The Impact of Space Missions on Humans 2

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Abstract *Space exploration has entered a phase where we now have enough valuable details and experience to make it a realistic goal to leave the safety of Earth for extended periods. These journeys will be carried out on long-duration missions, with the Moon as the first target, and eventually, with sufficient knowledge, to Mars. NASA's Artemis program plans to conduct a manned mission to the Moon by 2030, aiming to establish a base that will serve as a foundation for the first human mission to Mars by 2040. Successful long-term space exploration necessitates careful attention to the human factors essential for sustaining these missions. These long-duration, isolated missions are unfamiliar to humans, where, beyond the physical challenges, the mental, relational, and psychological stresses will also be extremely significant. It is important to study the effects of these factors.*

INTRODUCTION

In the first part of the article, I analyze in detail the effects of space on the human body and organs, revealing that no area of the human body remains unaffected by the harsh and challenging environment of outer space. Although the number of these factors and effects is almost infinite, and new discoveries are constantly emerging thanks to the ongoing missions, the exploration of these effects is far from complete. NASA's Human Research Program has highlighted five essential hazards that astronauts will encounter in space: space radiation, isolation and confinement, distance from Earth, gravity (and the lack of it), and closed or hostile environments. This is called RIDGE, a mosaic word derived from the names of the above factors.[1] Beyond physical factors, psychological, relational, and sensory impacts play an equally significant, if not greater, role

1 O'Shea, A. Claire, NASA: *5 Hazards of Human Spaceflight.*

in how space affects us as whole beings. Space presents an environment unlike anything experienced on Earth, where the absence of gravity, altered light cycles, and confined spaces lead to significant sensory and psychological challenges. Astronauts must adapt to weightlessness, which alters their sense of balance, spatial orientation, and perception of movement.[2] Prolonged exposure to such conditions can disrupt the body's natural rhythms, affecting sleep, cognition, and overall well-being. For example, astronauts frequently report a reduced sense of taste and smell, which is linked to fluid shifts in the body that resemble nasal congestion, affecting their ability to perceive flavors.[3] In addition to sensory disruptions, psychological effects play a major role during long-duration space missions. Isolation from Earth, confinement with a small crew, and the stress of operating in a dangerous, alien environment can take a toll on mental health. Disorientation can heighten anxiety and stress, further intensifying the already challenging conditions of space travel. As we look toward humanity's long-term space ambitions, the challenges increase in complexity and scale. In the short term, the focus is on mitigating the effects of microgravity, isolation, and confinement during missions on the International Space Station (ISS). For the medium term, we must address the greater isolation and distance from Earth that will come with extended stays on the Moon, where astronauts will face partial gravity as a new adaptation challenge. Looking further ahead, the long-term goal of colonizing Mars will involve coping with even greater distances, extreme isolation, the lack of gravity during transit, and the need to adjust to partial gravity on the Martian surface.

The unique combination of sensory deprivation and psychological strain requires focused research and the importance of developing comprehensive strategies to ensure astronauts' well-being and optimal performance on future missions, especially as humanity looks to extended stays on the Moon and Mars.

SLEEP IN SPACE

During a space mission, it is often challenging to provide the crew with a sufficient quantity and quality of sleep. It is well-documented that sleep deprivation increases the likelihood of errors, which can be critical in such an unusual environment.[4] Studies have also shown that exhausted, fatigued individuals often struggle to recognize or acknowledge that they are not operating at full capacity.[5] Space professionals also experience negative effects from sleep deprivation, confronting disruptions to their circadian rhythms, which deteriorate neu-

2 Carriot, Jérome et al.: *Challenges to the Vestibular System in Space: How the Brain Responds and Adapts to Microgravity.*

3 Olabi, A. A. et al.: *The Effect of Microgravity and Space Flight on the Chemical Senses.*

4 Harrison, Yvonne, Horne, James: *Sleep loss impairs short and novel language tasks having a prefrontal focus.*

5 Flynn-Evans, Erin et al.: *Risk of Performance Decrements and Adverse Health Outcomes Resulting from Sleep Loss, Circadian Desynchronization, and Work Overload.*

rological responses and exacerbate existing stress. Inadequate sleep routines and a demanding work pace can lead to deficiencies that jeopardize the success of the mission and ultimately the safety and well-being of those on board. The nature of sleep in space is often compromised due to the highly variable light and dark cycles on the different space stations and inadequate illumination during daytime hours inside the habitat. Additionally, even the habit of looking out of the window before sleeping can send misleading signals to the brain, leading to inadequate sleep rhythm. According to former ESA (European Space Agency) astronaut Tim Peake's report, a major mistake is made if someone looks at the Sun before sleeping for any reason, as it can lead to significant difficulties falling asleep. This is because the intense ultraviolet radiation from the Sun halts the body's production of melatonin, the hormone responsible for regulating sleep. This disruption can completely confuse the circadian rhythm, making it extremely difficult for the individual to fall asleep for hours.[6] In light of this and other reports, it is clear that light is the primary factor disrupting circadian rhythms. The frequency of the phenomenon adds to the challenge, as the space station orbits the Earth every 1.5 hours, resulting in 16 sunrises and sunsets each day. Even with careful attention, complete relaxation remains elusive, as work on space stations is constant. Various spacecraft regularly arrive, and the schedule for experiments must be strictly adhered to. Noise levels are notably high on such stations due to the constant operation of ventilation systems and air circulators, which are essential for maintaining the proper living conditions required for humans accustomed to Earth's environment. A decade-long research of over 80 space travelers found that most needed to take powerful sleep aids to obtain sufficient sleep quality, additionally, 75% of spacecrew use hypnotics for better rest. The research indicated that although astronauts typically aim for 8.5 hours of sleep, they were only able to achieve around 6 hours of restful sleep, even with the use of medication.[7]

Figure 1: In weightlessness, it does not matter what position we sleep in relative to our surroundings (https://www.standard.co.uk/news/tech/astronauts-struggle-to-sleep-a4555931.html /24-09-20/ *Downloaded: 20.09.2024.)*

As early as the Apollo program, researchers studied the factors affecting sleep quality and found that certain conditions positively influenced rest. These factors were as follows: All astronauts on board the spacecraft must sleep at the same time, and work should be organized to allow for at least a 6-hour break from radio transmissions every 24 hours. The disruption to the circadian rhythm should be minimized. Crew members should be able to remove their

6 Peake, Tim: *Ask an astronaut.*

7 Christiansen, Anna: *Ten-year astronaut sleep study reveals widespread use of sleeping pills in space.*

work attire before sleeping, and dedicated sleeping areas must be designated. Restraints should be provided to prevent astronauts from floating and colliding with objects or each other during sleep. The temperature should be kept comfortable, the brightness of equipment should be reduced, and eye masks should be provided to block out light. Additionally, fan speeds should be lowered to reduce noise levels. On the ISS, shift work may be implemented, with blue and red teams alternating during rotation phases. Otherwise, the entire crew sleeps simultaneously, following a schedule based on Greenwich Mean Time, typically from 9:30 pm to 6:00 am. Each astronaut has a private "closet", which is dark and somewhat soundproof. They climb into a sleeping bag, zip themselves in, and secure the bag to the wall to prevent it from floating.[8]

STRESS

One of the greatest challenges during a space mission is the time spent in this hostile environment, as it is significantly different from life on Earth and presents numerous sources of stress. These can include, but are not limited to, noise, workload, microgravity, confinement, limited social interactions, and poor sleep. The longer a mission lasts, the more this exposure affects astronauts, which can, in turn, negatively impact their physical and mental well-being, as well as their overall performance. In some cases, the so-called long-term spaceflight composite stress (LSCS) may lead to depression and cognitive impairment partly by disrupting the brain's neuroplasticity. Like in space, analog settings on Earth – isolated settings combined with extremely threatening environmental challenges – can easily lead to profound psychological changes (depression, mood instability) even in remote ground-based situations (e.g. Antarctic research station as space analog) and emotional downgrading (negative patterns) can interfere with proper verbal and written communication among team members.[9] These effects warrant significant attention. As space exploration advances and more entities enter the field, we are inevitably moving toward a future where more people will be sent to space and experience the challenges of living in such an extreme environment. Private space companies, such as SpaceX, are openly aiming to colonize Mars. In these unprecedented missions, as well as in the growing field of space research today, humans remain the critical link for successful execution. This makes it essential to focus on the human factor, particularly from a psychological perspective. Decades of experience have shown that individuals working in space are subjected to significant stressors, often leading to undesirable outcomes. These stressors can trigger psychological issues such as anxiety, depression, and

8 Day, Dwayne A.: *Working on the Moon.*

9 Ehmann, Bea et al.: *Emotionality in Isolated, Confined and Extreme (ICE) Environments: Content Analysis of Diaries of Antarctic Winteroverers.*

cognitive decline.[10] NASA has conducted research in this area and released data indicating that 85.2% of female astronauts and 22.8% of their male counterparts experience symptoms of anxiety. The numbers shift slightly when it comes to depression, with 43.2% of women and 34.8% of men reporting similar symptoms. These findings are significant and highlight the psychological challenges faced by astronauts in space. In addition, further studies have found that during missions lasting several hundred days, stress-induced mental disorders appeared in 60% of the individuals examined.[11] The majority of astronauts returning from missions reported cognitive and functional impairments, which clearly point to the malfunctioning of the central nervous system.[12] NASA, in collaboration with Roscosmos, conducted an experiment where individuals stayed on the International Space Station for a year. One of the participants had an identical twin who remained on Earth. The examination of the twin brothers revealed that the sibling who stayed in space was still experiencing cognitive problems six months after returning. With this in mind, researchers must carefully plan and implement effective prevention and recovery strategies if we aim to successfully carry out deep space missions.[13] To this day, research on the central nervous system remains one of the most relevant topics from the perspective of the human factor. At the same time, the brain's ability to adapt to new stimuli and environments, known as neuroplasticity, is gaining increasing attention in the field of study. A thorough understanding of this factor will be essential for achieving our future ambitions. This adaptive mechanism may help explain the neurobiological basis of depression and cognitive discrepancies during long-term space missions. This paper explores the combined stressors that affect astronauts' emotions and cognition during long-term spaceflight and examines the neurological basis of these effects, particularly focusing on neuroplasticity, as well as potential countermeasures to address cognitive and emotional challenges. Going further for longer deep-space missions, even the possible deterioration of cognitive performance should be calculated due to the high intensity of cosmic radiation. The microgravity itself through different changes in cerebral perfusion (due to the cephalad shift) can contribute to the deterioration of certain cognitive functions based on comparison with ground-based head-down tilt bedrest.[14, 15]

10 Yin, Yishu et al.: *Long-term spaceflight composite stress induces depression and cognitive impairment in astronauts—insights from neuroplasticity.*

11 Friedman, Eric, Bui, Brian: *A Psychiatric Formulary for Long-Duration Spaceflight.*

12 Clément, Gilles, Thu Ngo-Anh, Jennifer: *Space physiology II: adaptation of the central nervous system to space flight—past, current, and future studies.*

13 Garrett-Bakelman, Francine E. et al.: *The NASA Twins Study: A multidimensional analysis of a year-long human spaceflight.*

14 Cherry, Jonathan D. et al.: *Galactic Cosmic Radiation Leads to Cognitive Impairment and Increased aβ Plaque Accumulation in a Mouse Model of Alzheimer's Disease.*

15 Barkaszi, Irén et al.: *Are head-down tilt bedrest studies capturing the true nature of spaceflight-induced cognitive changes? A review.*

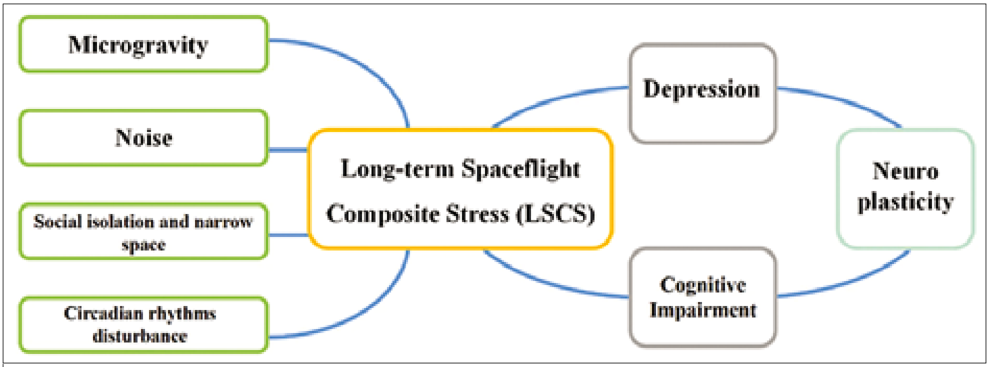

*Figure 2: Illustrative model of stress development in astronauts (*https://www.nature.com/articles/s41398-023-02638-5/figures/1 *Downloaded: 20.09.2024.)*

EMOTIONAL EFFECTS

Long-Duration Space Explorations (LDSEs), or Long-Distance Space Exploration Missions (LDSEMs), such as missions to Mars, may last up to 30 months. On shorter missions, space agencies have managed emotional challenges through preventive measures (selecting the "right stuff") and protective strategies (countermeasures). However, these approaches may not suffice for LDSEs, where even highly experienced astronauts can encounter adaptation issues and emotional disturbances.[16] For instance, during his 211-day mission on the Salyut 7 space station, cosmonaut Lebedev exhibited typical symptoms of depression, including irritability, anhedonia, and sleep disruptions. If left unchecked, affective disorders could, in the medium to long term, negatively affect team dynamics, communication, sleep quality, and cognitive and executive functions, and potentially hinder the crew's ability to respond to emergencies.[17] A study on long-duration spaceflights declared that the third week marks a turning point, as attention tends to diminish the most due to the challenges of adapting to the extreme environment.[18] In the early days, astronauts aboard the Skylab and Salyut space stations were predominantly from a single nation and spent several months on board. However, today's scenario is different. The International Space Station (ISS) hosts a multicultural environment where scientific research is conducted by crews from diverse linguistic and cultural backgrounds. While this diversity may not cause extreme difficulties, it does measurably increase stress levels. At the same time, there are positive aspects to this environment when

16 Salas, Eduardo et al.: *Teams in Space Exploration: A New Frontier for the Science of Team Effectiveness.*

17 A van Kleef, Gerben et al.: *Emotional influence in groups: the dynamic nexus of affect, cognition, and behavior.*

18 Manzey, Dietrich et al.: *Mental performance in extreme environments: results from a performance monitoring study during a 438-day spaceflight.*

viewed through the lens of emotional well-being. The collaborative efforts between nations have eliminated the host/guest dynamic often observed on earlier space stations, significantly reducing the anxiety caused by isolation.

In the near future, we will establish a foothold on the Moon and set up a base there, using the experience gained to send humans to Mars. We have already discussed the mental and physical challenges that arise during space travel, but this extremely long-duration and long-distance mission will magnify those issues. Considering the distance between Mars and Earth, communication between Mission Control and the crew will experience a delay of approximately 25–30 minutes. This delay not only limits real-time responses during unexpected situations but also significantly impacts crew morale and their sense of safety negatively. Experts are already developing various protocols to improve communication efficiency, even though signals traveling at the speed of light cannot be made faster. Alternative solutions are necessary, such as sending periodic summary "packages", using text-based messages, and optimizing the content of each message for maximum effectiveness. Personnel on a trip to Mars will not be able to rely on real-time communication with Mission Control to coordinate their schedules or activities, meaning they will need to operate with a higher level of autonomy compared to astronauts aboard the International Space Station.

While research from Earth-based space simulations indicates that crews can still meet mission objectives under autonomous conditions, more investigation is needed to understand how reduced contact with Mission Control affects crew dynamics and collaboration. Typically, Mission Control offers immediate guidance for dealing with issues or emergencies, but this real-time assistance will be unavailable on a Mars mission. To address this challenge, scientists could design simulations on Earth where varying levels of communication with Mission Control are tested.[19] This would help researchers observe how crew members interact, how well they cooperate, and how effectively they complete tasks when working independently. Spending extended periods of time in close quarters with a small group can create tension and conflicts among crew members. It has been revealed that when interpersonal stress arises, astronauts may redirect their frustration toward Mission Control, blaming them for scheduling issues or insufficient support. This can generate misunderstandings and strained communication between the crew and ground control. A potential solution to manage this tension is to set aside time each week for the crew to openly discuss any interpersonal conflicts in scheduled sessions. Research has shown that supportive commanders can significantly enhance team unity.[20] A commander with a focus on emotional support, or someone trained in conflict resolution, could lead these discussions to help crew members address and resolve their issues before they escalate and jeopardize the mission.

Spending extended time away from home can take a toll on astronauts' morale. They often feel the absence of their

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19 Dingfelder, Sadie F.: *Mental preparation for Mars.*

20 Barratt, Emma: *The psychological challenges of putting humans on Mars.*

*Figure 3: In this image, Earth is seen as photographed by the Voyager spacecraft, effectively conveying the size of our planet and the sense of uncertainty this perspective can evoke (*https://www.businessinsider.com/nasa-voyager-pale-blue-dot-photo-30th-anniversary-2020-2 *Downloaded: 02.10.2024.)*

loved ones and express worry about the well-being of family members back on Earth, particularly if a family member is ill or facing a crisis. To simulate the conditions of a Mars mission, researchers could send astronauts to the lunar space station Gateway for six-month intervals, incorporating elements such as delayed communication, greater autonomy, and distant views of Earth to mimic the outbound and return phases of the mission. The length of the mission itself will also impact crew members. A Mars mission is broken into three key phases: the journey to Mars, the stay on the Martian surface, and the trip back home. Each phase presents different challenges—while the excitement of exploring Mars could boost morale, the monotony of the return journey might lead to a decline in spirits. For those who orbit planet Earth, the view of their home planet offers a comforting reminder that family and friends are still relatively close. However, for those journeying to Mars, watching Earth gradually diminish into a tiny speck in the distance may evoke a strong sensation of isolation and homesickness. Equipping the spacecraft with telescopes that allow the crew to view Earth as a vibrant sphere in space or providing virtual reality experiences of familiar landscapes and loved ones could help alleviate the emotional impact of Earth's vanishing presence. However, these methods could also risk amplifying feelings of loss as astronauts reflect on what they are leaving behind.[21]

TASTE IN SPACE

Since the beginning of space exploration, astronauts have observed changes in how nourishment tastes in orbit. Some report that foods seem flavorless, while others notice that their preferred dishes lose their appeal. Interestingly, some astronauts develop a liking for foods they would not usually enjoy, while others claim they experience no noticeable change in taste at all. Astronauts

21 Kanas, Nick: *The psychological challenges of a long voyage to Mars.*

frequently opt for bold-flavored foods to counteract the dulling of their taste sensations in space.[22] Diet requires multiple senses, such as sight, hearing, taste, touch, and smell. For instance, when enjoying an apple, we rely on various sensations: the sweetness or sourness, the aroma, the crunch, the color, and the texture. If any of these senses are diminished, our pleasure in food changes. In space, the experience of eating differs greatly from what we are accustomed to on Earth. One reason for this could be the absence of gravity. In microgravity, bodily fluids are not pulled toward the feet but instead shift toward the head, creating a sensation similar to nasal congestion. Just like when one has a cold, this affects the sense of smell, which in turn reduces the ability to taste and enjoy food.

The environment in space is both unfamiliar and persistently repetitive, which may also alter the way we perceive food. The context in which we eat plays a significant role in our overall experience. Research has demonstrated that consuming the same meal in dissimilar environments can lead to non-identical reactions and preferences. A spacecraft is a confined, enclosed space where astronauts are surrounded by equipment and wiring, with no clear separation between work and personal areas, which may influence how they experience their meals.[23] Australia's Royal Melbourne Institute of Technology aimed to explore factors that might affect appetite in zero gravity.[24] Rather than testing their hypotheses aboard the ISS, they chose a more straightforward method using virtual reality headsets. Fifty-four volunteers donned VR goggles that simulated a room on the ISS and were asked to smell samples of lemon essential oil, along with vanilla and almond extracts. They then compared these scents to how they experienced them in a typical earthly environment. Overall, participants reported that the sweeter vanilla and almond aromas were stronger in the VR space setting, while the intensity of the lemon scent remained consistent, even though they were still physically on Earth. A series of tests combined with virtual reality ultimately proved that the sense of taste of the participants in the study did indeed change in a measurable and describable way. The food chemists on the team identified benzaldehyde, a sweet-scented compound, as a potential explanation for the heightened sensitivity to certain aromas. Researchers suggest that enhancing food aromas could significantly improve astronauts' appetites in future space missions. This approach, however, is not limited to space travel. According to the research, the findings from this study could also help customize diets in socially isolated settings, such as nursing homes, and boost nutritional intake. Though further research is required, incorporating compounds like benzaldehyde into astronaut meals may soon become a key strategy for improving their dining experience both on the ISS and during future missions.[25]

22 NASA's Space Operations Mission Directorate: *Matter of taste.*

23 Low, Julia et al.: *Astronauts don't eat enough because food tastes bland in space. We're trying to work out why.*

24 Paul, Andrew: *Why food tastes more bland in space.*

25 Loke, Grace et al.: *Smell perception in virtual spacecraft? A ground-based approach to sensory data collection.*

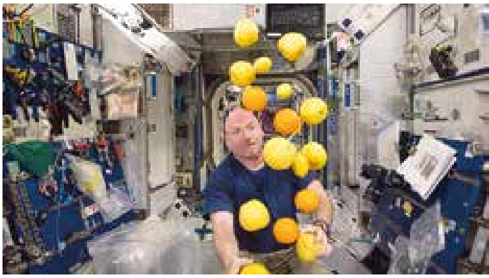

*Figure 4: A rare treat aboard the International Space Station: fresh, delicious fruit (*https://eu.jsonline.com/story/entertainment/books/2017/10/13/endurance-astronaut-scott-kelly-chronicles-his-year-space/747945001/ *Downloaded: 02.10.2024.)*

SUMMARY

Human experience in space has now been several decades, giving us a better understanding of how the body adjusts to life beyond Earth. However, with plans for further space industrialization and exploration of distant planets, humans will need to endure much longer periods in space. Most current data comes from shorter missions, meaning that many extended physiological impacts remain unknown. A voyage to Mars using today's technology is estimated to require at least 18 months of travel time. Preparing for such journeys stands in need of a deep understanding of how the body reacts to increased time in space. Onboard medical facilities must be able to handle various health issues and emergencies and be equipped with a broad range of diagnostic tools and treatments to maintain crew health throughout the mission. So far, only well-trained and rigorously tested astronauts have been exposed to space environments. As off-world colonization becomes a possibility, a wider variety of people, including children, will face these risks, and the effects on younger individuals remain unexplored. Presently, there are approximately 700 highly trained astronauts (580 male, 90 female), who are selected with scrutiny. When astronaut John Glenn, a member of the original Mercury 7, returned to space at age 77 in 1998, his nine-day mission gave NASA valuable data about the impact of space on older adults. Factors such as dietary needs and living circumstances, which have not yet been thoroughly examined, will become increasingly relevant. Overall, there is limited knowledge about the full spectrum of impacts that living in space has on a human as a whole, making it difficult to address all potential risks. The International Space Station is currently being used as a platform to study these hazards. Space remains largely uncharted, with likely still unknown dangers. However, future technologies like artificial gravity and advanced life support systems may eventually help reduce some of these risks. Colonization (mining and manufacturing) is much more complex than a longer EVA (extravehicular activity), so it will be crucial to plan and master these activities accurately in order to execute them effectively. From Earth to Orbit: the ISS can provide a "sea-level home" with reasonable weight and volume (still cost-effective) limits. From ISS to deep space: a much smaller "independently-run" home with much fewer resources. Optimal space medicine tools need to be specified. New health risk models are needed for BLEO (beyond low Earth orbit) to ensure that the risks of human presence are reduced.

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Kulcsszavak emberi tényező, érzelmi reakciók, pszichológiai hatás, érzékelési zavar, felépülés, kapcsolatok

Absztrakt *Az űrkutatás napjainkban egy olyan szakaszba lépett, ahol már megfelelő mennyiségű értékes adat és tapasztalat áll rendelkezésünkre ahhoz, hogy reális cél legyen elhagyni a Föld nyújtotta biztonságot hosszabb időre is. A hosszú távú küldetések során, az első cél a Hold lesz, majd – kellő tudás és tapasztalat birtokában – a Mars. A NASA Artemis programjának keretén belül tervezik, hogy egy legénység legfeljebb 2030-ig elutazik a Holdra, ahol egy olyan bázis létrehozása a cél, amely szilárd alapot biztosít az első emberi Mars-küldetéshez 2040 környékére. A hosszú távú űrkutatás sikeres megvalósítása érdekében gondos előkészületek szükségesek az emberi tényező terén, mivel ezek elengedhetetlenek a küldetések fenntartásához és sikeres végrehajtásához. A hosszú, elszigetelt missziók az emberek számára ismeretlenek, és a fizikai kihívásokon túl a mentális, kapcsolati és pszichológiai stressz is rendkívül jelentős lesz. Kulcskérdés tanulmányozni és értelmezni a vizsgálni kívánt tényezők hosszú távú hatásait.*