

Causes of Higher Cortisol Levels in Astronauts During Space Missions and Effects of Implemented Stress Reduction Measures

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ABSTRACT

Mental health challenges among astronauts have become a critical concern as space agencies prepare for longer missions to the Moon and Mars. Although spaceflight technology has advanced to support physical survival in microgravity, the psychological effects of isolation, confinement, and sensory deprivation remain major obstacles to human performance and mission success. This paper reviews published literature on mental health decline during extended space missions, focusing on environmental, physiological, and interpersonal factors. Drawing on NASA behavioral health reports, analog environment studies, and literature on cortisol as a stress biomarker, this review synthesizes evidence linking chronic physiological stress with emotional and cognitive deterioration. The reviewed literature suggests that astronauts may experience elevated cortisol levels, poor sleep quality, and increased mood disturbances over time. Elevated cortisol and sleep disruption are frequently discussed alongside reports of anxiety, irritability, and emotional detachment, particularly during the midpoint and later stages of missions. Disrupted circadian rhythms, sensory monotony, and interpersonal conflict emerge as major contributors to psychological strain. The literature also highlights important research gaps, including small sample sizes, reliance on self-reported data, and insufficient study durations to accurately model deep-space missions. The synthesized evidence indicates that current countermeasures, including structured communication and relaxation protocols, may be insufficient for maintaining mental health during multi-year expeditions. Potential future interventions include improved environmental design, real-time biomarker monitoring, expanded use of virtual reality therapy, and enhanced psychosocial training. Protecting astronaut mental wellbeing is therefore essential not only for individual health but also for safe and successful long-duration space exploration.

Keywords: Astronauts; Space; Stress; Cortisol; App; Circadian Rhythm; Isolation; Confinement

INTRODUCTION

Imagine waking up and seeing sixteen sunrises in just one day. For astronauts, this is a normal part of life in

space. Sunita Williams, renowned American astronaut, herself quoted “Space is my happy place” (1). Williams enjoys her time in space while exploring the treats and treasures of the outside world. “You don’t see any borders between countries from space”. But alongside this unique experience, astronauts face lots of challenges they have to deal with differently away from Earth. Spaceflight also exposes astronauts to hazards such as radiation related DNA damage and increased long duration health risk, including cancer risk beyond Earth’s protective environment (2). Astronauts also experience

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mental challenges. Isolation from family, disrupted sleep cycles, heavy workloads, and constant stress make space missions not only physically demanding but also mentally exhausting. These struggles strike an important question: How can astronauts take care of their mental health when they are millions of miles away from Earth?

On Earth, technology has already become a major resource for people struggling with anxiety, depression, and stress. Apps like Calm and Headspace, online therapy platforms such as Better Help, and even AI chatbots make support more accessible than ever. These tools give people privacy, flexibility, and new ways to manage their emotions, though they cannot fully replace traditional methods like in-person therapy, peer support, or lifestyle changes. In spaceflight contexts, the design of well-being supportive technologies has already been identified as an important component of behavioral health support (3).

Astronauts, who cannot access those traditional supports in space, often rely heavily on technology for their mental well-being (3-5). From advanced communication systems that keep them connected to loved ones, to digital tools that support sleep, stress management, and cognitive health, technology plays a key role in helping them stay psychologically strong during missions (3-5).

The reviewed literature suggests that astronauts may experience measurable declines in mental health during long duration missions. These declines are commonly associated in literature with isolation, disrupted biological rhythms, and elevated cortisol levels (5-9). Current research and agency risk assessments identify persistent concerns related to behavioral health, psychiatric risk, and psychosocial strain during long duration missions (6, 10). These problems may be reduced by technological features on various mental health-based tools, which can provide support when direct Earth based care is limited (3-4, 11-12). This paper is presented as a narrative review rather than an original empirical study. It synthesizes published findings from institutional reports, narrative reviews, and representative studies to provide a conceptual overview of recurring stress pathways, reported psychological effects, and potential mitigation strategies relevant to long duration missions.

EFFECTS OF SPACEFLIGHT STRESS

The reviewed literature underscores the intricate and interconnected nature of psychological decline in astronauts during long duration space missions. Elevated

cortisol levels are frequently described as a physiological marker of sustained stress, aligning with behavioral indicators such as fatigue, irritability, and cognitive dulling (5-6, 8). The literature also reports associations between cortisol dysregulation and self-reported mood disturbances, suggesting that the body's endocrine system is deeply affected by environmental and psychological challenges in space. These findings support prior literature emphasizing the stress inducing effects of confinement, sensory deprivation, and disrupted circadian rhythms in microgravity environments (6, 9). Figure 1 depicts mean cortisol levels during different phases of a mission.

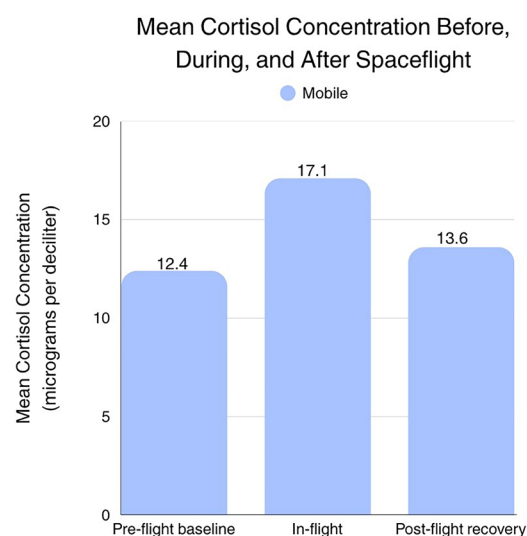


Figure 1. Mean cortisol concentrations before, during, and after spaceflight. Illustrative comparison of mean cortisol levels across pre-flight baseline, in-flight, and post-flight recovery phases, highlighting the tendency toward elevated physiological stress during space missions and partial normalization following return to Earth. Adapted from Arone A, et al. *The burden of space exploration on the mental health of astronauts: a narrative review* (6).

Furthermore, the reviewed literature reinforces the “third quarter effect,” a psychological phenomenon describing mid mission mood decline, typically linked to prolonged isolation and monotony. Reviewed analog studies and astronaut behavior reports describe this pattern alongside emotional detachment, sleep fragmentation, and declining morale in confined settings (5, 8). The consistency of this trend across analog studies, such as

the HI-SEAS, Mars500, and polar confinement literature, supports the view that neuroendocrine and behavioral responses co-evolve under prolonged isolation (5-8, 13).

Neurobiological Implications

The neurobiological consequences of elevated cortisol in space cannot be understated. Chronic hypercortisolemia, as observed in astronauts and analog populations, has been associated with suppressed neurogenesis, particularly within the hippocampus, a brain region integral to learning, memory, and emotional regulation (14). Under normal conditions, neurogenesis contributes to cognitive flexibility and stress resilience; however, when cortisol levels remain persistently elevated, synaptic plasticity declines, leading to decreased neural connectivity (14). In space, this effect is exacerbated by microgravity, which alters cerebrospinal fluid distribution and intracranial pressure (15). Figure 2 illustrates effects of elevated cortisol on different functional parts of the human brain.

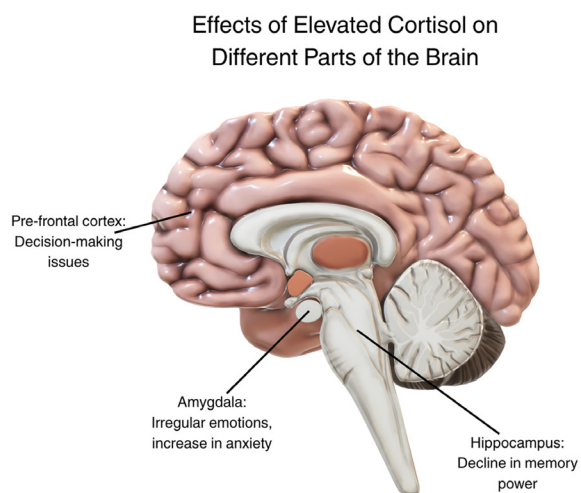


Figure 2. Neurobiological effects of elevated cortisol on major brain regions. Conceptual illustration summarizing reported associations between chronically elevated cortisol and functional changes in the prefrontal cortex, amygdala, and hippocampus, including impaired decision-making, altered emotional regulation, increased anxiety, and reduced memory performance.

Microgravity also affects brain morphology. MRI studies of astronauts' post flight have revealed gray matter redistribution, with significant volumetric reductions in the temporal and frontal lobes, areas critical for executive

function and emotion regulation (15). The compounded effect of radiation exposure further threatens neuronal health by inducing oxidative stress and DNA damage, potentially accelerating age-related neurodegenerative processes (2). Consequently, maintaining optimal brain function during long term missions requires proactive countermeasures that address both physiological and psychological dimensions of neural health (3-4, 14-15). Findings from analog studies also support concern about cumulative strain across different flight phases (5, 7-8).

Primary Causes of Mental Health Decline in Space

The reviewed literature indicates that mental health deterioration among astronauts is multifactorial, combining physiological, environmental, and social dimensions. The consistent elevation of cortisol suggests sustained activation of the body's stress system under chronic environmental challenge. Isolation and sensory monotony amplify this hormonal response by depriving the brain of varied stimuli, while microgravity further disrupts circadian rhythms and sleep quality, contributing to irregular emotional and health patterns (6-9). Together, these factors can contribute to mental fatigue that impairs decision making, emotional regulation, and interpersonal communication. Comparative studies on Earth based isolation, including submarine, polar, and Mars analog environments, describe similar stress trajectories, suggesting that confinement itself is a major driver of cognitive strain (5, 7-8). Figure 3 displays major known causes of mental health decline in astronauts during space missions. (6, 13).

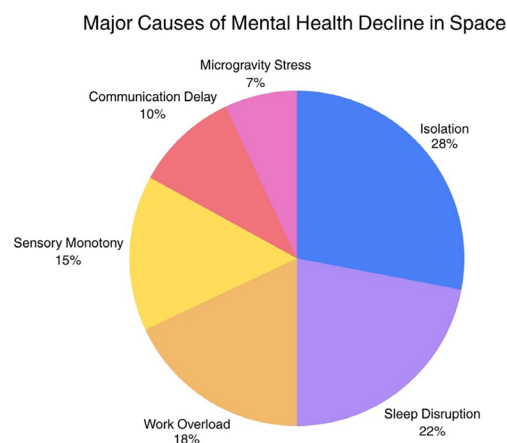


Figure 3. Major known causes of mental health decline in astronauts during space missions. Adapted from National Aeronautics and Space Administration. Risk of behavioral conditions and psychiatric disorders (10).

Cognitive and Emotional Dimensions

Cognitive fatigue, emotional flatness, and decreased interpersonal sensitivity are frequently reported during long duration missions. These symptoms reflect both biochemical and psychosocial processes: elevated cortisol can impair the prefrontal cortex’s ability to regulate emotional impulses, while prolonged confinement disrupts normal social feedback loops. The resulting deficits in communication and mood regulation pose risks not only to individual well-being but also to crew cohesion, a cornerstone of mission success (6, 13).

Cognitive performance declines under stress. Reviewed studies describe slower reaction times, diminished working memory, and reduced executive functioning when cortisol remains elevated for extended periods. Such cognitive impairment in high stakes environments can compromise mission safety, making psychological health not just a medical issue but an operational concern (6, 8).

Isolation intensifies these effects by limiting social stimulation and emotional expression. The absence of natural light cycles, sensory diversity, and spontaneous social interaction creates an artificial, uniform psychological environment that challenges human adaptability. Over time, astronauts may experience “psychological distance” from Earth, a growing detachment that undermines motivation and emotional stability. This phenomenon parallels findings from polar expedition teams, where extended confinement leads to slower emotional recovery (6). Figure 4 shows decreasing positive emotions experienced by astronauts over time.

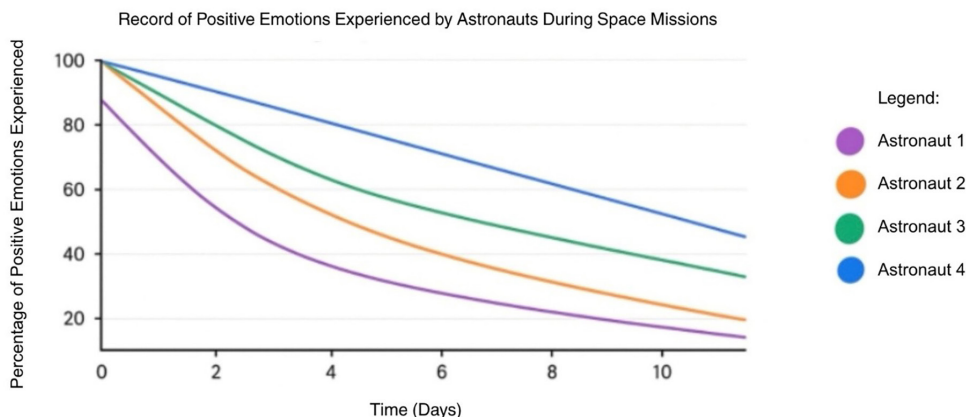


Figure 4. Astronaut positive emotion levels over time during space missions. Adapted from Stuster J. Behavioral issues associated with long-duration space expeditions: review and analysis of astronaut journals (5).

Environmental and Social Contributors

Environmental stressors amplify physiological and social responses in complex ways. Temperature fluctuations and noise from spacecraft machinery create a background stress load that can intensify irritability. Spatial confinement restricts personal privacy, contributing to interpersonal tension. Sleep deprivation, one of the most cited stressors, arises from inconsistent light dark cycles and physical discomfort in microgravity, directly correlating with hormonal imbalance and negative effect (5, 7). Figure 5 compares varying categories of aspects (biological, psychological, and social) of raised stress levels during astronauts’ space missions.

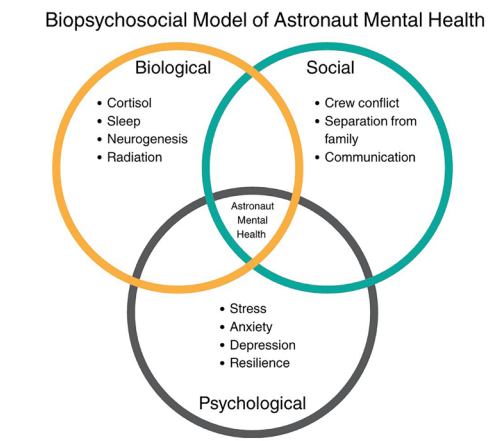


Figure 5. Biological, Psychological, and Social causes/ aspects of raised stress levels during astronauts’ space missions. Source: conceptual synthesis created by the author based on the reviewed literature.

Social dynamics within small crews further compound stress. Hierarchical structures, task distribution, and differences in coping styles can either mitigate or amplify psychological strain. In successful missions, strong interpersonal trust and role clarity have been shown to buffer stress and maintain morale. Conversely, breakdowns in communication or unresolved interpersonal conflict can lead to emotional withdrawal and decreased mission performance (5, 7). These findings underscore that astronaut mental health is not solely an individual concern but a systems level issue dependent on environmental design, crew dynamics, and structured psychosocial support.

TECHNOLOGICAL COUNTERMEASURES

Given the communication delay between Earth and deep space missions, autonomous psychological support technologies are becoming essential (3-4, 12). AI driven chatbots, such as those using Natural Language Processing (NLP) and Large Language Models (LLMs), can offer immediate emotional assistance and behavioral guidance when direct human interaction is impossible (3-4). Integrating such systems into astronaut support frameworks can help identify early indicators of distress through speech analysis, facial recognition, and mood tracking (3-4).

Furthermore, virtual reality (VR) has emerged as a promising tool for psychological restoration. Simulated natural environments, forests, oceans, or even Earth landscapes provide sensory variety and visual relief from the monotony of spacecraft interiors (3, 11-12). Reviews of VR based stress management interventions and off-world mental health technologies suggest that such tools can reduce perceived stress and improve positive affect when thoughtfully implemented (3-4, 11). These interventions can be enhanced by pairing VR with biofeedback technologies, enabling astronauts to monitor their heart rate variability, cortisol levels, and sleep quality in real time (3, 4, 11, 12).

Despite their promise, technological solutions have limitations. Overreliance on automated tools can diminish human emotional engagement, and excessive screen time may worsen sleep quality or social withdrawal (3, 4). Moreover, the lack of physical human empathy in AI systems can limit their long-term therapeutic impact (3, 4). Therefore, technology must complement, not replace, human connection, maintaining a balance between automation and authentic emotional communication (3, 4).

Ethical and Regulatory Considerations

Implementing mental health technologies in space introduces ethical and regulatory complexities. Data privacy, informed consent, and the secure handling of psychological records are crucial, especially when continuous biometric and behavioral monitoring is involved (4). Astronauts operate within broader legal and institutional frameworks, including the Outer Space Treaty and NASA guidance on Space Act Agreements, which shape how technology and operational partnerships are governed in space related activities (16, 17). Integrating mental health monitoring into these frameworks requires transparency to prevent misuse of sensitive emotional data. (16, 17).

Additionally, the ethical boundaries of AI intervention must be clearly defined. If an AI detects early signs of depression or psychological instability, questions arise: who receives that information, how is it acted upon, and what are the implications for crew autonomy? Establishing ethical guidelines for data sharing, informed consent, and algorithmic accountability will be essential before deploying these systems on future missions (4, 16).

Implications for Deep Space Exploration

As humanity prepares for missions to Mars and beyond, psychological sustainability will be as critical as technological readiness (3-4, 6-7, 10). Deep space missions will expose astronauts to unprecedented durations of confinement, potentially exceeding 1,000 days, with limited communication windows and total isolation from Earth based real time support. These conditions amplify every stressor identified in shorter missions: isolation, microgravity and circadian disruption (2, 7).

The reviewed findings imply that psychological resilience must become a central selection and training criterion for astronauts (5-6, 10, 18). Beyond technical expertise, crew members will need to demonstrate high emotional intelligence, adaptability, and conflict resolution skills (5-7, 18). Preflight psychological conditioning, including stress inoculation, mindfulness-based stress reduction (MBSR), and cognitive behavioral therapy (CBT) training, can equip astronauts with tools to regulate their own mental state under pressure (18).

Space agencies must also invest in designing habitable environments that support mental health, including natural lighting, private spaces, sensory stimulation, and real time emotional support systems (3-5, 7). The future of space exploration will depend not only on engineering

precision but also on the ability to preserve the human mind's stability in alien environments (3, 7).

Human Connection and the Psychology of Isolation

Despite the promise of advanced technology, human connection remains irreplaceable. The simple act of conversation, facial expression, or shared laughter provides emotional grounding that AI systems cannot replicate. Research on confinement and long duration expeditions consistently suggests that social support can buffer stress responses and help preserve morale under isolated conditions (5, 7). Thus, maintaining strong relational ties with mission control, family, and crewmates should remain a top priority in space psychology protocols. Innovations such as asynchronous video messages and virtual family interactions can bridge emotional gaps when real time communication is impossible. Moreover, group based mental health programs, where astronauts openly discuss experiences, frustrations, and coping mechanisms can foster trust and solidarity (5, 6).

Bridging current research gaps through long term, integrated, and ethically governed studies will be vital for ensuring that future astronauts not only survive in space but thrive within it (3, 4, 6, 7, 10). As we look toward Mars, the Moon, and beyond, understanding and protecting the human mind remains the most essential frontier of all.

RESEARCH GAPS AND FUTURE DIRECTIONS

A review of existing research on astronaut mental health reveals several critical and persistent gaps that limit current understanding of long duration spaceflight's psychological implications. One of the most significant deficiencies lies in the lack of longitudinal psychological tracking. While numerous studies have examined short term missions or simulations extending up to twelve months, few have followed subjects for periods equivalent to the projected duration of Mars expeditions, which may last several years (7, 8). This absence of extended datasets introduces considerable uncertainty about the cumulative psychological impact of prolonged isolation, confinement, and sensory deprivation. Without continuous multiyear tracking, researchers cannot fully predict how stress responses evolve over time or how coping strategies might deteriorate or adapt in the extreme conditions of deep space (6, 8).

A second limitation involves inconsistent hormonal monitoring across studies. Cortisol, a primary biomarker

of physiological stress, has been measured using a wide variety of sampling methods, including saliva, urine, and blood plasma. These differences in collection technique, timing, and environmental control create inconsistencies that make it difficult to directly compare results between missions or experimental analogs. Moreover, fluctuations in cortisol levels can reflect not only stress but also sleep disruption, physical exertion, or dietary variation, factors that are not always controlled uniformly (6, 7). Consequently, the hormonal data that could otherwise serve as a reliable index of mental health is often rendered ambiguous by methodological discrepancies (6, 9).

Participant diversity also represents a substantial limitation in current research. Astronauts are a uniquely self-selecting population: highly trained, psychologically screened, and exceptionally resilient. Their coping mechanisms and adaptability to stress are far from representative of the general population. While this makes sense for mission safety, it introduces a scientific blind spot by narrowing the range of psychological responses studied. The lack of demographic and psychological diversity obscures the broader spectrum of human mental variability, leaving open questions about how less extreme profiles of personality, stress tolerance, or emotional regulation might fare in similar conditions (5, 7, 8). As future missions expand to include more diverse crews, potentially including scientists, engineers, and even private citizens, this limitation becomes increasingly critical to address (5, 6).

Another major gap lies in the insufficient integration of psychological and physiological data streams. Current studies often collect information on emotional well-being and cognitive function separately from biological measures such as cortisol or heart rate variability. This separation hinders efforts to establish direct, causal relationships between hormonal changes and specific emotional or cognitive outcomes. A more integrated approach, combining continuous physiological tracking with real time psychological self-assessment, could provide a dynamic and holistic understanding of how the body and mind interact under the stresses of spaceflight. Such integration would also improve predictive modeling, helping mission planners detect early warning signs of psychological decline before they manifest behaviorally (4, 6, 7).

Addressing these gaps is essential for preparing humanity's next steps into deep space, where psychological support will have to function autonomously without real time assistance from Earth. To mitigate these limitations, several evidence-based countermeasures

and potential solutions can be proposed. Structured behavioral schedules are among the most effective approaches, helping to stabilize circadian rhythms and minimize mood fluctuations (5-7, 9). By maintaining consistent light exposure, sleep, and work rest cycles, astronauts can reduce the amplitude of cortisol variations that often accompany irregular routines. Similarly, virtual reality (VR) and sensory enrichment technologies have shown promise in alleviating the sensory monotony inherent to spacecraft environments (11, 12). Immersive simulations of natural landscapes or social spaces can temporarily restore a sense of novelty and groundedness, thereby reducing feelings of confinement and isolation (3, 11, 12).

In addition to environmental interventions, emerging AI assisted monitoring systems hold potential for proactive mental health management (3, 4). These systems could analyze subtle behavioral cues such as tone of voice, facial microexpressions, or sleep patterns to detect early signs of psychological distress before they escalate (3, 4). Coupled with preflight psychological resilience training, including mindfulness and stress inoculation techniques, these tools could enhance astronauts' ability to self-regulate under pressure (4, 18). Finally, structured communication protocols that facilitate meaningful social contact with both crewmates and loved ones on Earth are crucial for maintaining morale (5-7). Regular, emotionally supportive communication acts as a psychological buffer, mitigating loneliness and reinforcing a sense of connectedness despite the vast distances involved (5, 7). Together, these measures form a multilayered framework that, if implemented systematically, could significantly strengthen the mental health resilience of future astronauts during extended missions (3-7, 12, 18).

Reviewed studies and agency report consistently describe elevated in-flight cortisol relative to preflight baseline, although the magnitude of increase varies across mission phase, sampling method, and study design. These elevations were accompanied by reported symptoms of irritability, emotional exhaustion, and concentration difficulties, and some reports suggested partial normalization within weeks after Earth reentry (5, 6, 10).

Reported behavioral outcomes are consistent with these physiological patterns. Reports indicated that emotional desensitization and reduced motivation typically emerged after the third month of long duration missions, a pattern consistent with the "third quarter phenomenon" described in other isolated environments

(5, 8). Sleep disruption was also prevalent, attributed largely to altered light dark cycles and irregular circadian rhythms.

Reviewed comparisons across mission lengths suggest that psychological symptoms may intensify with longer exposure to isolation and confinement. Longer and more demanding missions were more often associated with interpersonal tension and depressive mood states than short term flights, while stronger emotional adaptability and social cohesion appeared to buffer some stress related disruption (5, 6, 8).

Limitations of this review

This manuscript is a narrative review based on secondary sources rather than a systematic review or original dataset. The reviewed studies vary substantially in mission context, analog environment, sample size, cortisol sampling method, and outcome measures, which limit direct comparability across findings. In addition, some cited evidence comes from analog or institutional sources rather than standardized controlled trials, and these differences may introduce selection bias, reporting bias, and uncertainty when extrapolating to future deep space missions.

CONCLUSION

This narrative review synthesized published literature on the multifaceted causes of mental health decline among astronauts in space, integrating physiological, psychological, and environmental dimensions of stress. The synthesized evidence indicates that increased cortisol levels, a biological marker of chronic stress, are often reported alongside behavioral symptoms such as fatigue, anxiety, and emotional desensitization. These effects appear most strongly during prolonged missions, where isolation, microgravity, and disrupted circadian rhythms compound one another (5-9). The reviewed findings suggest that while many symptoms may improve after re-entry, the potential cumulative toll on brain health and neurogenesis remains a serious concern for future deep space expeditions.

This review also highlights critical research gaps that limit current understanding. Long term hormonal data and integrated behavioral biological monitoring remain sparse, particularly for missions extending beyond one year (4, 6-8). The lack of diverse sampling and uniform data collection protocols further constrains the generalizability of existing findings (5-8). Additionally, despite the rapid advancement of teletherapy platforms,

virtual reality tools, and AI assisted support systems, few have been systematically tested in microgravity or deep space conditions, leaving their long-term efficacy uncertain (3-4, 11, 12).

Addressing these shortcomings will require a multidisciplinary approach that unites neuroscience, behavioral science, and aerospace engineering (3, 4, 6, 7, 14, 15). Future studies should prioritize longitudinal tracking of stress biomarkers, cognitive performance, and emotional wellbeing to develop predictive models of astronaut resilience (4-7, 10). This integrated framework will not only improve mission safety and crew cohesion but also inform Earth based applications for individuals facing isolation and high stress environments (3-7, 10, 13).

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CONFLICT OF INTEREST

The author declares that there are no conflicts of interest related to this work.

REFERENCES

1. Sharma D. "Space: The Indian Story" Bloomsbury India; 2025. ISBN: 9789361315459.
2. National Aeronautics and Space Administration. Space radiation [Internet]. Washington (DC): NASA; 2024. Available from: <https://www.nasa.gov/hrp/radiation> (accessed on 2026-2-20)
3. Smith N, *et al.* Off-world mental health: considerations for the design of well-being-supportive technologies for deep space exploration. *JMIR Form Res.* 2023; 7: e37784. <https://doi.org/10.2196/37784>
4. Sharp J, *et al.* Virtual reality and artificial intelligence as psychological countermeasures in space and other isolated and confined environments: a scoping review. *Acta Astronaut.* 2025; 232: 666-77. doi:10.1016/j.actaastro.2025.04.002.
5. Stuster J. Behavioral issues associated with long-duration space expeditions: review and analysis of astronaut journals. NASA/TM-2010-216130. Houston (TX): National Aeronautics and Space Administration; 2010.
6. Arone A, *et al.* The burden of space exploration on the mental health of astronauts: a narrative review. *Clin Neuropsychiatry.* 2021; 18 (5): 237-46. doi:10.36131/cnfliortitidore20210502.
7. Pagel JI, Choukèr A. Effects of isolation and confinement on humans-implications for manned space explorations. *J Appl Physiol.* 2016; 120 (12): 1449-57. <https://doi.org/10.1152/jappphysiol.00928.2015>
8. Basner M, *et al.* Psychological and behavioral changes during confinement in a 520-day simulated mission to Mars. *PLoS One.* 2014; 9 (3): e93298. <https://doi.org/10.1371/journal.pone.0093298>
9. Guo J, Gan X, Ma H. Time in space: advances in the study of circadian rhythms under microgravity. *Chinese Journal of Space Science.* 2021; 41 (1): 145-57. doi:10.11728/cjss2021.01.145.
10. National Aeronautics and Space Administration. Risk of behavioral conditions and psychiatric disorders [Internet]. Washington (DC): NASA; 2024. Available from: <https://www.nasa.gov/reference/risk-of-behavioral-conditions-and-psychiatric-disorders> (accessed on 2026-2-15)
11. Meshkat S, *et al.* Virtual reality and stress management: a systematic review. *Cureus.* 2024; 16 (7): e64573. doi:10.7759/cureus.64573.
12. Joshi Y, Mardon A. Using virtual reality for long-duration space missions. *Technium Soc Sci J.* 2021; 20: 627-31. <https://doi.org/10.47577/tssj.v20i1.3406>
13. Palinkas LA. The psychology of isolated and confined environments: understanding human behavior in Antarctica. *Am Psychol.* 2003; 58 (5): 353-63. <https://doi.org/10.1037/0003-066X.58.5.353>
14. Sapolsky RM. Stress and the brain: individual variability and the inverted-U. *Nat Neurosci.* 2015; 18 (10): 1344-6. <https://doi.org/10.1038/nn.4109>
15. Koppelmans V, *et al.* Brain structural plasticity with spaceflight. *npj Microgravity.* 2016; 2: 2. doi:10.1038/s41526-016-0001-9.
16. United Nations Office for Outer Space Affairs. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies [Internet]. Vienna: United Nations Office for Outer Space Affairs. Available from: <https://www.unoosa.org/oosa/en/our-work/spacelaw/treaties/outerspacetreaty.html> (accessed on 2026-2-20)
17. National Aeronautics and Space Administration. Space Act Agreements Guide [Internet]. Washington (DC): NASA Office of the General Counsel; 2023. Available from: https://nodis3.gsfc.nasa.gov/OPD_Docs/NAII_1050_1E_.pdf (accessed on 2026-2-20)
18. Skorupa A, *et al.* Mindfulness in simulated space missions: enhancing job satisfaction, coping with stress, and balancing emotions. *Mindfulness.* 2025; 16 (8): 2184-95. <https://doi.org/10.1007/s12671-025-02617-5>