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Touch Some Grass: Cognitive Influences to Inform Environmental Modifications for Long-Duration Space Missions

Danielle F. S. Rosales
Embry-Riddle Aeronautical University

Karis N. Cooks
Embry-Riddle Aeronautical University

Shelby C. Loftis
Embry-Riddle Aeronautical University

Astronauts experience an array of cognitive stressors on the International Space Station with durations of up to one year. This, however, does not compare to the future demand for long-duration space missions to achieve exploratory milestones beyond the Moon. Isolation, confinement, and drastically reduced access to resources are primary contributors to lowered cognitive and perceptual ability. This integrative review aimed to identify available literature about the effects of extended living in space on astronauts' cognitive and perceptual influences to improve their human-environment interactions. Congruent to the popularized internet meme "Touch Some Grass," the provided baseline design considerations may mitigate these effects and allow astronauts to reconnect with the environmental modifiers only accessible on Earth such as stimulating colors, vegetation, and open air.

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The internet meme “Touch Some Grass” was popularized on social media platforms and used for those with excessive internet activity, in which the person involved would be encouraged to “go outside and touch some grass.” This saying was used in the context of essentially reconnecting with the reality of life and things, hence why they should reacquaint themselves with nature. However, this was modified not only as a way of bringing those back to reality from a slightly similar, yet different standpoint, specifically from the dangers of being in space for a long period but also from a mental standpoint, the way it was originally intended. With the national goal of having humans on the moon once more by 2030 and eventually Mars, it is crucial to provide support for future astronauts who are completing deep space or long-duration missions (LDMs).

This paper will highlight the considerations and demands of LDMs in space. This includes a review of the stressors astronauts experience during pre-flight, in-flight, and post-flight processes including physical and cognitive demands such as extended work hours, isolation, and reduced sensory stimulation. The next section will address the ideal factors that astronauts must have for optimal human performance (e.g., sleep, human behavior, psychological adaptation) along with why these factors are important to address in the context of LDMs. The third section will tackle physical environment modifications for deep space missions (the incorporation of color, greenery, and windows), including potential recommendations on what to include both within future orbital space station designs and planetary base designs. The final section will summarize what was discussed throughout the paper, where we are now, and will provide input on how this could assist in moving the Human Factors field forward. “Touch Some Grass” is then appropriated from an entertaining statement to now being associated in a logical context, used as a means of providing a way for mitigating monotony and boredom in LDMs through environmental modifications.

Long-Duration Missions: Considerations and Demands

LDMs are frequently utilized within the realm of interplanetary exploration, extending the trip length as a means to maintain space stations or venture farther into the galaxy. This type of spaceflight is incredibly costly, requiring extensive preparation and testing before presenting a feasible project. LDMs are defined by NASA as missions exceeding 90 days aboard, however, the longest single-mission human stay was 437 days by Russian cosmonaut Valeri Polyakov, after having already spent 240 days in space on a previous LDM (New Mexico Museum of Space History, 2021). With astronauts spending such significant time onboard spacecraft, recognizing how they interact with technological systems, unfamiliar environments, and their fellow crew members is imperative to mission success. Providing a habitat built with adaptability at the forefront of the design process will help astronauts who are expected to rapidly adapt to foreign and extreme environments.

Considerations for LDMs are chosen by searching for the specific and possibly unconscious aspects of the spacecraft environment with potential for improvement, whether through technological efficiency or psychological perception. Designing future space habitats around certain aspects of living in space can serve to greatly improve the experience of astronauts and even pave the way for accessible space tourism. By going through each separate phase of LDMs, it becomes easier to determine which considerations are of the highest priority to enhance overall livability within a spacecraft.

The three different phases of LDM flight are pre-flight, in-flight, and post-flight. Each of these phases presents individual effects on the health and performance of crewmembers. Astronauts will experience a variety of physical and cognitive abnormalities they are not typically faced with when operating normally on Earth.

Pre-Flight

Physical and cognitive challenges are first addressed during pre-flight as crewmembers are required to undergo adaptation training to help in countering motion sickness during spaceflight (Harm & Parker, 2013). Astronaut training includes a review of the in-flight considerations that are widespread due to the diverse nature of LDM-related tasks. Important areas to focus on are those involving work, hygiene, privacy, sleep, and leisure. Crewmembers typically spend 12-hour workdays completing task lists sent by their command center, with breaks for meals and 2.5 hours of physical exercise split up between working on experiments, maintaining the space station, and cleaning, (NASA, 2009). To ensure all these tasks can be completed seamlessly, astronauts need access to highly ergonomic and efficient workstations taking into account long hours and team-based projects.

In-Flight

There are multitudinous stressors to be wary of when astronauts begin in-flight operations. Perceptual errors are immensely common due to heightened spatial disorientation and poor motor coordination while in microgravity, (Harm & Parker, 2013). This means it is essential to provide crewmembers with the most effective tools to complete their missions with a minimal margin of error, particularly involving manageable storage, integrating standardized interfaces, and autonomous usability of machinery all while conducting ongoing training, (Hauplik-Meusburger, 2010). Since attention levels and expectations about position and movement influence perception, it is necessary to be aware of how the spacecraft environment looks from irregular angles. Some astronauts reported that multiple light sources coming from each wall confuses astronauts when trying to reorient upright (Schlacht, 2012).

The limited area of space stations, and the inability to leave, can also affect the comfortability of leisure time, as many astronauts reported spending a large majority of the allocated time looking at Earth through windows in the spacecraft. Exercise equipment is typically designated to the same zones used for leisure time and can impede attempts at mental relaxation over time. (Schlacht, 2012). Privacy and sleep also play a huge role in mental well-being when living inside a space station, necessitating undisturbed, safe, and quiet sleeping areas along with private storage of personal items (Hauplik-Meusburger, 2010). Astronauts also experience a reduction in sensory stimulation. A distinct lack of natural sounds, reduced scents due to odor-eliminating filtration, and reduced lighting in favor of artificial replacements within space habitats can lead to a monotonous, sterile living environment (Jiang, Schlacht, & Yao, 2022).

Post-Flight

During post-flight, astronauts reported feelings of anxiety not related to personal safety but instead to the success of their personal job performance on the mission (Jones, 2016).

Addressing these anxieties by providing crewmembers with the appropriate habitable space and equipment can offer great help in alleviating the innumerable stressors these individuals are exposed to. Eliminating minor or unperceived stressors one by one may seem inconsequential in the grand scheme of space exploration. However, the long-term benefits of various small alterations can drastically improve crewmembers' psychological and physical health throughout an LDM.

Factors for Optimal Human Performance

The International Space Station (ISS) serves great operational and research value that aids in the design and development of future platforms for LDMs. Commercial space stations, however, are taking advantage of developing platforms that prioritize crew considerations including crew safety and comfort at the core of mission success. NASA's previous work, while developed within very specific limitations, provides a standardized framework for iterative design.

A two-step process developed by the NASA Johnson Space Center Behavioral Health and Performance Group (JSC-BHPG) defines optimal human performance as consisting of "to think," also known as cognition, and "to act," also recognized as decision-making. Contributing to these phases are four factors — sleep, human behavior, psychological adaptation, and human-to-system interaction (HSI). The first of these three factors reframe LDM preparation to prioritize HSI through environmental modifications.

Sleep

As a recognized critical risk factor for astronaut health across space agencies, sleep is a prioritized aspect of mission planning (Oluwafemi et al., 2021). Astronauts are given a minute-by-minute schedule that includes allotted time for sleep as much as it does for mission operations. Sleep is a primary objective, and this is because of the significant impact it can have on crew performance and mission success. In a review on astronaut health, Oluwafemi et al., (2021) reaffirm that a decrease in sleep and circadian rhythm is a "common condition" in spaceflight resulting in poor performance, reduced concentration, and reduced attentiveness. Mission planning prioritizes schedules that provide a simulated sense of day and night to best support astronauts' circadian rhythms and therefore their work (Oluwafemi et al., 2021).

However, this strict management of astronaut time takes away the astronaut's sense of control and togetherness, often leaving them feeling out of control. Another study by Nasrini et al., on cognitive performance encourages a review of the quality of sleep itself by exploring the effects of confinement and sleep deprivation on spaceflight crewmembers and mission success (Nasrini et al., 2020). NASA analog astronauts were given a manipulated sleep restriction challenge with groups asked to operate under varying conditions from limited to no sleep. Tasks like spacesuit preparation and payload management were provided to assess performance while replicating the common workload stressors experienced during spaceflight operations. Following this, participants completed a cognition battery that revealed a significant decrease in overall moods, motivation, psychomotor vigilance, and performance. Participants were "slower and less accurate" when fulfilling tasks at increased increments of sleep deprivation (Nasrini et al., 2020).

While both sleep, and the quality of that sleep, are critical components there are uncontrollable aspects of spaceflight missions including the need to respond in the event of an emergency. Though scheduled sleep cycles seem like a solution, circadian rhythms are often interrupted to facilitate emergency response. In a review led by Liu et al., several analog mission studies on the physiological effects of spaceflight on the human body define space as an extreme environment that shifts natural circadian rhythms - a key characteristic that, when altered, provides "the largest disruption to an individual's sleep cycle." In a comparison between an analog study with a 72-hour window of isolation and sleep deprivation, and another study with 15- and 45-day spaceflight missions; empirical evidence from participants' resulting POMS and PANAS indicated significant changes to the overall mood as duration windows increased.

Human Behavior

In a study by Pastore and Andersen (2022), participants "experienced" four buildings with different designs centered around varying levels of customization. Resulting surveys and questionnaires revealed a correlation between autonomy and satisfaction. This was observed with designs that had windows that had a range of customizable settings versus a window with only two points of customization like 'open' or 'closed.' It was also found that aesthetic and non-functional characteristics in space were more appreciated and contributed to a higher emotional perception of the environment (Pastore & Anderson, 2022).

Similar themes of autonomy were identified in a study on crew self-organization in which participants completed analog missions of increasing durations including 4 months, 8 months, and 12 months. Akin to space-based missions and future long-duration Mars missions, the participants or 'crew' maintained isolation and confinement during the entire duration, but with the contrast of having total autonomy to develop their schedules (Heinicke et al., 2021). As mission durations increased crew members were more likely to 'seek privacy' than to participate in group activities, workouts, or meals.

Unlike analog missions, the ISS is space-limited with very few places for solitude but the crew behaviors and demand for privacy are consistent. In a review of case studies from Häuplik-Meusburger (2010), astronauts enjoyed having a shared space for meals but outside of concurrent schedules, their interests and needs are still very different. Astronauts also expressed the need for personal quarters and storage as ways to cater to "individual" behavior like sleeping (Häuplik-Meusburger, 2010).

Psychological Adaptation

Further understanding of psychosocial issues like those reflected in the previous section reveals opportunities to aid in the psychological adaptation of crew over time. Eng et al. (2005), encourage an honest acceptance of the "symbiotic nature" of the human-environment relationship. Viewing this relationship as a "two-street" suggests that concepts of isolation and confinement, and the cognitive effects it has on crews, are best aided in ensuring the environment aids the hosts as much as the inverse (Eng et al., 2005). In a study using an adaptive entertainment exhibit with self-learning tiles, Ada, was used to capture human behavior data, attendee tile navigation, and to provide sensory stimulants to direct attendees in a particular pattern (Eng et al., 2005). Doing so successfully, this distributed adaptive control (DAC) highlights the role interactive cues of signaling within an environment can influence its inhabitants.

Oluwafemi et al. characterize this symbiosis in another review of astronaut mental health reports and their psychosocial challenges (2021). During LDMs astronauts are subjected to interact only with those on the mission, they are confined, and their autonomy is traditionally limited. Their communication or access to Earth-based teams will also become a great challenge for LDMs beyond Earth's orbit in which the delay increases from 1.4s, a timeframe familiar to ISS astronauts, to approximately 22 minutes when orbiting Mars (Kintz et al., 2016). This enlarged window of indirect contact, and therefore increased isolation, influences the crew's adaptation to the space environment. Sensory stimulation is limited in space and LDMs push these boundaries of human comfort even further. While the body might change as a result of microgravity and radiation, humans still have the same basic needs (Oluwafemi et al., 2021). Training the senses to accept the consequences of LDMs - from a cognitive and psychosocial perspective - is a viable solution; but much like Ada, the opportunity presents itself to have the crew and environment work with and for each other.

Environmental Modifications and Recommendations

While the previous sections focused on behavioral adaptations and the potential considerations to take into account for LDMs, this section focuses on the physical environment that astronauts and future commercial partners will be inhabiting. Reviewing the current interior design layout for the ISS reveals that the space station itself is outdated and can be considered an environment that is difficult for humans to acclimate to in modern times. Because there is a unified goal of normalizing humans in space, it is crucial to ensure that the living space for future space stations and potential ground base designs are optimal and suitable for these future endeavors. The modifications suggested can enhance performance, increase productivity, and create a more favorable environment for astronauts and, later on, non-astronauts to interact in.

Color

The implementation of color within different areas of the inhabited space is crucial for mitigating monotony and boredom. During a study conducted on space habitability, the primary focus involved using the Integrated Design Process to increase and enhance the habitability and capabilities of designing human space missions (Schlacht, 2012). This involved two three-person crews, where both teams were undergoing long-duration mission simulation. The results of this study revealed that interior colors, patterns, and textures were all beneficial to astronauts' mental health and well-being. In the Delphi study conducted by Jiang et al. (2021), the main focus was to observe how color affects and impacts astronauts' stress levels within the space station's hygiene area. Thirty experts were brought in and asked to complete a color selection questionnaire. This study concluded that low-saturated, cooler colors were more likely to be chosen within the hygiene and urine collection area. In contrast, the garbage collection interface and negative pressure packaging interface required eye-catching, highly saturated colors to stick out.

Another study involving the use of color was also conducted by Jiang et al. (2022), in which the primary purpose was to identify whether multicolor lighting can improve a person's psychological state within an isolated and confined environment over seven days. There were two gender-based teams: ten men and ten women, twenty participants in total, one group placed in a multicolor lighting room, and the other group placed in the white lighting room. Those placed in the multicolor lighting room were shown to have significantly lower levels of negative emotions and anxiety than the white lighting group. Multicolor lighting was also shown to increase a sense of visual interest compared to the strong visual monotony reported by those in the white lighting room group. Regarding the different tasks completed within the multicolor lighting group, blue lighting was often associated with and used for reading, yellow lighting was used for winding down and sleeping, and red lighting was unanimously disliked by the participants. These are but a few of many articles that discuss incorporating color within future habitats either in low orbit or on the lunar surface.

Greenery

While there was not much to consider regarding artificial greenery, it could be intertwined with what was referenced back to color. However, a previously referenced study undertaken by Peldszus et al. (2013), mentioned the positive effects of artificial greenery on the crew members. Maintaining plant-growth facilities was considered a meaningful activity, as it assisted with mitigating and reducing monotony and was seen as a central restorative measure for crew members, specifically when they would be observing and tending to them. When crew members would engage in pranks during their leisure time, it was highlighted that there would be the incorporation of ready-made props (e.g., plastic cucumbers), and they would be used to prank other crew mates. The products of plant-growth facilities would also be used as gifts or tokens of appreciation to other crew members or relatives and would also be used as a supplement for diet (Peldszus et al., 2013). This resulted in a positive association among crew members when it came to greenery and the care of plants. When referencing the Mars500 crew as well as the orbital crew, it was noted how the crews among both groups cherished the greenhouse within their spaces, whether it involved using it as a method of relaxation, for conducting experiments, as a source of food, or as a source of gift-giving. Referencing back to “Touch Some Grass”, this concept acts as a way of realigning crew members with their reality by providing entertainment during menial tasks.

Windows and Design

Similar to the use of greenery and fresh foods, disrupting the routine experiences of LDMs present an opportunity for a comparable environment to that of Earth including access to alternating views or scenery. In an article by Hauplik-Meusburger (2010), a six-level case study was conducted to observe how better habitability and safety can be achieved by designing from a more human-oriented perspective rather than a strict engineering perspective. These six levels focused on reviewing the Apollo missions, Salyut, Skylab, Shuttle-Mir, and the ISS. Within these results, it was found that regarding work-related tasks, a design should be incorporated for efficient work production while also having manageable storage. Integrating standardized interfaces, user autonomy, and ongoing training was recommended; there should also be increased flexibility in the work area, including playful leisure activities and windows.

Similar to this, a study conducted by Andersen and Pastore (2022), focused more on satisfaction within the office; the main question posed whether there was a measurable level of imperfection “forgiveness” or facade that humans would accept while maintaining peak qualities of perceived comfort and satisfaction. This study involved a satisfactory questionnaire for 289 people and a second questionnaire which 269 people answered about specific interior space features. One of the study's results involved a desire to have control over the opening of windows and was linked to higher satisfaction, with indicators that autonomy leads to greater satisfaction. Similar designs are already implemented within the ISS, in which there are controllable shutters on windows within the station that give a beautiful celestial view of the Earth and the surrounding scenery of space.

Referencing back to the article by Schlacht (2012) on space habitability and user experience, one of the results highlighted how participants spent most of their leisure time looking out of the windows, with a note including how windows made crew quarters feel less claustrophobic. This is crucial to implement in future designs as this can be shown to steadily improve human behavior within the physical environment within space. In another study conducted by Peldszus et al. (2013), the main focus involved mitigating monotony for deep-crewed space missions through habitability designs. This involved the review of six onboard analogs from crew members within orbital and simulator missions. The results of this study emerged within three themes, one of which was a relationship to nature as manifested within the use of windows and plant-growth facilities. The incorporation of windows would often elicit a sense of curiosity and wonder about the natural environment as crew members would often look through portholes and windows as a continuously changing display.

Environmental Awareness

While the space within the area is limited, it is recommended by Cohen (1991), who, after conducting a full-scale architectural simulation for extreme environments, suggested incorporating a sense of ceiling height, which is crucial to creating a perception of spaciousness. This was done through the rotation of the module by 45 degrees, allowing the creation of the "loft" feeling. Cohen recommended using illumination to provide a spatial orientation by incorporating an up/down differential within laboratories. This involves washing the rack faces with even illumination and providing visual cues to the local vertical by making the brighter illumination "up." Cohen was not the only one who referenced the manipulation of light within the designated space. In Martinez's article on the architecture design for space tourism, it was recommended that light design could be used as a simulation for the natural rhythm of day and night, and this would serve to improve the occupant's feeling of well-being (Martinez, 2009). Regarding the physical space, it was suggested that floors, walls, and ceilings should be used as interchangeable storage spaces for changing furnishings, similar to yachts.

Hauplik-Meusburger's (2010) article on incorporating a more human-oriented perspective within space habitats stated that designing for undisturbed, safe, and quiet sleep was crucial while also ensuring privacy was provided, along with private storage sleep areas to be used during the day. There was mention of allowing adjustments to individual preferences both within the sleep areas and within the work area. A key consideration to implement within the design calls for an increase in aesthetic and non-functional characteristics, which can enhance the emotional perception of the environment (Andersen & Pastore, 2022). However, referencing Andersen & Pastore's study, instead of having an overly detailed space, minimalism through a pleasant and comfortable environment was recommended to be preferred over spaces with an increased amount of detail.

The Habemsi Study focused on developing a coherent plan that involved the extension of a permanent European manned system presence in low earth orbit (LEO), which included the capacity to support different missions (Basile et al., 1990). Regarding the results of what was completed, extensions were deemed necessary for optimum living conditions for a total of three crew members during six-month missions. There was a recommendation involving the division of habitable volume with the large compartments through the incorporation of flexible architecture. This was subdivided into three areas: the quiet area at 25%, the buffer area at 40%, and the common area at 35% (Basile et al., 1990).

Final Factors to Consider

Ensuring a noticeable separation between the different areas of LDM habitats will be crucial in providing the optimal environment for inhabitants, by manipulating the lighting or physical design and spatial orientation. Incorporating aesthetic designs, whether done through leisure activities or greenery, is also crucial in preventing monotony or boredom when in space and can provide a healthy way of entertaining and passing the time. However, creating a cluttered space can be considered overwhelming for those inhabiting it, as architecture is meant to guide movement and circulation within the space (Parreno, 2015). Excessive minimalism could also cause the environment to be remembered too clearly and create a catalyst for monotony to form (Parreno, 2015). There has to be a healthy balance within the space. The use of windows, while already implemented within current designs, can be enhanced by incorporating extended reality. While there is little research on the use of extended reality technologies within windows for space-based environments, this has the potential to provide a more inclusive environment through the use of scenery. This could assist in limiting homesickness and depression through changing sceneries and enhanced sensational perception of different Earth environments.

Conclusion

While the topics listed above do not include all of the environmental recommendations possible, they serve as essential examples in addressing what can be included within the design aspect of LDMs to assure astronauts' ability to 'touch some grass' and realign with their more familiar, Earthly environment. Our understanding of the effects LDMs have on astronauts' cognition and perception is still quite limited. The accounts of previous astronauts, particularly those with ISS stays exceeding one month, will provide a situational foundation to consider throughout the development of future spaceflight habitats. To date, their shared experiences have highlighted how their relationship with their surroundings greatly affects their relationship to the self, crew, and the mission. However, until LDMs in space are more commonplace, analog missions provide a system to observe human-environment interaction and to assess what characteristics such as color, greenery, windows, and orientation may manipulate performance and mission success. Optimal human performance is best understood today in the context of factors such as sleep, human behavior, and psychological adaptation; but there is a need to further understand these factors in the context of LDMs in which the return to home and the ability to 'touch some grass' is not guaranteed. These exceed the human comprehension of isolation. A future study in which isolated participants can explore their autonomy in manipulated environments by implementing extended reality technologies would provide greater insight into how human needs may be best met not by others, but rather in a space they can call their own.

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