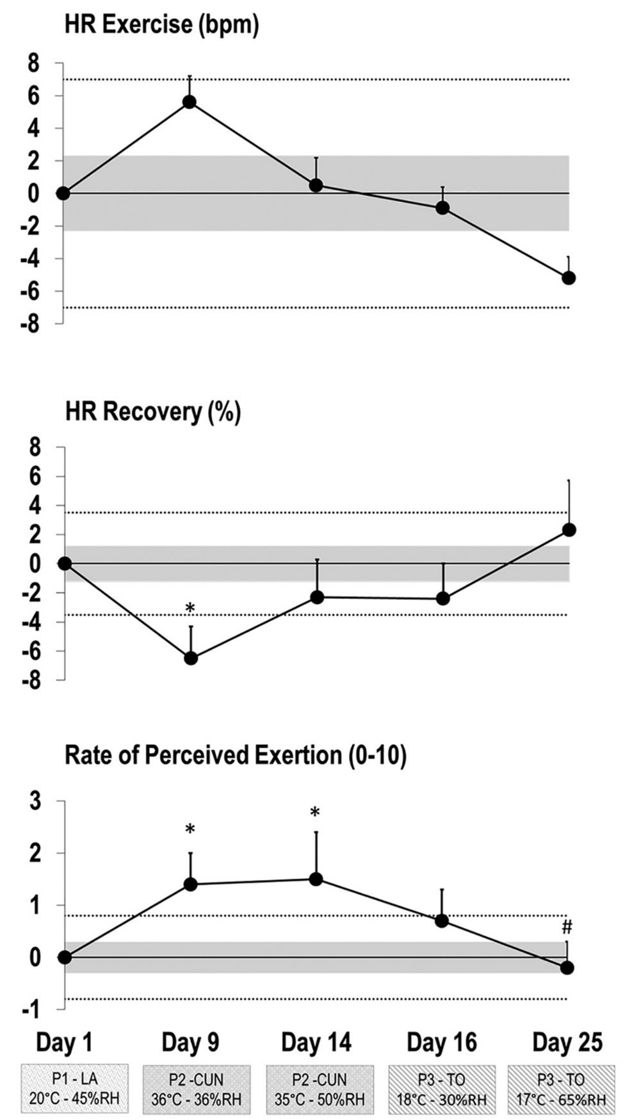

FIGURE 5 | Changes in heart rate (HR) response and rate of perceived exertion (RPE) during the 5′-1′ submaximal running test at each time point compared to day 1 in Los Angeles (P1—LA).The shaded area represents trivial changes, and the dash line represents the lower limit for moderate changes [<0.20, >0.60, and >1.20 of baseline between-subject standard deviation (SD)]. Bars are SDs of changes from baseline to the ensuing testing occasions during phase 2 in Cancun (P2—CUN) and phase 3 in Toronto (P3—TO). *Significant difference from LA ($p < 0.01$); #significant difference from CUN 1 and 2.

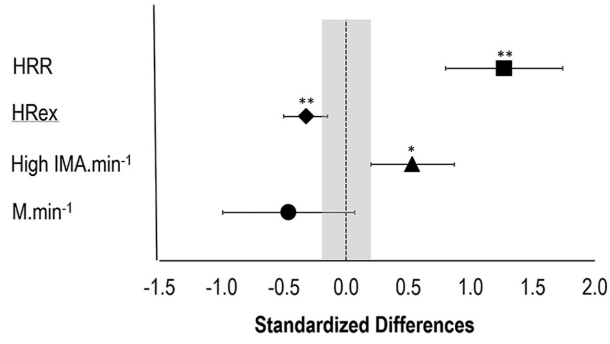

FIGURE 6 | Standardized differences (±90% confidence intervals) in physical performance during a four-a-side small-sided soccer game played in phase 2 in Cancun on day 9 (36°C–36% RH) and the last day of phase 2 on day 14 (35°C–50%RH). The shaded gray area represents trivial differences (i.e., <0.20). *Significant difference ($p < 0.05$ and $^{**}p < 0.01$) between day 9 and day 14. HRR, HR recovery; HRex, HR at exercise; high IMA min^{-1}, number of high inertial movement action (>2.5 m s^{-2}) per minute; m min^{-1}, meters per minute.

observed in as little as five field-based HA sessions (Chalmers et al., 2014; Periard et al., 2016).

A novel finding from the submaximal test was the large improvement in HR response observed 11 days post-HA in a temperate condition (**Figure 5**; day 25). This finding challenges previous research suggesting that competitive athletes may only retain HA for up to 1 week (Pandolf, 1998); it also highlights the importance of a submaximal retest up to 2 weeks post-HA, since the fitness gains may not be complete for several days post-acclimation and/or athletes needs to shed fatigue from the extra training stress induced by a hot environment (**Table 1**). This finding is further supported by Buchheit et al. (2016) who utilized a 4-min submaximal test (12 km h^{-1}) before, immediately post, and 3 days after a HA camp and found that the greatest reduction in HR response did not occur immediately, but 3 days following the camp. This delayed cardiovascular/aerobic adaptation post-HA could be partly attributed to an improvement in neuromuscular efficiency after recovering from HA (Buchheit et al., 2016). Furthermore, a recent study has shown that intense training in the heat can cause impairments in performance, most probably due to the added environmental stress causing early signs of over-reaching (Reeve et al., 2019). Although external training load was less in phase 2 than phase 1 (**Figure 3**), internal load (e.g., time above 90% HRmax) was actually greater. Previous evidence has shown increased sympathetic activity and a reduced vagal activity during periods of intensified load (Baumert et al., 2006), which could have affected the HR response to submaximal exercise. These effects are typically a result of over-reaching and are known to resolve after 3–4 days of recovery (Baumert et al., 2006; Buchheit, 2014). Studies have shown that physical fitness typically plateaus at the final stages of in-season training (Clark et al., 2008). This suggests that the markers of improved aerobic capacity in the current study are not exclusively due to a training adaptation, due to the fact that players were at their highest aerobic fitness (2 weeks before the FIFA World Cup), but due to the additional stimulus of HA. The optimal time to engage in HA without having to re-acclimate before a competition is still uncertain and requires further investigation, although some aspects of heat periodization, and retention, are starting to emerge in the literature (Casadio et al., 2016, 2017).

Small-sided soccer games have been validated as an effective test for replicating match play as the smaller field dimensions allow for continued ball contact and short intermittent running in order to attain similar cardiovascular, mechanical, and technical demands as in competitive matches (Dellal et al., 2011; Lacome et al., 2018). Just five training sessions in hot conditions (phase 2) induced meaningful heat adaptation that improved the density of explosive actions and associated HR response and recovery during and between 4v4SSG (**Figure 6**). The small and non-significant decrease in average intensity (meters per minute) could be a response to the players choosing to be more explosive and to cover less distance at low speed to achieve more ball interactions due to greater comfort and lower HR response in the heat (Dellal et al., 2011; Lacome et al., 2018). Those locomotive changes are unlikely to be a response to coaching as the SSG was set up to be free play and did not have any explicit or implicit coaching cues. By design, 4v4SSG is characterized by a greater density in explosive actions than match play or bigger SSG (Lacome et al., 2018), and it could be argued that an increase in high IMA is more relevant to a positive locomotive change in a 4v4SSG as compared to meters per minute. Still, SSGs provide a valid replication of the performance physical demands of competitive match play under more control conditions (e.g., limited ball out of play, less players, and no set pieces) and allow for a meaningful interpretation of soccer match performance, when an environmental factor such as heat is added to training (Fenner et al., 2016).

With this training camp occurring only 2 weeks prior to the FIFA World Cup, we were unable to include a control group. Therefore, the observed ergogenic effect of HA in the current study may be confounded by the effects of training load, travel fatigue, changes in sleep, recovery, diet, and motivation. Another limitation was the inability to control for the effect of menstrual phase as this has previously been shown to affect the T_c response in females (Fortney et al., 1994; Logan-Sprenger et al., 2012).

There are also a number of factors that can impact the increase in PV including (i) the acclimatization day when PV is measured; (ii) the type of method used to measure PV; (iii) the hydration state when measured; (iv) T_{skin} at the time of measure; and (v) fluctuation in training load (Sawka et al., 1984; Periard et al., 2016). However, beyond environmental strain, training load is also a significant impactor of PV responses, and thus, our study took a lot of care to characterize the training loads throughout the entire study (**Table 1**). Indeed, there was not a significant difference between phase 1 and phase 2 for total training duration, and phase 2 actually featured significantly less total distance run and high-intensity efforts (**Table 1**), and we therefore believe most of the outcomes are due to the heat stress, and not training volumes, and associated cardiovascular responses to heat (as shown by higher HR's during phase 2). While there was a positive increase in PV overall, the lack of consistent elevation of T_c at a target threshold on a daily basis during phase 2 training likely limited the increase in total body water. It is also possible that athlete hydration status within each training session may have impacted the extent of PV expansion, as hydration level can cause fluid shifts between the circulatory system and interstitial spaces during exercise in the heat (Sawka et al., 1984). While we were able to use a consistent sampling site while measuring PV, we were unable to account for the change in fluid intake throughout both phases of acclimatization. Furthermore, Hct and Hb are highly responsive to changes in plasma osmolality; therefore, the inability to effectively monitor plasma osmolality via fluid intake may have resulted in a larger variation of Hct during the training camp, which in turn would have largely impacted the accuracy of blood sampling and the overall change in PV (Kavouras, 2002; Watson and Maughan, 2014). However, the average USG values in athletes on blood testing days were within the norms of adequate hydration status.

There are also several methodological limitations to using the Dill and Costill method as opposed to the CO rebreathing method, which has proven to be more effective in reporting consistent and accurate values of PV (Schmidt and Prommer, 2005; Alis et al., 2015). While it would have been preferential to continue to use the CO rebreathing method beyond baseline testing and within both phases of the training camp, this method requires a longer protocol (∼30–40 min per athlete), and we wanted to limit the time taken out of an athlete's schedule prior to competition. Therefore, the CO rebreathing technique was only utilized to obtain an absolute baseline for which the percentage change in PV was determined throughout the remainder of the camp.

CONCLUSION

The present research provides an insight on the efficacy of a 2-week field-based HA protocol to elicit physiological adaptations and improved physical performance-related metrics, with ergogenic effects demonstrated in both temperate and hot conditions. The current findings support the use of daily, on-field training load monitoring of GPS external load, HR metrics, T_c and heat load real-time monitoring, and session RPE to monitor intensity and adaptations within HA. It is also recommended that athletes perform a sport-specific measure of performance, and while the current study utilized a 4v4SSG, it could be more effective to utilize eight players over a larger field dimension (8v8SSG) and to use 6–8-min small-sided games instead of 2-min games. Furthermore, due to potential immediate residual fatigue from heat, monitoring physiological and performance metrics during HA for up to 2 weeks post-HA is recommended. In terms of performance, there is no current evidence of neuromuscular fatigue monitoring in combination with HR response during HA, which could potentially be used as a secondary method to monitor the fatigue induced by environmental heat stress, allowing one to fully understand the periodization puzzle of HA integration in preparation for a major event.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of British Columbia Clinical Ethics Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CM, KB, WP, and JT were all involved in the data collection and processing of the data. Data analysis was primarily conducted by CM, KB, TS, and MK. All authors took part in the design of the study and contributed to manuscript write up and final edits.

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Sprint Mechanical Characteristics of Female Soccer Players: A Retrospective Pilot Study to Examine a Novel Approach for Correction of Timing Gate Starts

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The purpose of this study was to compare model estimates of linear sprint mechanical characteristics using timing gates with and without time correction. High-level female soccer players ($n = 116$) were evaluated on a 35-m linear sprint with splits at 5, 10, 20, 30, and 35 m. A mono-exponential function was used to model sprint mechanical metrics in three ways: without a time correction, with a fixed (+0.3 s) time correction, and with an estimated time correction. Separate repeated-measures ANOVAs compared the sprint parameter estimates between models and also the residuals between models. Differences were identified between all modeled sprint mechanical metrics; however, comparable estimates to the literature occurred when either time correction was used. Bias for both time-corrected models was reduced across all sprint distances compared to the uncorrected model. This study confirms that a time correction is warranted when using timing gates at the start line to model sprint mechanical metrics. However, determining whether fixed or estimated time corrections provide greater accuracy requires further investigation.

Keywords: mono-exponential function, maximum acceleration, maximum sprint speed, power, force

INTRODUCTION

The assessment of sprint mechanical properties has become popular since a simple method for estimating force, power, and mechanical efficiency was recently published (Samozino et al., 2016; Morin et al., 2019). The outcomes from using this model have potential value for sports scientists by helping identify limitations of short sprint performance as well as to evaluate return to play for injured athletes (Mendiguchia et al., 2014; Morin and Samozino, 2016; Haugen et al., 2019). To date, the literature provides descriptions of sprint mechanical characteristics of male (Buchheit et al., 2014; Samozino et al., 2016; Morin et al., 2019; Edwards et al., 2020) and female (Jiménez-Reyes et al., 2018; Haugen et al., 2019, 2020b; Marcote-Pequeno et al., 2019) athletes for a wide range of sports, but variation in the hardware used to capture sprint performance could influence the modeled kinetic parameters.

The use of force plates is considered the gold standard for assessing mechanical properties of sprinting; however, there are logistical and financial restrictions to capturing the profile of an entire sprint with force plates (Samozino et al., 2016; Morin et al., 2019). Radar and laser technology are more commonly used field-based methods by researchers (Buchheit et al., 2014; Jiménez-Reyes et al., 2018; Marcote-Pequeno et al., 2019; Edwards et al., 2020) but not readily accessible or practical for most practitioners working in sports. To efficiently assess sprint ability within a team setting, the majority of practitioners use timing gates positioned at various distances. Some researchers have incorporated timing gates for sprint testing (Buchheit et al., 2014; Haugen et al., 2019, 2020b) and used the split times to subsequently model force-velocity properties (Samozino et al., 2016; Morin et al., 2019).

The vast majority of practitioners evaluating sprint qualities of athletes use timing gates. There is an inherent limitation when using timing gates to estimate sprint mechanical factors because of the lag time between the first instance of force generation and when the timing gates are initially triggered (start of sprint timing). This lag time results in overestimated parameter estimates for several of the derived metrics (e.g., force, power). In an attempt to resolve this issue, a fixed time correction (+0.5 s) has been recommended (Haugen et al., 2019, 2020b) but not always applied in the literature when using timing gates (Buchheit et al., 2014; Rakovic et al., 2018; Haugen et al., 2020a). Interestingly, the mean difference in duration between timing gates and a block start for 40 m sprint time was +0.27 s (Haugen et al., 2012), but the fixed time correction based on this evidence was nearly two times greater (Haugen et al., 2019, 2020b). Therefore, although a time correction is warranted when using timing gates to avoid errors in estimated kinetic variables, care should be taken when applying one that may be too large that could potentially have the opposite effect (e.g., underestimate power, force). Additionally, implementing a fixed time correction implies that all individuals require an identical correction. Individualizing the time correction is also possible by including it as an estimated parameter within the current model (Samozino et al., 2016; Morin et al., 2019). A recently published study was the first to apply this approach during on-ice sprints with hockey players (Stenroth et al., 2020). However, researchers and practitioners should avoid the assumption that outcomes from male hockey players sprinting on the ice can be directly applied to female athletes sprinting on turf.

Therefore, the purpose of this pilot study was to estimate force-velocity profiles (Samozino et al., 2016; Morin et al., 2019) for female soccer players using timing gates and compare outcomes from three models: without a time correction, with a fixed (+0.3 s) time correction, and with an estimated time correction.

MATERIALS AND METHODS

This was a retrospective analysis using a subset of existing data from high-level female soccer players from the United States ($n = 116$, 23.6 ± 2.4 yr, 167.4 ± 6.4 cm, 62.3 ± 7.0 kg) (data from a randomly selected portion of players was used in exploratory analysis and not included in the current study). Ethics approval was provided by an institutional review board, and all athletes signed consent prior to participation. The protocol for assessing linear sprint speed has been described previously (Vescovi, 2012, 2014, 2016). Briefly, all athletes performed a standardized warm-up (∼15 min) that included general exercises, such as jogging, shuffling, multidirectional movements, and dynamic stretching exercises. Infrared timing gates (Brower Timing, Utah) were positioned at the start line and at 5, 10, 20, 30, and 35 m at a height of ∼1.0 m. The sprint distance and splits were chosen to enable maximal speed to be achieved and assessed. Participants stood with their lead foot positioned ∼5 cm behind the initial infrared beam (i.e., start line). Only forward movement was permitted (no leaning or rocking backward), and timing started when the laser of the starting gate was triggered. This start technique eliminates the potential for a "flying" or "rolling" start. The best 35-m time and all associated split times were kept for analysis. The assessment of linear sprints using infrared timing gates does not require familiarization (Moir et al., 2004).

Sprint Modeling

Short sprints have been modeled using a mono-exponential function (Equation 1.1) (Furusawa et al., 1927), which has become recently popularized (Samozino et al., 2016; Clark et al., 2019). Equation (1.1) represents the function for instantaneous horizontal velocity (v) given time (t) and two model parameters:

$$v(t) = MSS \times (1 - e^{-\frac{t}{TAU}}) \tag{1.1}$$

The parameters of Equation (1.1) are maximum sprinting speed (MSS = m/s) and the time constant (TAU). Mathematically, TAU represents the ratio of MSS to maximum acceleration (MAC = m/s/s) (Equation 1.2):

$$MAC = \frac{MSS}{TAU} \tag{1.2}$$

For split times, distance is the predictor, and time is the outcome variable; thus, Equation (1.1) becomes

$$t(d) = TAU \times W(-e^{\frac{-d}{MSS \times TAU}} - 1) + \frac{d}{MSS} + TAU, \tag{1.3}$$

where (W) in Equation (1.3) represents Lambert's W function (Goerg, 2020).

When using timing gates, a time correction is required because of the lag time between the first instance of force generation and when the timing gates are initially triggered. Without accounting for this lag time the model estimates are inaccurate. Equation (1.3) becomes

$$\begin{aligned} t(d) &= TAU \times W(-e^{\frac{-d}{MSS \times TAU}} - 1) + \frac{d}{MSS} + TAU \\ &- time\ correction \end{aligned} \tag{1.4}$$

The time correction in Equation (1.4) can be provided as a fixed correction that is selected a priori (Haugen et al., 2012, 2020a), or it can be estimated within the model along with TAU and

MSS parameters. The current study implemented a fixed (+0.3 s) time correction as well as an estimated time correction. The fixed correction duration chosen was lower than the previous recommendation based on the following: The average difference for 40-m sprint duration between block starts (capture initial force production) and timing gates is +0.27 s (Haugen et al., 2012). In addition, studies using +0.5 s time correction placed the initial pair of timing gates 60 cm in front of the start line (Haugen et al., 2019, 2020b). Compared with the rolling start, the start procedure in the current study would be expected to result in a shorter duration between initial force production and start time.

Sprint split time data were analyzed separately for each participant with model parameters, force-velocity profiles, and derivative metrics (i.e., force-velocity slope, maximal ratio of force [RFmax], and rate of decrease in RF [DRF]) (Morin and Samozino, 2016) estimated by following previous methods (Samozino et al., 2016; Morin et al., 2019) using the "shorts" package (Jovanović, 2020; Jovanović and Vescovi, 2020) written in R language (R Development Core Team, 2020). The "shorts" package uses non-linear least squares regression implemented in the "nls" function in R (Bates and Watts, 1988; Bates and Chambers, 1992). Both R and the "shorts" package are open-source software.

Statistical Analysis

Repeated-measures ANOVAs compared each sprint mechanical metric between models. Repeated-measures ANOVAs were also used to compare residual errors between the predicted (modeled) and observed duration for each distance. The average residual error values are reported as the bias. An LSD *post hoc* analysis was used to identify pairwise difference when main effects were observed. Statistical significance was accepted at $p < 0.05$. Cohen's d provided the effect size (ES) for pairwise comparisons (Cohen, 1988) and were considered trivial (<0.2), small (0.2–0.6), moderate (0.61–1.20), large (1.21–2.0), and very large (2.1–4.0) (Hopkins et al., 2009). Pearson product correlations were used to examine the relationship between the estimated time correction value and the associated outcome parameters for maximal acceleration and maximal sprint speed. Data are presented as mean (SD). Statistical procedures were performed using SPSS version 20.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Unadjusted sprint durations from the timing gates were 1.20 (0.08) s, 2.00 (0.09) s, 3.39 (0.13) s, 4.71 (0.17), and 5.36 (0.22) s for the 5, 10, 20, 30, and 35 m distances, respectively. The estimated time correction was +0.25 (0.09) s.

Table 1 provides the sprint mechanical parameters and derivative metrics for the three models. All main effects ($p < 0.001$) and pairwise comparisons ($p < 0.001$) revealed differences between the models for each of the variables. Effect sizes between the uncorrected model and both time-corrected models were moderate ($d = 0.97$–1.15 for V0) and very large ($d = 2.67$–4.33 for all other parameters). The effect sizes between the time-corrected models were moderate ($d = 0.64$–0.67 for FV Slope and RFmax) and small ($d = 0.22$–0.59 for all other parameters).

Figure 1 includes the bias (SD) for each model grouped by distance. There were main effects ($p < 0.001$) for each distance with differences for all pairwise comparisons ($p < 0.001$). Effect sizes were large to very large for 5–20 m ($d = 1.2$–3.4), small for 30 m ($d = 0.20$–0.24), and large for 35 m ($d = 1.47$–1.62) when comparing the uncorrected model against both models with time correction. Effect sizes between the two models with time correction were trivial to moderate ($d = 0.06$–0.65).

Table 2 shows the maximum acceleration and maximum sprint speed values for the uncorrected, fixed time correction, and estimated time correction models. There was a main effect for acceleration ($p < 0.001$) with differences found for all pairwise comparisons ($p < 0.001$). The effect sizes for the model with no time correction and the other maximal acceleration values were very large and between the time-corrected models was moderate. There was also a main effect for maximum sprint speed ($p < 0.001$) with differences found for all pairwise comparisons ($p < 0.001$). The effect sizes between the model with no time correction and both time-corrected models were moderate, whereas it was trivial between the two time-corrected models.

Figure 2 shows the scatterplots between the estimated time correction value and the corresponding maximal acceleration and maximal sprint speed parameter outcomes. There was a strong linear relationship between the time correction value and maximal acceleration ($r = -0.564$, $p < 0.001$) but no correlation with maximal sprint speed ($r = 0.119$, $p = 0.21$).

DISCUSSION

The current study extends the findings of other researchers and demonstrates the model with no time correction produced substantially different estimates of sprint mechanical parameters in female soccer players when using timing gates. The outcomes uniquely highlight that fixed (+0.3 s) and estimated time corrections (0.25 ± 0.09 s) improved these estimates, which were better aligned with values previously reported in the literature for similar cohorts. Furthermore, bias was substantially reduced for both time-corrected models.

To obtain accurate estimates from timing gate input with this method (Samozino et al., 2016), the start time needs to be very closely associated to initial force production into the ground. As expected, the uncorrected model outcomes displayed substantially different values compared with the outcomes from both time-corrected models (**Table 1**). The time corrected models provided estimates that were closely aligned with previous studies reporting on female soccer players (Jiménez-Reyes et al., 2018; Haugen et al., 2019, 2020b; Marcote-Pequeno et al., 2019). The observed differences with studies that also used timing gates is likely a result of the start procedure and time correction that was used. One group of researchers has implemented two types of timing systems and two types of starts (both approaches were simultaneously assessed and demonstrated no differences in 40 m

TABLE 1 | Sprint mechanical metrics from current study and other studies with female soccer players.

Study	TAU (s)	F0 (N/kg)	V0 (m/s)	Pmax (W/kg)	FV Slope (N/s/m/kg)	RFmax (%)	DRF (%)
Current							
No time correction	0.68 (0.12)	11.2 (1.7)	7.61 (0.38)	21.3 (3.3)	−1.48 (0.25)	59 (3)	−13.2 (2.1)
Fixed time correction	1.20 (0.18)	6.6 (0.8)	8.14 (0.53)	13.4 (1.5)	−0.81 (0.12)	46 (3)	−7.6 (1.1)
Estimated time correction	1.10 (0.16)	7.1 (0.9)	8.03 (0.48)	14.2 (1.8)	−0.89 (0.13)	48 (3)	−8.2 (1.1)
Statistics (*p*-value, d)							
No correction vs. fixed	<0.001, 3.40	<0.001, 3.46	<0.001, 1.15	<0.001, 3.08	<0.001, 3.42	<0.001, 4.33	<0.001, 3.34
No correction vs. estimated	<0.001, 2.97	<0.001, 3.01	<0.001, 0.97	<0.001, 2.67	<0.001, 2.96	<0.001, 3.67	<0.001, 2.98
Fixed vs. estimated	<0.001, 0.59	<0.001, 0.59	<0.001, 0.22	<0.001, 0.48	<0.001, 0.64	<0.001, 0.67	<0.001, 0.55
Marcote-Pequeno et al. (2019) (Radar)		6.3 (0.4)	8.12 (0.44)	12.7 (1.2)		46 (4)	−7.2 (0.5)
Jiménez-Reyes et al. (2018) (Radar)							
Elite/internat		6.5 (0.3)	8.18 (0.47)	13.2 (1.0)			
Semi-prof		6.5 (0.6)	7.60 (0.38)	12.2 (1.3)			
Haugen et al. (2019) (Gates-0.5 s fixed)		∼7.6	∼8.1	∼15.5	∼-0.94	∼43	∼-9.2
Haugen et al. (2020b) (Gates-0.5 s fixed)							
National		7.6 (0.5)	8.1 (0.4)	15.5 (1.3)	−0.99 (0.07)	43 (2)	−8.9 (0.7)
Top		7.5 (0.4)	7.8 (0.4)	14.7 (1.3)	−0.97 (0.06)	42 (2)	−9.2 (0.6)
Junior		7.6 (0.7)	7.8 (0.4)	14.8 (1.3)	−0.97 (0.08)	42 (2)	−9.2 (0.8)

TAU-time constant; F0-theoretical maximal horizonal force production; V0-theoretical maximal running velocity; Pmax-maximal horizontal mechanical power output; FV slope-force velocity slope; RFmax-maximal value for ratio of force; DRF-rate of decrease in ratio of force with increasing speed during sprint acceleration. There were main effects (p < 0.001) and pairwise differences between all three models for each sprint mechanical variable.

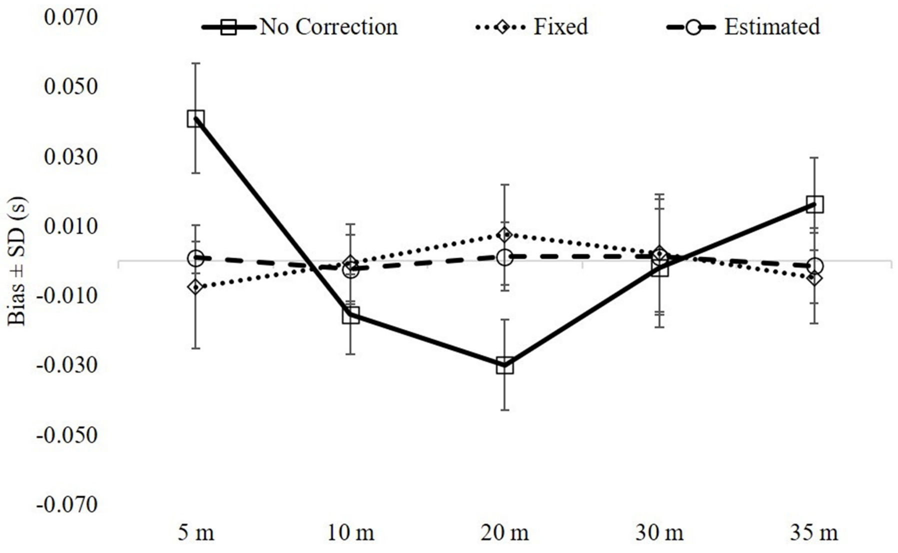

FIGURE 1 | The overall model fit metrics (bias ± SD) grouped by distance. There were main effects ($p < 0.001$) for each distance with differences for all pairwise comparisons between the three models ($p < 0.001$). See text for effect sizes.

sprint time) (Haugen et al., 2019, 2020b). The first method had a touch pad under the athlete's front foot that would trigger the timing start when released. The second method positioned a single-beam timing gate and the athlete's center of mass 60 and 50 cm in front of the start line, respectively (Haugen et al., 2019, 2020b). A +0.5 s fixed correction was applied in these studies to adjust the triggering of the timing system to "first movement." Another study with elite female handball players also used a touch pad under the foot to trigger the timing gates but applied no time correction, yet still reported similar sprint mechanical characteristics to other studies that used time correction (F0 = 7.3 ± 0.3 N/kg, V0 = 8.0 ± 0.3 m/s, Pmax = 14.6 W/kg, FV slope −0.91 ± 0.04 N/s/m/kg) (Rakovic et al., 2018). In contrast, players in the current study placed the toes of their front foot 5 cm behind the start and were only allowed to move forward to begin the sprint, thereby reducing the gap between initial force production and the start time. The difference in start technique is the reason for using a smaller fixed time correction (+0.3 vs. +0.5 s). Surprisingly, the mean estimated time correction (0.25 ± 0.09 s) was very similar to the fixed correction as well as the difference reported between block and standing sprint starts (0.27 ± 0.12 s). Taken together, these outcomes highlight that the type of start technique could influence the time correction required and may lend support for using an estimated time correction.

To the authors' knowledge, only one recently published study has included an estimated time correction into this model (termed time shift optimization) (Stenroth et al., 2020). Hockey players performed a 30 m sprint on the ice, and outcomes demonstrated improved intra- and inter-rater reliability for the model using a time shift when evaluating force-velocity profiles. The average time shift reported was +0.14 s, which is smaller than the fixed and estimated time correction in the current study. This could possibly reflect improved sensitivity for capturing the first instance of force production when using video compared with the timing gates in our study. Alternatively, it might represent performing sprints on two different surfaces (ice vs. turf). Also worth noting is that the range of estimated time correction values in the current cohort were all positive (+0.07 to +0.50 s) (**Figure 2**) and reached as high as the fixed values previously reported (Haugen et al., 2019, 2020b). The negative linear relationship between the estimated time correction values and maximal acceleration highlights that individuals with faster acceleration had smaller corrections. Taken together, these outcomes seem to support the use of methodology-specific time shifts (corrections) estimated on an individual level instead of fixed shifts.

The current study used a method for capturing sprint time that is unique in the literature (i.e., position of the athlete relative to the start line, plus the two time corrections). Therefore, direct comparisons of model outcomes to other studies poses a challenge. Nonetheless, there are some interesting illustrations. A study with U18 boys (radar) demonstrated slower mean 5 m (1.33 vs. 1.20 s), similar 10 m (2.07 vs. 2.00 s) and 20 m (3.35 vs. 3.39 s), and faster 30 m sprint times (4.57 vs. 4.71 s) than the current group of players (Edwards et al., 2020). The resulting modeled outcomes provided greater F0 (8.0 N/kg), V0 (8.85 m/s), and Pmax (17.7 W/kg) values but comparable FV slope (−0.91 N/s/m/kg), RFmax (45%) and DRF (−8.2%) (Edwards et al., 2020) with the current athletes. This was also reflected with a mixed group (male and female) of team handball players using a similar testing approach with timing gates (uncorrected) and showed greater F0 (7.8 N/kg), V0 (8.65 m/s) and Pmax (17.1 W/kg) values, but comparable FV slope (-0.92 N/s/m/kg), RFmax (45%), and DRF (−8.5%) outcomes (Haugen et al., 2020a). Despite recording faster sprint times in the current group of athletes than previously published for high-level female soccer players (timing gates: 10 m = 2.17 ± 0.06 s; 20 m = 3.55 ± 0.11 s;

TABLE 2 | Sprint timing metrics.

	MACC (m/s/s)	MSS (m/s)
Models		
No correction	11.3 (1.7)	7.46 (0.36)
Fixed	6.6 (0.8)	7.85 (0.46)
Estimated	7.2 (0.9)	7.77 (0.43)
Statistics (*p*-value, d)		
No correction vs. fixed	<0.001, 3.54	<0.001, 0.94
No correction vs. estimated	<0.001, 3.01	<0.001, 0.78
Fixed vs. estimated	<0.001, 0.70	<0.001, 0.18

MACC, maximal sprint acceleration; MSS, maximal sprint speed. There were main effects (p < 0.001) and pairwise differences between all three models.

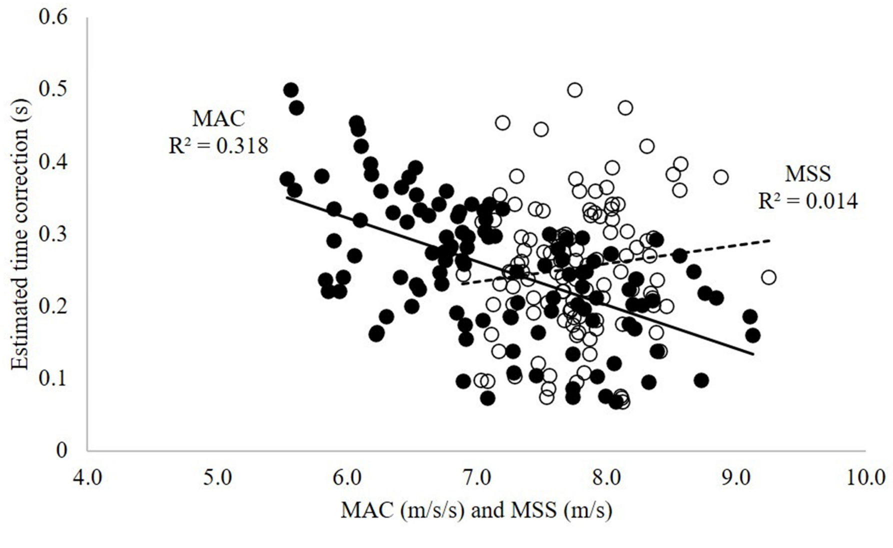

FIGURE 2 | Scatterplot for the estimated time correction value with maximal acceleration (MAC-solid circles, solid line) and maximal sprint speed (MSS-open circles, dashed line).

30 m = 4.84 ± 0.16 s), there were larger values for force, power, FV slope, and DRF reported in the literature (**Table 1**) (Haugen et al., 2019). It is unclear if this demonstrates that primary sprint mechanical metrics (i.e., force, velocity and power) may be more sensitive to data inputs than other derived metrics (i.e., FV slope, RFmax, DRF) or if the various approaches used (e.g., touch pad start, timing gate start with and without correction, etc.) have a greater influence on the models. Regardless, there were differences between the two time corrected models for all of the variables in the current study, and even though small-to-moderate effect sizes were observed, the differences were greater than previously reported CV% (Morin et al., 2019; Haugen et al., 2020a). Therefore, additional research is warranted to determine which method of time correction (fixed vs. estimated) provides more accurate parameter estimates when using timing gates.

The time constant (TAU) represents the duration it takes a system (in this case an athlete that is sprinting) to achieve 63.2% of maximum (speed). TAU has been thought of as a useful indicator of acceleration with smaller values representing the achievement of maximum sprint speed more quickly and vice versa (Healy et al., 2019). Previous studies with NFL players (Clark et al., 2019) and elite female sprinters (Greene, 1986) reported TAU values between 0.77 and 0.91 s, whereas elite male sprinters have consistently shown values between 1.0 and 1.2 s (Greene, 1986; Healy et al., 2019; Morin et al., 2019). Upon first inspection, this might be perceived as female soccer players having similar acceleration qualities as 100 m Olympic/World Championship male sprinters. However, when taken in context of the duration taken to cover equivalent distances, then the differences in performance over a short sprint becomes evident between the current cohort (20 m = 3.39 s) and male sprinters (20 m = 2.82 s) (Healy et al., 2019). Indeed, it has been shown that smaller TAU values only occurred for faster sprinters after controlling for maximum velocity and is the reason these parameters need to be considered together (Healy et al., 2019). Therefore, maximal acceleration (Equation 1.2) is a better estimate for this sprint quality and should be used instead of TAU.

CONCLUSION

The primary outcomes from the current study confirm that a time correction is warranted when using timing gates to estimate sprint mechanical parameters. A limitation of the current retrospective pilot study is that a reference method (i.e., laser, radar) was not used; therefore, additional investigation is warranted to determine whether a fixed time correction or estimated time correction provides greater accuracy when assessing force-velocity profiles from sprints performed on turf. It is likely that the previously suggested fixed time correction (+0.5 s) is too large (Haugen et al., 2019, 2020b) because the mean estimated time correction (+0.25 ± 0.09 s) was closer to the fixed time correction as well as the previously reported difference between block and standing starts (+0.20 to +0.33 s) (Haugen et al., 2012). It may also be possible that methodology-specific time corrections are needed (Stenroth et al., 2020).

Until it can be determined which method offers better estimates for sprint mechanical metrics when using timing gates, it might be prudent (and simpler) for practitioners to utilize a fixed time correction. Keep in mind, the sprint start procedure will influence the value chosen. For example, +0.30 s was used in the current study because of the specific position of the athlete relative to the start line. If the athlete is positioned further behind the start line, then it would be appropriate to use a larger time adjustment value. Practitioners interested in applying the individual estimated time correction can use the “shorts” package specifically designed for this purpose (Jovanović, 2020; Jovanović and Vescovi, 2020).

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because of pre-existing legal agreements. Requests to access the datasets should be directed to Dr. Jason Vescovi.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by York University, Office of Research Ethics. Written informed consent to participate in this study was provided by the participants.

AUTHOR CONTRIBUTIONS

JDV was responsible for study design, data collection, data interpretation, writing, and revision of the paper. MJ was responsible for data analysis and modeling, data interpretation, writing, and revision of the paper. Both authors contributed to the article and approved the submitted version.

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ORIGINAL RESEARCH
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Women's Rugby League: Positional Groups and Peak Locomotor Demands

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The aims of this study were to (a) use a data-based approach to identify positional groups within National Rugby League Women's (NRLW) match-play and (b) quantify the peak locomotor demands of NRLW match-play by positional groups. Microtechnology (Global Navigational Satellite System [GNSS] and integrated inertial sensors; $n = 142$ files; $n = 76$ players) and match statistics ($n = 238$ files; $n = 80$ players) were collected from all NRLW teams across the 2019 season. Data-based clustering of match statistics was utilized to identify positional clusters through classifying individual playing positions into distinct positional groups. Moving averages (0.5, 1, 2, 3, 5, and 10 min) of peak running and average acceleration/deceleration demands were calculated via microtechnology data for each player per match. All analysis was undertaken in R (R Foundation for Statistical Computing) with positional differences determined via a linear mixed model and effect sizes (ES). Data-based clustering suggested that, when informed by match statistics, individual playing positions can be clustered into one of three positional groups. Based on the clustering of the individual positions, these groups could be broadly defined as backs (fullback, wing, and center), adjustables (halfback, five-eighth, and hooker), and forwards (prop, second-row, and lock). Backs and adjustables demonstrated greater running (backs: ES 0.51–1.00; $p < 0.05$; adjustables: ES 0.51–0.74, $p < 0.05$) and average acceleration/deceleration (backs: ES 0.48–0.87; $p < 0.05$; adjustables: ES 0.60–0.85, $p < 0.05$) demands than forwards across all durations. Smaller differences (small to trivial) were noted between backs and adjustables across peak running and average acceleration/deceleration demands. Such findings suggest an emerging need to delineate training programs in situations in which individual playing positions train in positional group based settings. Collectively, this work informs the positional groupings that could be applied when examining NRLW data and supports the development of a framework for specifically training female rugby league players for the demands of the NRLW competition.

Keywords: female athlete, GPS, match demands, microtechnology, team sport

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INTRODUCTION

Recently, there has been an increase in the participation rates, playing opportunities, and professionalization of female rugby league (Cummins et al., 2020b). For example, at the elite level, a women's premiership competition (National Rugby League Women's [NRLW]; inaugural year: 2018) was recently established by the National Rugby league (NRL). The NRLW is structured via a round robin format, whereby each of the teams ($n = 4$) play each other once. At the completion of the regular season (round robin), the two highest ranking teams contest the grand final in order to determine the overall premiership winner. The NRLW is governed by similar rules as the men's NRL competition with matches being played on the standard full-size field (~68 m wide x 120 m long [including the in-goal area]). There are, however, several differences between NRLW and NRL matches. Specifically, NRLW matches are shorter in duration than that of the NRL competition with matches being played over halves of 30 min (plus additional time allocated for stoppages). Furthermore, the NRLW competition includes the 40/30 kick advantage and permits more interchanges than the men's NRL competition (10 vs. 8 interchanges per match, respectively).

The use of microtechnology (Global Navigational Satellite System [GNSS] and integrated inertial sensors) has provided an enhanced understanding of the demands of team sports (Cummins et al., 2013). Although such devices have been used extensively to understand the locomotor demands (i.e., the physical demands associated with motion, for instance, this may include walking, running, or sprinting) of men's rugby league (Johnston et al., 2014; Hausler et al., 2016; Glassbrook et al., 2019), comparatively less is understood about women's rugby league (Cummins et al., 2020a; Emmonds et al., 2020; Quinn et al., 2020; Newans et al., 2021). Although the aforementioned research reports on automated tackle detection (Cummins et al., 2020a), the peak (Emmonds et al., 2020) and whole match (Emmonds et al., 2020; Quinn et al., 2020) locomotor demands of international teams, the whole and peak locomotor demands of the Women's Super League (WSL) competition (Emmonds et al., 2020), and the whole match locomotor demands of the NRLW competition (Newans et al., 2021), to the authors' knowledge, no research exists on the peak locomotor demands of the NRLW competition.

Examination of match characteristics provides an understanding of the locomotor demands of rugby league players. The intermittent nature of the game, however, means that such analysis may not truly represent the highly variable intensity of match-play (Whitehead et al., 2018). For example, English international female backs cover an average of 75.2 m.min^{-1} throughout a match, and the same players cover an average of 144, 93, and 81 m.min^{-1} across 1-, 5-, and 10-min durations, respectively (Emmonds et al., 2020). This equates to 68.8, 17.8, and 5.8 m.min^{-1} more than the overall match intensity, respectively (Emmonds et al., 2020). Due to such discrepancies, examining locomotor demands across duration-specific time periods is important in enabling practitioners to develop training programs that specifically prepare players for the maximum demands and intensities of match-play.

Additionally, there is an inconsistency in the classification of positional groups throughout rugby league research (Cummins et al., 2013). Research within the women's game specifically has reported on the locomotor demands of match-play by each position (Newans et al., 2021) as well as by two (i.e., forwards and backs) (Emmonds et al., 2020) and three (i.e., backs, halves, and forwards) (Quinn et al., 2020) positional groups. Due to the disparities in the physical qualities of male (Johnston et al., 2014) and female players (Jones et al., 2016) and the evolving nature of women's rugby league, it is possible that such positional groups may not represent the true positional groupings and, therefore, not reflect the actual demands of female rugby league players.

Collectively, the paucity of research on the demands of women's rugby league hinders the development of a framework to inform female-specific development, training, and management practices (Cummins et al., 2020b). Therefore, the aims of this study were to (a) use a data-based approach to identify positional groups within NRLW match-play and (b) quantify the peak locomotor demands of NRLW match-play by positional groups.

MATERIALS AND METHODS

Participants

Match-play data were collected from professional female rugby league players representing all NRLW teams ($n = 4$; $n = 80$ players) over one competitive season (2019). Institutional ethics approval was granted by the University of New England Human Research Ethics Committee.

Microtechnology Data Collection

Microtechnology data ($n = 142$ files; $n = 76$ players) were captured via microtechnology devices (OptimEye S5; Catapult Sports Melbourne, Australia), which record a 10 Hz GNSS sampling rate through the inbuilt GNSS-chip. Each NRLW team was responsible for collecting and downloading microtechnology data from each match with the corresponding raw data being utilized in the calculation of peak locomotor demands.

Data Manipulation

A database was created that contained the 10 Hz GNSS data (Catapult Sports Melbourne, Australia) and match-play statistics (Stats Perform, Chicago, Illinois, United States) as retrieved from the RLeague Analyser (Fair Play, Jindalee, Queensland, Australia).

The microtechnology and match-play statistics data sets were synchronized in order to apply the start and end times of each half per match (and extra time) as well as the interchange times for each player. Erroneous data within a file was flagged if any of the following criteria was met: (a) acceleration >6 m.s^{-2} (Weston et al., 2015), (b) velocity >10 m.s^{-1} (Weston et al., 2015), or (c) a traveled distance of >10 m in a 1 s time period. This combination of criteria ensured that erroneous velocity and distance data calculated via either the doppler-shift or positional differentiation methods were identified (Malone et al., 2017). Similar to common practice within high-performance settings, any period of erroneous data (including 1 s of data on either side) was removed and, therefore, excluded from analysis.

From the initial 142 microtechnology files, files were removed due to poor signal quality, whereby more than 5% of the raw data was flagged as erroneous and removed, or a total match duration of less than a quarter (i.e., 15 min, which is equivalent to 20 min, within men's rugby league; Dalton-Barron et al., 2020). A total of 131 files were included in the analysis.

Locomotor Variables

To calculate duration-specific peak average running demands (m.min^{-1}), each players' instantaneous velocity was used in a custom-built algorithm (R Foundation for Statistical Computing, Vienna, Austria; version 4.02) to calculate a moving average of instantaneous running speed (m.min^{-1}) (Delaney et al., 2015; Weaving et al., 2018) across six different durations (0.5, 1, 2, 3, 5, and 10 min) for each match. The peak average acceleration/deceleration (m.s^{-2}) was calculated as the rate of change in velocity regardless of direction (Delaney et al., 2016). This was achieved through averaging the absolute value of all acceleration and deceleration data across defined periods (Delaney et al., 2016) of six different durations (0.5, 1, 2, 3, 5, and 10 min) for each match. Within the context of load monitoring, this measure provides insight into the overall acceleration/deceleration load experienced by an athlete and can be utilized to inform training prescription (Delaney et al., 2016). This measure is shown to demonstrate increased interunit reliability when compared with the use of threshold-based acceleration measures (Delaney et al., 2018). Specifically, when multiple 10 Hz devices were attached to a sprint sled throughout a team sport simulation protocol, the interunit reliability of the average acceleration/deceleration measure was 1.2% (coefficient of variation; CV), and the interunit reliability ranged from 3.3 to 5.9% (CV) across intensity-based thresholds (Delaney et al., 2018). It is also suggested that, although a 10 Hz device can determine whether an acceleration or deceleration has occurred, there is a degree of error in the measurement of instantaneous velocity (Varley et al., 2012). This suggests that the average acceleration/deceleration measure may be more appropriate than threshold-based measures in monitoring the acceleration demands of team sport athletes (Delaney et al., 2018).

Positional Groups

The parameterized finite mixture model algorithm from the "mclust package" (Fraley and Raftery, 1999) was used on match statistics data ($n = 238$ files; $n = 80$ players) to classify individuals into distinct positional groups. This algorithm is designed to take independent identically distributed observations and provide model-based hierarchical clustering, heuristically calculating probabilities (percentage) that each independent player's observations belong to a particular classification, attempting to realize wider population patterns based on the limited sample data. The variables of minutes played, hit-ups, run meters (i.e., meters run in possession of the ball), line breaks, kicks, tackles, and passes were utilized based on their relationship to playing style and the authors' expertise in women's rugby league. Although these variables are not completely independent (e.g., a player on the field for fewer minutes is likely to have reduced match statistics), the algorithm still has potential to offer insight into positional groups even if results cannot be conclusive. The individual positions were partitioned until the algorithm could make no further grouping with each position clustered into the grouping containing the majority of data points.

Statistical Analysis

All statistical analyses were undertaken in R (R Foundation for Statistical Computing, Vienna, Austria; version 4.0.2). Data are presented as mean ± 90% confidence intervals (CI) unless otherwise stated. Positional group differences were compared using a linear mixed model with Bonferroni *post-hoc* testing. The level of significance was accepted at $p \leq 0.05$. Cohen effect size (ES) with 90% CI were also used to examine differences between playing positions. Effect sizes were categorized as trivial (<0.2), small (0.2–0.6), moderate (>0.6–1.2), large (>1.2–2.0), or very large (>2.0) (Hopkins et al., 2009).

RESULTS

As seen in **Figure 1**, data-based clustering classified players into one of three groups: 1 (fullback, wing, and center), 2 (halfback, five-eighth, and hooker), and 3 (prop, second-row, and lock). The figure shows, for example, that 52.6% of centers are clustered in group 1, 28.9% are clustered into group 2, and 18.4% are clustered into group 3. Based on the clustering of the individual positions, these groupings could be broadly defined as backs (group 1), adjustables (group 2), and forwards (group 3). The probability (represented as a percentage) of each position belonging to the respective group was 52.6–69.6% for backs, 74.2–83.3% for adjustables, and 53.3–93.3% for forwards.

Backs and adjustables demonstrated greater peak running (backs: ES 0.51–1.00; $p \leq 0.05$; adjustables: ES 0.51–0.74, $p \leq 0.05$) and average acceleration/deceleration (backs: ES 0.48–0.87; $p \leq 0.05$; adjustables: ES 0.60–0.85, $p \leq 0.05$) demands than forwards across all durations (**Tables 1**, **2**). Smaller differences (trivial to small) were noted in the peak running and acceleration demands between backs and adjustables (**Tables 1**, **2**).

DISCUSSION

To the authors' knowledge, this is the first study to examine the positional groups and peak locomotor demands of NRLW match-play. The findings identify that, within this data set, individual playing positions can be clustered into three positional groups (i.e., backs, adjustables, and forwards) and that, when compared with forwards, both backs and adjustables demonstrate increased peak running and average acceleration/deceleration demands. Together, this work informs the positional groupings that could be applied when examining NRLW data and supports the development of a framework for specifically training female rugby league players for the demands of the NRLW competition.

Data-based clustering suggests that, when informed by match statistics, individual playing positions can be clustered into one of three positional groups (**Figure 1**). Based on the clustering

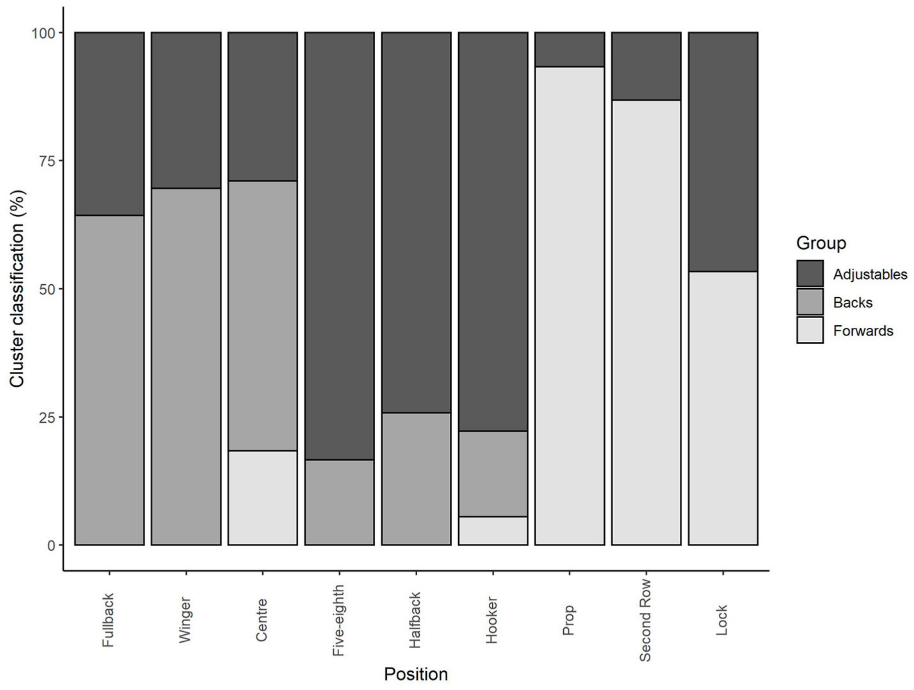

FIGURE 1 | Cluster classification of positional groups.

TABLE 1 | Peak running demands.

	Adjustables (m.min^{-1})	Backs (m.min^{-1})	Forwards (m.min^{-1})	Adjustables vs. Backs (ES ± 90% CI)	Adjustables vs. Forwards (ES ± 90% CI)	Backs vs. Forwards (ES ± 90% CI)
0.5 min	179.6 ± 7.5	188.8 ± 8.2	161.1 ± 5.3	−0.31 ± 0.38	0.74 ± 0.37*	1.00 ± 0.36*
1 min	149.1 ± 6.0	147.6 ± 5.4	136.9 ± 4.4	0.07 ± 0.38	0.60 ± 0.37*	0.53 ± 0.34*
2 min	121.7 ± 5.0	121.1 ± 4.3	112.0 ± 3.6	0.03 ± 0.38	0.58 ± 0.37*	0.56 ± 0.35*
3 min	111.6 ± 4.2	110.7 ± 3.7	102.3 ± 3.4	0.06 ± 0.38	0.62 ± 0.37*	0.56 ± 0.35*
5 min	99.9 ± 4.3	99.1 ± 3.0	92.5 ± 3.2	0.06 ± 0.37	0.51 ± 0.36*	0.51 ± 0.35*
10 min	88.6 ± 4.3	89.1 ± 2.6	81.0 ± 3.1	−0.04 ± 0.38	0.53 ± 0.36*	0.66 ± 0.35*

*Data presented as mean ± 90% confidence interval (unless otherwise stated); CI, confidence interval; ES, effect size; *, significant difference ($P \leq 0.05$).*

of the individual positions, these groupings could be defined as backs (fullback, wing, and center), adjustables (halfback, five-eighth, and hooker), and forwards (prop, second-row, and lock). The differences in classifications indicate that, irrespective of their named position (e.g., center), individual players undertake specific roles on the field. For example, although the majority of centers were classified as a back, 28.9% and 18.4% were classified as adjustables or forwards, respectively. Such findings suggest that some centers within women's rugby league undertake a more ball playing (e.g., adjustable) or defensive (e.g., forward) role on the field. For the forward position, although the positions of prop (93.3%) and second row (86.8%) distinctly fell into the category of a forward, the lock was categorized as a forward (53.3%) or adjustable (46.7%), suggesting that, across the NRLW, some teams may utilize a lock player in a more ball-playing role. The exhibited variances in positional classifications across the three groups could be attributable to a myriad of factors, including team tactics/game plays, whereby the coaching or playing style across the four teams competing within the NRLW may influence the role undertaken by individual players. Additionally, these variances may reflect the evolving nature of women's rugby league, whereby as the data was gleaned from the second NRLW season, it is plausible that female rugby league players are yet to differentiate into distinct positions or that players may rotate between positions (Clarke et al., 2018). Similarly, within the inaugural year of the Australian Football League Women's competition, it was reported that there may not have been sufficient time for the development of distinct technical and tactical demands across playing positions (Clarke et al., 2018). Conversely, it may be that female rugby league players demonstrate a more homogenous style of play across playing positions. It should also be noted that microtechnology data

TABLE 2 | Average acceleration/deceleration demands.

	Adjustables (m.s^{-2})	Backs (m.s^{-2})	Forwards (m.s^{-2})	Adjustables vs. Backs (ES ± 90% CI)	Adjustables vs. Forwards (ES ± 90% CI)	Backs vs. Forwards (ES ± 90% CI)
0.5 min	0.92 ± 0.03	0.95 ± 0.02	0.87 ± 0.02	−0.26 ± 0.38	0.60 ± 0.37*	0.87 ± 0.36*
1 min	0.77 ± 0.02	0.77 ± 0.02	0.72 ± 0.02	0.04 ± 0.38	0.62 ± 0.37*	0.60 ± 0.35*
2 min	0.64 ± 0.02	0.63 ± 0.01	0.60 ± 0.01	0.27 ± 0.37	0.67 ± 0.37*	0.48 ± 0.35*
3 min	0.60 ± 0.02	0.58 ± 0.01	0.55 ± 0.01	0.41 ± 0.38	0.84 ± 0.37*	0.57 ± 0.35*
5 min	0.54 ± 0.02	0.52 ± 0.01	0.49 ± 0.01	0.36 ± 0.38	0.85 ± 0.38*	0.66 ± 0.35*
10 min	0.49 ± 0.02	0.47 ± 0.01	0.43 ± 0.01	0.26 ± 0.37	0.83 ± 0.37*	0.76 ± 0.35*

*Data presented as mean ± 90% confidence interval (unless otherwise stated); CI, confidence interval; ES, effect size; *, significant difference ($P \leq 0.05$).*

was unable to cluster individual positions into clear groups. Despite the aforementioned variances within the positional classifications, the findings are supportive of an emerging need to delineate training programs in situations in which individual playing positions train in positional group based settings. Further, this informs the positional groupings that could be applied when examining or conducting research on NRLW data that is gleaned from one team where the influence of individual players (i.e., one fullback) reduces the translation of position-specific findings across teams more broadly. Further work is warranted to elucidate whether these groupings change with additional NRLW seasons as well as the positional groupings that could be utilized across other female rugby league competitions, such as the WSL.

Positional group differences were apparent with backs and adjustables demonstrating increased peak running and average acceleration/deceleration demands than forwards (**Tables 1**, **2**). Conversely, backs and adjustables demonstrated close similarity in peak running and average acceleration/deceleration demands. Previous work suggests that practical differences (i.e., the smallest threshold that can be translated into both prescription and monitoring) can be observed via a threshold of 10 m.min^{-1} (Delaney et al., 2015). Based upon this, there is no practical difference between the peak running demands of backs and adjustables across the reported duration-specific time points, thereby indicating that, although position-specific training intensities may be required between backs/adjustables and forwards, it may not be necessary to train adjustables and backs separately in regards to this metric. The increased average acceleration/deceleration profile of adjustables and backs when compared with forwards suggests that, alongside maintaining an increased running intensity, they are engaged in more start/stop actions. This suggests that backs and adjustables should undertake training and conditioning drills that replicate these demands through a focus on sustained intensity as well as accelerations/decelerations and changes of direction. The ability to compare such findings to previous work is hindered through differences in playing durations, whereby NRLW matches are 60 min in duration and WSL matches are 80 min in duration (Emmonds et al., 2020), the different positional groupings across studies (Emmonds et al., 2020; Quinn et al., 2020; Newans et al., 2021) as well as the reporting of different locomotor metrics (Quinn et al., 2020; Newans et al., 2021).

It should be acknowledged that the relatively small number of teams ($n = 4$) competing within the NRLW means that the team tactics/game plays and preferences of the coaching staff could have an influence upon the positional groupings and locomotor demands that were elucidated within this work. Despite this potential and unavoidable limitation, the findings of this work inform the positional groupings that could be applied to the analysis of NRLW data and the development of a framework to support female-specific training programs that prepare players for the peak demands of match-play. Future work should look to review the positional groups and peak demands of NRLW match-play as the game continues to develop.

CONCLUSION

This study suggests that three positional groups (i.e., backs, adjustables, and forwards) exist and that, when compared with forwards, both backs and adjustables demonstrate increased peak running and average acceleration/deceleration demands. Such findings suggest that backs and adjustables should undertake training and conditioning drills that replicate increased peak running and average acceleration/deceleration demands through a focus on sustained intensity as well as accelerations/decelerations and changes of direction. Collectively, this work informs the positional groupings that could be applied when examining NRLW data and supports the development of a framework for specifically training female rugby league players for the demands of the NRLW competition.

DATA AVAILABILITY STATEMENT

The data sets presented in this article are not readily available because the authors do not have permission to share the respective datasets. Requests to access the data set should be directed to cloe.cummins@une.edu.au.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of New England human research ethics committee. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

CC: conceptualization, design, and original drafting of the manuscript. JC: data collection. CC, GC, and DP: data interpretation and analysis. CC, GC, DP, KS, SB, JC, and AM: critical revision of the manuscript. All authors contributed to the article and approved the submitted version.

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The remaining 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.

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