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Space psychology: a comprehensive approach to the future of astronaut wellbeing

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As humanity embarks on Space Age II, the revival of human space exploration brings unprecedented opportunities and challenges. The commercial spaceflight industry has significantly lowered barriers, enabling government agencies to pursue more ambitious missions to the Moon and Mars in the coming decades. This renewed momentum necessitates a more comprehensive approach to the psychological and wellbeing aspects of human space exploration. Drawing on the authors training as a psychologist and co-founder of digital technology startup, this paper explores how immersive technologies, particularly Virtual Reality (VR) and advanced interfaces can address some of the unique psychological and social challenges posed by isolated, confined, and extreme (ICE) environments. It highlights the importance of integrating scientific and psychological theories into digital therapies to create comprehensive evidence-based interventions. These interventions aim to significantly improve the quality of life and mission success for future space explorers, offering more than stand-alone one-off solutions. This will require continuous innovation and research in leveraging advanced technologies to meet the evolving demands of human space exploration and habitation.

KEYWORDS

immersive technologies, advanced interfaces, virtual reality, space psychology, ICE environments

Introduction

The progress in space exploration has sparked renewed enthusiasm within government space organizations, including the National Aeronautics and Space Administration (NASA), the UK Space Agency (UKSA), the European Space Agency (ESA), and the Japan Aerospace Exploration Agency (JAXA). These entities are accelerating their plans for human missions to the Moon and Mars in the coming decades, evolving into a global effort characterized by both competition and collaboration (Marshall, 2019; Marshall, 2023; White, 2021).

With growing public interest, rapid innovation, and strategic cross-sector and multinational alliances, large-scale projects such as NASA's Artemis program and Elon Musk's vision of establishing a self-sustaining human population on Mars could begin to materialize within the next few decades (NASA, 2024; Pagnini et al., 2023; Tangermann, 2020). These initiatives could grant unprecedented access to space for future generations.

As of today, no human has set foot beyond low Earth orbit since the 24 people who participated in the historical Apollo moon missions. This means there is a lack of empirical evidence on how people will respond to living and working in the extreme environment of deep space. Ultimately preparing for future long-duration deep space missions will involve careful consideration of the anticipated psychosocial and health challenges. Innovative evidence-based wellbeing solutions must be developed to address the needs of the crew for increasingly long-term missions extending beyond 1 year in deep space, as well as careful consideration of how we can seamlessly integrate these solutions into the requirements of space infrastructures and systems (Arone et al., 2021; Pagnini et al., 2023). Therefore, the design processes of space therapies must not only attempt to draw lessons from previous extreme missions and expeditions but must also be informed by our current understanding of engineering, computer science, and human health and psychology.

The role of immersive technologies in astronaut mental health

Extended Reality (XR) is a term for technologies like virtual reality (VR), augmented reality (AR), and mixed reality (MR) that alter our perception of reality through computer-generated environments and interactions. XR includes fully virtual worlds (VR), digital overlays on the real world (AR), and real-time interactions between physical and digital elements (MR) (Milgram and Kishino, 1994; Riva et al., 2016).

A growing body of evidence highlights the important role of immersive technologies and advanced interfaces in addressing social, mental health, and medical challenges on Earth (Freeman et al., 2017; Nakisa, et al., 2020; North and North, 2017; Park et al., 2019; Riva et al., 2016; Riva and Serino, 2020; Turner and Casey, 2014). Recent findings also support the potential of Extended Reality (XR) technologies for applications in unique environments such as isolated, confined, and extreme (ICE) conditions, including space missions to low Earth orbit (LEO), near-Earth orbit (NEO), the Moon, Mars, and beyond (Anderson et al., 2023; Pagnini et al., 2023; Whiteley et al., 2018; Wu, 2015).

Future advancements in technology will continue to drive research and innovation in this area, offering new psychological support solutions for individuals both on Earth and in space. As a psychologist and the co-founder of EarthscapeVR, this author explores the critical importance of integrating innovative thinking and psychological principles, in the creation of digital space therapies and the design of off-world habitats aimed at promoting wellbeing.

The importance of understanding stress

Societal progress, driven by rapid technological advancements, has brought unprecedented comfort and choice (Pinker, 2017). These advancements, while improving life quality, have also increased stress levels related to modern life (Maté, 2022).

Today's world presents a notable division between plentiful creature comforts, demonstrated by streaming entertainment, online shopping, and climate-controlled environments, and a multitude of challenges such as information overload, social disconnection, increased daily responsibilities, and societal expectations for success and productivity (Maté, 2022). This oscillation between these opposing poles can lead to diverse outcomes. On one end, the relentless pursuit of pleasure may ensnare individuals in a hedonic or comfort treadmill. Conversely, the enduring stress of daily life may precipitate a form of life dysmorphia. Consequently, modern human survival diverges from our evolutionary origins, where innate survival strategies tackled tangible and immediate threats, while contemporary challenges impose a persistent low-level strain, gradually affecting wellbeing over time (Maté, 2011; Benton et al., 2021).

We've also witnessed the social and individual impact of chronic stress during major global events like the COVID-19 pandemic (Kar et al., 2021; Huy et al., 2021). Historical examples, such as 19th-century Arctic expeditions (Cacho, 2020) and more recent cases of people like Paul Alexander, 'The Man in the Iron Lung,' (Snowdon, 2024) highlight the toll stress in the form of extreme confinement and isolation can have on the mental and physical health of individuals and groups. These instances also underscore human resilience and adaptability in enduring harsh conditions.

Stress is the activation of bodily responses typically triggered by undesirable situations or conditions. It can be experienced both positively (eustress) and negatively (distress). Stress manifests in various forms: acutely, episodically, or chronically. The nature, intensity, and duration of stress significantly influence its effects. Environmental, biological, and psychological factors also shape our stress responses (Al'Absi et al., 2021; Antonovsky, 1979; Butler and Finn, 2009). Ultimately, an overactive stress response can be disruptive to the nervous and immune systems, thereby increasing the risk of complex health conditions developing (Maté, 2011).

The General Adaptation Syndrome (GAS), proposed by Hans Selye in 1936 (Selye, 1950), describes the body's response to stress as occurring in three stages: alarm, resistance, and exhaustion. In the alarm stage, the body recognizes the stressor and activates the fight-or-flight response, releasing stress hormones such as cortisol and adrenaline. The resistance stage follows, during which the body attempts to adapt to the ongoing stressor by maintaining physiological arousal while coping with the stress. Finally, if the stress continues unabated, the exhaustion stage sets in, where the body's resources become depleted, leading to physical and psychological breakdown.

Acute, intense stressors that threaten homeostasis cause stress-induced analgesia, a short-term pain suppression as part of the fight-or-flight response. Conversely, prolonged stress leads to stress-induced hyperalgesia, exacerbating pain and increasing psychological and psychosomatic symptoms. This illustrates the mind-body connection and how different forms of stress can either dampen pain responses or produce psychosomatic symptoms. In this way, understanding homeostasis and the fight-or-flight response are fundamental to stress theory and research (Al'Absi et al., 2021; Butler and Finn, 2009).

As an applied and experimental psychologist, I have observed an increase in chronic stress, supported by empirical evidence (Al'Absi et al., 2021; Butler and Finn, 2009; Maté, 2011). Psychological disorders can in part stem from emotional stress, particularly fear and anxiety. Debilitating fear related to uncertainty, judgment, or catastrophe can lead to mental distress and pathological conditions (American Psychiatric Association, 2013). For instance, OCD can arise from fear of uncertainty, while social anxiety can stem from fear of judgment (DSM-5). Effective clinical treatments must therefore acknowledge and address these underlying fears.

Contrary to the detrimental effects associated with negative forms of chronic stress, certain acute stressors or eustressors appear to exert a positive influence on our internal systems. Notably, expressions of intense positive emotions, such as excitement and awe (Stellar et al., 2015) as well as lifestyle practices including intermittent fasting (Mattson et al., 2017), cold-water immersion (Hohenauer et al., 2015), and high-intensity interval training (HIIT) (Kilpatrick et al., 2014), have demonstrated some beneficial effects on both mental health and physical wellbeing.

As our understanding of stress advances, we gain insights into both its potential adverse effects and benefits. It becomes evident that prolonged periods of comfort and satiation may not always be optimal for the human system, particularly when not balanced with brief periods of positive stress that push individuals beyond their comfort zones. This concept aligns with the notion of the "window of tolerance," wherein intermittent stressors, when within this window, can facilitate resilience and adaptation (Siegel, 1999).

The stress of human space flight

Long-duration space missions pose unprecedented psychological challenges for astronauts including astronauts having to deal with existential threats, living in confined and mechanical environments, being far away from Earth, and having to content with daily monotony (Gabriel et al., 2012; Pagnini et al., 2023; Whiteley et al., 2018).

Sensory underload emerges as another potential notable stressor among astronauts (Pagnini et al., 2023), an area less commonly recognized. Unlike the sensory-rich environments prevalent on Earth, space habitats often lack the diverse stimuli integral to shaping our daily perceptual experiences. Prolonged exposure to such environments can lead the brain to compensate for this lack of stimuli by allowing neighboring areas to take over inactive regions (neuroplasticity) or by generating visual or auditory hallucinations to fill the gaps left by the absence of varied external stimuli (Whiteley et al., 2018). For example, the Ganzfeld effect, resulting from prolonged sensory underload or deprivation, prompts the brain to react to the absence of external stimuli, potentially inducing altered states of consciousness (Storm and Tressoldi, 2017). Understanding these phenomena can inform the design of wellbeing measures to mitigate perceptual stressors by providing sensory stimulation or by promoting relaxation.

Another significant stressor demanding attention during long-duration space missions is the disruption to the circadian rhythm. The International Space Station (ISS) orbits the Earth every 90 min, this means, when time permits, astronauts can experience approximately 16 sunsets and sunrises every day. The disruption to circadian rhythm means they typically lose around 2 h of sleep per night, with some resorting to medication to facilitate sleep onset. In this context, the perception of day and night diverges significantly from the typical experience of most Earth-dwellers (Whiteley et al., 2018; Wu et al., 2018). Our body's internal clock and circadian rhythm are intricately linked to the natural rhythm of the Earth. Any substantial disruption to this rhythm negatively impacts sleep quality and mood.

This discussion is by no means an exhaustive list of all the stressors and relevant psychological theories applicable to space health and habitat design. Instead, it serves as a reminder that through understanding psychological systems, and by defining the nature of stressors astronauts may encounter, we can devise more effective strategies for managing them.

Integrating physical and mental wellbeing: insights from modern science

Recent perspectives have highlighted the relationship between physical wellbeing and various physiological determinants such as inflammation, temperature regulation, hypoxia, glucose regulation, gut microbiota, and metabolic rate. These factors influence metabolic efficiency and cellular metabolism, playing crucial roles in overall health. Today, alongside social aspects like loneliness, immobility, and poverty, these physiological determinants are also increasingly recognized for their potential impact on mental health (Bohnen et al., 2023; Palmer, 2022).

As modern scientific discoveries accelerate, the theory that metabolic efficiency and cellular metabolism are correlated with mental health is gaining increasing support. Metabolic efficiency refers to an organism's ability to harness energy from nutrients to execute vital physiological functions while minimizing waste production. Cellular metabolism encompasses the intricate biochemical reactions responsible for both breaking down (catabolism) and building up (anabolism) molecules to produce and utilize energy. Regulating these processes is paramount for stabilizing cellular function, thus fostering enhancements across all levels of biological organization and potentially yielding positive clinical outcomes (Bohnen et al., 2023; Palmer, 2022).

Christopher Palmer's recent book, "Brain Energy," explores the interaction between biological processes, the brain, and the mind, presenting a unifying theory that posits mental disorders as metabolic disorders of the brain. Palmer's exploration elucidates the mechanisms through which biological systems endeavor to safeguard both body and mind from harm, swiftly mobilizing adaptive responses when confronted with stressors. This theory offers new solutions aimed at long-term healing rather than mere symptom reduction (Palmer, 2022).

Another emerging area of interest lies in exploring quantum effects within living systems and human biology (Al-Khalili, 2023; Palmer, 2022). Quantum mechanics delves into the behavior of particles at the smallest scales. While further research is required to fully grasp the role of quantum phenomena in biology, studies suggest quantum coherence may enhance energy transfer in photosynthesis (Al-Khalili, 2023; Engel et al., 2007; Romero et al., 2014), quantum entanglement might aid in animal navigation, such as magnetoreception in birds (Al-Khalili, 2023; Holland, 2014), and quantum processes could influence enzyme reactions and protein functions within cells, with quantum tunneling potentially impacting enzyme catalysis (Ball, 2015). However, despite the connections being explored, additional research is necessary to fully understand the role of quantum phenomena in biology and their implications for human health and disease.

Nikola Tesla's renowned aphorism, "If you want to find the secrets of the universe, think in terms of energy, frequency, and vibration" (Tesla, 1900), resonates not only within the field of physics but also potentially in our understanding of human biology and wellness. This aligns with theories like The Frequency Resonance Hypothesis (FRH) that suggest psychological and physiological states can be influenced or harmonized through exposure to bioelectromagnetic forces or specific frequencies. The core idea is that every system—whether biological, psychological, or environmental—has its own natural frequency, and when these frequencies are in resonance, optimal functioning and wellbeing can be achieved (Levin, 2003; Oschman, 2015). By acknowledging the interplay of factors influencing quantum, molecular, and cellular processes, we can enhance our understanding of the nuanced relationship between these processes and overall organismal wellbeing.

Conclusions about digital therapies for space

To conclude, developing evidence-based wellbeing measures for future space missions requires considering several key factors. Firstly, we must adopt a model that recognizes the interconnected nature of human existence. Rather than viewing ourselves as isolated entities, we're integrated beings, deeply connected to both our internal processes and the external world. Thus, understanding the human ecosystem as part of a larger whole is essential.

Secondly, mood and emotions play a significant role in determining our wellbeing. It is crucial to distinguish between different types of emotions and to investigate their impacts. Similarly, exploring various forms of stress, such as acute and chronic stress, distress, and eustress, is essential for understanding their distinct effects on mental and physical health. This understanding facilitates the development of interventions that can address not only the adverse effects of chronic stress but also potentially teach us how to harness positive stress effectively.

Thirdly, in designing off-world space therapies, habitats, and space vessels, principles from psychology, such as Gestalt theory, can inform well-being measures. Gestalt psychology emphasizes the mind's tendency to perceive incomplete stimuli as unified wholes (Wagemans et al., 2012). Applying this concept, wellbeing environments should prioritize clear visual cues and holistic design to promote a sense of completeness and coherence, which can further reduce stress and enhance well-being (Christou and Parker, 2023).

Finally, we must consider the intricate processes of communication and information exchange within the human organism, spanning from the quantum to the biological and psychological levels. Each level appears to operate with its own distinct mechanisms, influencing the processing and exchange of energy and information. Understanding these dynamics is emerging as a crucial area for designing novel well-being measures that address the diverse needs of human beings.

The groundwork is being laid for a unified science of wellbeing, underscoring the importance of adopting a comprehensive approach to health that encompasses both physical and mental wellbeing. Ranging from positive to negative stress and spanning disciplines from psychology to biology and even physics, including quantum biology and Tesla's foundational universal principles, the integration of these theories stands to drive forward innovative therapeutic applications that can undergo empirical scrutiny. Embracing such a holistic perspective is crucial for nurturing innovative therapeutic interventions aimed at mitigating the psychosocial impacts of extreme environments, both terrestrial and potentially within the area of human space exploration. The development of a comprehensive digital therapeutic framework is crucial and will be reliant on the strategic integration of immersive technologies and advanced interfaces. These innovations must be grounded in psychological principles and can combine restorative immersive environments with biofeedback interfaces, artificial intelligence, affective computing systems, and sensory stimuli such as lights, pulses, and vibrations (Nakisa et al., 2020). This approach will enhance clinical outcomes by leveraging the synergy between engineering, computer-science and psychological insights.

Interventions can further be enhanced by leveraging insights from conventional evidence-based psychological therapies such as Cognitive Behavioral Therapy (CBT), nature-based therapies, Eye Movement Desensitization and Reprocessing (EMDR), and Dialectical Behavior Therapy (DBT) (David and Cristea, 2018; Harvey et al., 2019; Wilson et al., 2018). When integrated into habitat design and daily routines, these interventions can aid astronauts in stress restoration, emotional regulation, relaxation, and engagement—essential components for maintaining their well-being during space missions.

Space Age II will inevitably redefine space psychology and may lead to the identification of novel space syndromes. Rather than solely focusing on conventional assessments and countermeasures, a holistic and systemic approach will be necessary. This approach should encompass psychological diagnostic and evaluation measures, comprehensive data collection systems, and robust training methods and wellbeing support across key developmental needs and levels of daily life in space and upon the crew's return.

The Overview Effect, a perspective shift reported by astronauts viewing Earth from space, fosters feelings of interconnectedness and awareness of the planet's fragility (White, 2021). EarthscapeVR®, a social impact company I co-founded, emerged from my psychology doctoral research on the Overview Effect's therapeutic potential. Specializing in immersive, nature-based digital programs and therapeutics, we combine virtual experiences with positive psychology, neuroscience, and green therapies. Future advancements may include biofeedback and AI for proactive mental health support (Nezami, 2017).

Our initial research phase (McKeever et al., 2024; Van Horen et al., 2024) indicates that our stand-alone VR experiences can elicit awe and a sense of connection to nature. The next phase will evaluate a 12-week VR-assisted program aimed at supporting mental health in individuals facing stress and anxiety, and those working in extreme environments. Space mental health offers numerous research avenues, including exploring how sensory stimulation can reduce psychological stress and counteract sensory underload during extended isolation. Another potential area of focus could be to test the relevance of optimal arousal theory in space by examining how heightened awareness and reactivity (affect arousal) impact mood, physiology, metabolism, and cognitive performance. Additionally, studies can explore whether interoceptive biofeedback and arousal regulation can improve resilience, mood, and cognitive functioning in both Earth-based and space environments. The potential areas to research in mental health are endless.

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.

Author contributions

AN: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing–original draft, Writing–review and editing.

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Conflict of interest

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

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