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The future potential of virtual reality countermeasures for maintaining behavioural health during long duration space exploration

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Long duration space exploration is no longer a fantasy, with Elon Musk claiming to launch astronauts to Mars as early as 2029. The substantial increase in spaceflight duration required for a Mars mission has resulted in a stronger focus on behavioural health outcomes at NASA, with increased interest in using virtual reality countermeasures to both monitor and promote psychological wellbeing. From the perspective of a practitioner psychologist, this paper first considers the utility of virtual reality assessment of emerging behavioural health concerns for remote monitoring purposes. Key opportunities include using virtual reality for functional cognitive testing and leveraging the predictive abilities of multimodal data for personalised insights into symptomology. Suggestions are given as to how astronauts can self-monitor usage of virtual leisure activities that facilitate positive emotional experiences. Secondly, the potential to develop virtual reality countermeasures to deliver semi-structured therapeutic interventions such as collaborative cognitive-behavioural formulation in the absence of real-time communication is discussed. Finally, considerations for the responsible implementation of psychological monitoring tools are reviewed within a context of fostering psychological safety and reducing stigma.

KEYWORDS

virtual reality, space, Mars, behavioural health, monitoring, countermeasures, CBT (cognitive behavioural therapy), psychological safety

Introduction

Long-duration space exploration (LDSE) is no longer a fantasy, with Elon Musk claiming to launch astronauts to Mars as early as 2029 (Musk, 2022). Current estimates suggest that a round-trip to Mars will take at least 650 days (NASA Video, 2022, 24:24), whereas the longest number of consecutive days spent in space to date is 437 (ESA-K Oldenburg, 2010). Extending spaceflight, however, means extending the cumulative impact of multiple stressors, pushing the boundaries of human coping (Leach, 2016). Kanas and Manzey (2008) outline these stressors including lack of space, privacy, and resources; microgravity; radiation; monotony; sleep disruption; and isolation. A Mars mission is further complicated by communication delays, a disappearing Earth, and the inability to receive additional supplies or assistance.

While there are no reports of serious behavioural incidents occurring in space to date, a deterioration to wellbeing during LDSE appears probable (Alfano et al., 2018). Extrapolation from Antarctic analog data means that there is a 53.4%–89.3% likelihood of a severe behavioural health issue occurring during LDSE depending on whether incidence rate remains constant or not (Stuster, 2010). No matter how carefully astronauts are vetted for pre-existing resilience, contextual factors such as stressor severity and availability of coping resources influence psychological wellbeing in isolated, confined, and extreme (ICE) environments (Palinkas and Browner, 1995). Likewise, extended spaceflight may increase the possibility of mild to moderate affective changes. Kanas (2016) explains that adjustment disorders presenting via symptoms of depression and anxiety are the most common behavioural health issues observed in space. Likewise, Vessel and Russo (2015) share that subclinical levels of mood disorder have frequently been reported in ICE settings. While not immediately threatening to mission success, subtle affective shifts may insidiously impact upon individual wellbeing, crew cohesion, and performance over time (Slack et al., 2016). A preventative approach is optimal, with increased focus on monitoring behavioural health for early identification of issues in the absence of real-time communication with ground support, as well as developing countermeasures to promote salutogenesis (Slack et al., 2016).

Virtual reality (VR) can help to fill these research gaps (Salamon et al., 2018). Countermeasures include virtual exposure to natural and urban scenery (Lyons et al., 2020) and virtual windows (Kearney, 2016). There is substantial evidence supporting the health benefits of nature exposure, for example, improved cognitive function, psychological wellbeing, and physical activity levels (Jimenez et al., 2021). Stress recovery occurs even when viewing natural scenery indoors (Jo et al., 2019). However, in three ICE environments including two Mars analog studies, dynamic urban scenery was valued too, particularly after long periods of isolation (Anderson et al., 2022). Similarly, virtually simulated Earthscapes are being tested in the SIRIUS-21 analog to facilitate self-transcendent emotions under conditions of prolonged isolation (Stepanova, 2021). Earth gazing is a favourite leisure activity for several NASA astronauts and has been repeatedly associated with positive affective experiences (Johnson, 2010).

Another critical countermeasure is A Network of Social Interactions for Bilateral Life Enhancement or ANSIBLE (Wu et al., 2015; Wu et al., 2016). ANSIBLE is an immersive virtual ecosystem where astronauts participate in activities like meditation, shared messaging with family, and revisiting positive memories. Wu et al. (2016) found that ANSIBLE improved social connectedness in conditions of delayed communications with Earth. As AI capabilities progress, ANSIBLE will be populated with socially intelligent virtual agents to provide stimulation and monitor affective changes via speech and text interactions (Wu et al., 2015). Choukér and Stahn (2020) report that isolation and confinement is one of the most serious but least understood risks of spaceflight. Social isolation and loneliness on Earth have been consistently associated with decreased psychological and cardiovascular health (Leigh-Hunt et al., 2017). Furthermore, hippocampal and prefrontal cortex volume losses observed in Antarctic expeditioners were attributed to isolation and monotony (Stahn et al., 2019). Relatedly, multisensory VR stimulation is under development (Carulli et al., 2019) since sensory deprivation increases the potential for conflict, negative affect, and impaired performance (Palinkas and Suedfeld, 2008).

VR is also being utilised to enhance fitness routines and track stress levels by incorporating biofeedback of respiration and heart rate (Josh, 2020). Choukér and Stahn (2020) mention several research efforts to combine exercise with VR to encourage brain plasticity and provide sensory stimulation during isolation and confinement. Keller et al. (2022) investigated the addition of VR to an exercise device and protocol already tested on the International Space Station and found positive trends for motivation, affect, and mood restoration. Lower negative affect and fatigue levels were reported during VR high intensity interval training. VR enhanced exercise was similarly reported to have a positive effect on mental and physical wellbeing outcomes during the COVID-19 lockdowns, where vast numbers of people were housebound for prolonged periods (Siani and Marley, 2021).

Evaluating and enhancing performance is another area of VR research. Neurotracker is a tool that has gathered interest in the space community (Smith, 2023a), which uses object tracking for cognitive training and has been employed by military populations (Vartanian et al., 2021). VR has been used to test aspects of astronauts' perceptive and psychomotor functions in space (Gaskill, 2021) and is used as a pre-flight trainer to induce and reduce symptoms of space motion sickness and spatial disorientation in microgravity (Stroud et al., 2005). Finally, due to the sense of presence and ecological validity afforded by VR, VR is commonly used for maintaining or enhancing job skills in safety critical roles. Examples include lunar surface training for astronauts (NASA, 2020, 11:44), stress management training for military personnel (Pallavicini et al., 2016), and firefighter training (Wheeler et al., 2021). This paper expands upon the possible uses of VR to both monitor and support wellbeing during LDSE from a practitioner psychologist perspective. Responsible implementation of behavioural monitoring at an organisational level is reviewed in the discussion.

Behavioural Health Monitoring in Virtual Reality

Basner et al. (2015) are currently expanding the range of cognitive performance measures beyond the traditional Space Cognitive Assessment Tool for Windows (WinSCAT; Kane et al., 2005), which presents an opportunity to develop VR measures for use in LDSE. VR has advantages when assessing domains of executive functioning, visuospatial abilities, and sensorimotor functions, because it captures user movement in 3D and simulates functional activities within dynamic and representative environments in an stimulating manner (Kane and Parsons, 2019). These domains rely heavily on brain regions that are vulnerable to damage during LDSE, including the prefrontal cortex, striatal memory systems, the hippocampus, and basal ganglia (Strangman et al., 2014). Furthermore, from clinical experience, there is not always clear alignment between the cognitive strengths and limitations indicated by the results of brain imaging or standard neurocognitive tests with actual performance. Assessment in VR offers one way to capture real-world equivalent performance in a controlled manner to offer predictive insights into behavioural health problems in remote monitoring situations (Bell et al., 2020). For instance, Voinescu et al. (2021) predicted symptoms of depression and anxiety beyond the abilities of classical testing methods by using Nesplora Aquarium, a lifelike test of attention and inhibitory control in a noisy virtual aquarium.

Another advantage is that VR captures multimodal data in one pass, which can be input into machine learning (ML) models to predict aspects of user behavioural health beyond traditional methodologies. Consequently, there is an emerging presence of VR-based psychiatric assessment tools, summarised by Chitale et al. (2022); Freeman et al. (2017); Lindner et al., 2019; Geraets et al. (2022). This body of research is in the early stages but Wiebe et al. (2022) declare that there is a growing evidence base for the assessment and treatment of anxiety disorders and phobias in particular, which have received the most attention. Nevertheless, the predictive strength of multi-modal data is already being demonstrated in the computerized assessment platform created by Thymia[1]; Fara et al. (2022a) discuss the improvement in accuracy of depression diagnosis when fusing modalities from performance features of the n-Back Task with linguistic and acoustic characteristics. Fara et al. (2022a) discovered that individual items from the depression questionnaire PHQ-8 (Kroenke et al., 2009) aligned to different features across these modalities, allowing symptoms to be predicted independently. Fara et al. (2022b) observed that model performance increased with extra modalities and the use of a Bayesian network enabled the generation of explainable model predictions. Multimodal data gathered in VR could thus assist in painting a detailed symptom profile across issues such as depression, generalised anxiety, or neurasthenia while providing a fun experience. This data could inform targeted and personalised treatment recommendations before reaching a clinical level of need. This level of specificity is of interest for the space community (Alfano et al., 2018).

While VR countermeasures are already being employed in ICE settings, VR for routine behavioural health monitoring has some inherent limitations that need to be resolved first. Simulation sickness from VR has reduced participation in some analog studies (Anderson et al., 2022). Gravity transitions contribute to sensorimotor dysfunctions like space adaptation syndrome (Roy-O'Reilly et al., 2021) and LDSE can increase risk for conditions like spaceflight associated neuro-optical syndrome (Lee et al., 2020). Preliminary evidence suggests that visuospatial abilities and attentional resources can remain impacted at later stages of spaceflight, without signs of cognitive adaptation (Takács et al., 2021). All of these factors may decrease willingness to engage with VR and interfere with assessments that are not explicitly testing for this. Consequently, in the author's view, tools that focus on emerging symptomology likely to occur in spaceflight and those that can provide information across multiple domains of behavioural health at once have the most promise for LDSE. The aim is to minimise time investment while maximising data collection and enjoyment since the behavioural health of astronauts is already extensively monitored and testing needs to occur regularly to capture fluctuating levels of psychological adaptation (Alfano et al., 2021).

Therapeutic applications of virtual reality countermeasures

In addition to assessment, VR can support formalised treatment interventions for behavioural health issues during prolonged stays in ICE settings. Accordingly, immersive VR is under consideration for the delivery of asynchronous therapy in LDSE (Gonzalez, 2022). There is evidence that VR can integrate well with cognitive-behavioural therapy (CBT) to support treatment for anxiety and depression (Baghaei et al., 2021). Virtual environments have been utilised for behavioural exposure and cognitive restructuring exercises, for example, virtually manipulating negative self-referential thoughts to reduce their power and believability (Prudenzi et al., 2019). CBT is the most evidence-based approach (David and Christea, 2018) and effects are demonstrable across diverse conditions and populations (Fordham et al., 2021), making this suitable for astronauts. Several components of ANSIBLE are commonly leveraged within CBT including gratitude journaling and mindfulness. This means that as well as being preventative, these aligned activities may be prescribed as part of a recovery treatment plan if required.

Likewise, formulation is an integral first step in CBT and could be included within asynchronous VR therapy. Formulation is a co-created visual map of specific cognitive, behavioural, bodily, emotional, and situational factors that feed into and maintain difficulties for an individual (Kuyken et al., 2011). Astronauts could be guided using pre-programmed reflective questions and templates to elicit relevant information for review and feedback by a psychologist. Drag and drop features for common safety behaviours, unhelpful thinking styles, and positive emotional regulation strategies could be available to assist in creation of the formulation. Formulation can also be strengths driven if preferred, focused on leveraging existing personal resources and positive strategies (Padesky and Mooney, 2012). The formulation process in itself builds metacognitive awareness, which is implicated for wellbeing at both an individual and systems level (Varshney and Barbey, 2021). Furthermore, in the author's experience, collaborative formulation is empowering, acts as a personalised treatment guide, and fuels the therapeutic alliance. The therapeutic alliance is a core mediator of therapeutic change (Baier et al., 2020), reciprocally linked to symptom reduction (Flückiger et al., 2020), and highly predictive of CBT outcomes for patients without a psychiatric history (Lorenzo-Luaces et al., 2017), the typical astronaut profile.

Moreover, there is growing interest in passive monitoring during spaceflight (Smith, 2023b), which refers to continuous unobtrusive digital observation (Sheikh et al., 2021). For instance, the Astroskin Bio-Monitor Vest tracks vital statistics like blood oxygen saturation Hexoskin[2]. With regards to psychological health, the focus has historically been centred on anxiety and stress management (Gatti et al., 2022), usually for discrete performance monitoring (Johannes and van Baarsen, 2020). However, to truly understand wellbeing, a holistic view is required to capture behaviour across multiple contexts including leisure time, which is pertinent when remaining in the same environment. One tool that could help astronauts self-manage their behavioural health is a virtual dashboard that automatically captures time spent across different VR-based leisure activities including sections of ANSIBLE. Computerised health dashboards have been trialled previously to feedback on behavioural and physiological parameters like heart rate (Mollicone, 2011; Mollicone, 2012). A virtual dashboard could determine the distribution of time devoted to VR activities that are personally meaningful and rewarding. For

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[1] https://thymia.ai/

[2] https://www.hexoskin.com/

example, pre-flight, astronauts could give wellbeing importance ratings to all available virtual activities alongside how much time they typically spend on each per week. Individual baseline ranges could already be established from previous space or analog missions. The dashboard may be presented at a self-selected time span and reflective questions triggered when consistent deviations from baseline occur to help astronauts identify and question changes in their usage patterns.

Similarly, there may be benefit in tracking virtual movement and interactional patterns with ANSIBLE avatars as a parallel form of sociometric tracking for astronauts' personal support networks. Sociometric tracking was trialled in the 520 Mars analog study to understand crew relationships and team cohesion (Johannes et al., 2015). Benchmarks would need to be adjusted for movement in a virtual world and individual baselines from ICE environments already established. Virtual data should be interpreted in context of in-person crew social interactions, since withdrawal from social support is common in missions with delayed ground communications (Landon et al., 2022). This combination of insights may alert astronauts to early indicators of affective change. Due to the intrusiveness of leisure time monitoring, these suggestions are best suited for self-monitoring purposes, otherwise they risk becoming a nuisance or even harmful.

Discussion

Several researchers have commented on the appropriateness and design of monitoring tools, highlighting that they need to feel acceptable to crew (Goemaere et al., 2019); transparent about reasons behind recommendations (Smith et al., 2023); and primarily for crew use rather than mission control (Johannes and van Baarsen, 2020). Some astronauts dislike psychological monitoring and may even attempt to give false results (Slack et al., 2016), likely because poor scores can threaten their careers (Kanas and Manzey, 2008). There is evidence from analog studies that self-report measures can become constant partway through the mission, preventing a granular understanding of affective states (Goemaere et al., 2019; Johannes et al., 2015, cited in Johannes and van Baarsen, 2020, p. 427). Moreover, Temp et al. (2020) discuss systematic underreporting of serious behavioural issues in the polar analog literature, obscuring the scope of the problem.

Clinically speaking, any form of assessment is only meaningful if partaken in willingly. Evidenced tools that utilise passive monitoring or ML to determine health status have the potential to be sensitive and revealing. These assessments are harder to impression manage since they either track data continuously over a sustained period or track a combination of co-occurring behaviours where the weightings of each feature in the model output is not always apparent to the user. These characteristics may equate to objective strength but low user acceptability. Seeing as remote assessment tools act as a stand-in professional, there needs to be a therapeutic alliance so that users understand the purpose and bounds of the tool, as well as any feedback provided. Hence fostering psychological safety should be paramount.

Psychological safety refers to an environment where all team members feel safe to take interpersonal risks such as disclosing mistakes and sharing concerns (Edmondson, 1999). Psychological safety is recognised as being critical in hazardous workplaces like The Armed Forces (Crown Copyright, 2022). It may be the single most important contributor to high performing teams (Rozovsky, 2015) and is positively and frequently linked to work satisfaction, engagement, and learning behaviours (Newman et al., 2017). To achieve psychological safety, fully informed consent should be acquired when using monitoring systems. Information may be shared on a need to know or voluntary basis with aligned medics and clinicians who have a wealth of experience in diagnostic decision making and are bound to a code of ethics from their respective professions. In a spaceflight scenario, the crew commander or select ground personnel may need to be privy to aspects of this information, but the means by which this occurs should be collaboratively agreed before disclosure. Crew should be allowed to question the outcomes of assessment tools and be involved in the design process from start to finish.

Another way to foster psychological safety is to review the processes surrounding disclosure of a behavioural health problem and the repercussions for future missions. It is the author's hope that building sensitive monitoring tools will empower users with personalised insights into their wellbeing to help them nurture emerging areas of need and track changes following participation in activities that facilitate positive emotional experiences. Evidence of meaningful engagement with such activities should be given fair weight in medical reviews since these can act as powerful buffers to promote wellbeing and performance even in the presence of symptomology (Alfano et al., 2021). Ideally, monitoring tools should serve to reduce stigma, provide a clearer picture of the prevalence and trajectory of behavioural health problems in ICE settings, and demonstrate progress and recovery to minimise any negative impact on a user's future career.

In summary, VR has the potential to enhance behavioural health monitoring by providing nuanced insights into emerging symptomology and by supplementing existing countermeasures for therapeutic interventions during LDSE. The ability to capture functionally representative and multimodal data while positively stimulating the user are key benefits that should invite collaboration and investment into VR research for ICE environments. However, successful adoption will only be possible if designed and implemented in a way that fosters comfort and psychological safety for all.

Author contributions

LJT is the sole contributor to this article and has approved it for publication.

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Conflict of interest

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

Publisher's note

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