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Countermeasures to Mitigate the Negative Impact of Sensory Deprivation and Social Isolation in Long-Duration Space Flight

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Acronyms

ICE	isolated, confined, and extreme
ISS	International Space Station
NEEMO	NASA Extreme Environment Mission Operations
NEO	near-Earth object

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Abstract

Long-duration space flight presents several challenges to the behavioral health of crew members. The environment that they are likely to experience will be isolated, confined, and extreme (ICE) and, as such, crew members will experience extreme sensory deprivation and social isolation. The current paper briefly notes the behavioral, cognitive, and affective consequences of psychological stress induced by ICE environments and proposes nine countermeasures aimed at mitigating the negative effects of sensory deprivation and social isolation. Implementation of countermeasures aims to maintain successful crew performance and psychological well-being in a long-duration space flight mission.

Introduction

As we chart new territories and strive to meet new challenges, the allure of long-duration space flight presents an viable focus for research and operations. However, sending people to Mars or a near-Earth object (NEO) is not without serious psychological challenges for the individuals involved. Thus, mitigating the risk of long-duration space flight, particularly in the realm of sensory deprivation and social isolation, is crucial to the success of the mission. In the current report, the researchers will provide definitions of sensory deprivation and social isolation, outline the risks associated with these concepts, and propose specific countermeasures that should be considered in the development of a long-duration mission. Finally, the researchers will briefly touch on additional considerations that may prove beneficial to the psychological health of astronauts in long-duration space flight, but do not specifically relate to sensory deprivation or social isolation.

Sensory deprivation is defined as a reduction of stimuli to one or more senses (Kubzansky, 1961). In a long-duration space flight context, astronauts may experience restrictions to several senses over a prolonged period of time, including the visual, auditory, olfactory, kinesthetic (i.e., motor), tactile, and gustatory (i.e., taste) systems as well as the individual's sense of time and chronology. Prolonged sensory deprivation has been linked to biological changes to the neurological structure of the brain and to several behavioral outcomes including hallucinations and anxiety (Merabet et al., 2004; Rasmussen, 1973).

Sensory deprivation can occur to a variety of senses, including the visual, auditory, olfactory, kinesthetic (e.g., motor), gustatory, and tactile systems. Additionally, sensory deprivation can change an individual's conception of time or chronology. These deprivations can occur to single systems or in conjunction with other systems (Kubzansky, 1961). In an isolated, confined, and extreme (ICE) environment, sensory deprivation may occur because of the mechanical constraints of the space craft or might build up over time because of sensory monotony. For example, the space craft vehicle will need to fit technical specification such as size and for function that will limit sensory stimuli. The resulting vehicle, by definition, will lack the complexities and uniqueness found on Earth.

The presence of new stimuli in our environment is important to healthy psychological functioning and well-being. According to the biophilia hypothesis, individuals have evolutionarily adapted to gather information by exploring their environment (Kellert & Wilson, 1993). Curiosity has been advantageous to our development. Contrariwise, the lack of sensory stimuli has deleterious effects on our cognition. Urban environments, which lack the variety and aesthetic appeal of nature, bring about neurological changes in individuals raised or living in such an environment (Lederbogen et al., 2011). Individuals raised in urban environments exhibit differential activity in the perigenual anterior cingulated cortex, whereas urban living is associated with increased activity in the amygdala. Both of these changes are related to the brain's stress response. This heightened stress response leads the individual to view their environment with a paranoid, negative outlook. In short, urban environments do not stimulate healthy brain function as well as natural environments do—in fact, they impose negative outcomes. From a biophilic perspective, urban or non-nature environments introduce stress because they require attentive processing (i.e., the environment requires focus to analyze and understand it and constitutes a top-down cognitive approach) and at the same time keep stress high because the environment lacks the restorative properties of nature, in which attention does not need to be focused actively, providing a bottom-up cognitive response. Urban environments constitute a threat and instigate a "fight or flight" response (Kellert & Wilson, 1993).

In ICE environments, one of the main threats to sensory deprivation is the imposed monotony of the space craft. A small space is easily explorable and will be learned in a short period of time. Visual monotony, for example, comes from the lack of new and interesting things to see and limited information to gain from in the environment. In analog environments, such as the Antarctic, visual monotony imposed by the lack of sunlight and confined space constitutes a major stressor on the crew (Otto, 2007). In a long-duration mission, there will be sensory deprivation from monotony in many forms, including eating the same foods (menu fatigue), noise from the air circulation system (noxious sound), and smell. Additionally, there will be monotony in interpersonal relationships, termed social isolation.

Social isolation refers to the lack of contact an individual has with others (Cacioppo & Patrick, 2008). In the context of space flight, social isolation includes the lack of human contact outside of the crew that individuals will experience. As social beings, humans experience significant decrements to their cognitive and affective states when isolated from others (Cacioppo & Patrick, 2008). Interaction with others benefits the physiological and psychological systems (Otto, 2007). Cut off from significant others, countermeasures must be employed to keep individuals from experiencing the negative consequences of social isolation, including but not limited to loneliness, anxiety, paranoia, and depression (Cacioppo & Patrick, 2008).

Individuals experience social connection at a variety of levels. As shown in Figure 1, the closest network to the individual (self) is the family unit. From this center point, the network expands to include friends, coworkers, acquaintances, community members, and so on out to humanity as a whole. Once the astronauts are out of view of Earth, they will no longer have these important social connections.

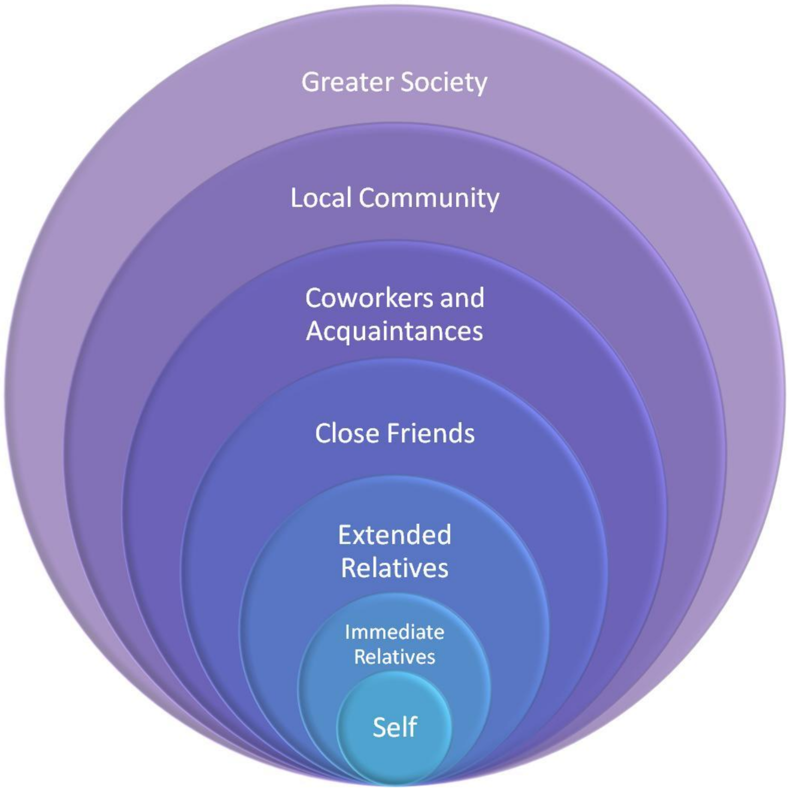

Figure 1. Levels of social interconnectedness

Evolution has favored individuals able to work effectively in group settings. As such, we view instances of social isolation as threatening (i.e., a cue for the stress response) and seek socialization as a means of survival (Cacioppo & Patrick, 2008). In an ICE environment, there will be limited individuals with whom to interact. Crew members will be limited to physical contact with only the other crew members and just verbal communication with those on Earth. Furthermore, connections with important others such as spouses, children, and friends will be extremely limited.

Stress is *the* undesirable outcome of sensory deprivation and social isolation that we are attempting to mitigate. Increased stress causes numerous physiological and psychological maladaptations to the individual. Usually, individuals have opportunities to "decompress" by removing themselves from stressful situation so that they can distance themselves from the source of stress and rejuvenate. Astronauts in a long-duration space flight will not have the ability to create the necessary distance from sources of stress to heal, so stress will continue to build over time without an outlet. As such, providing these outlets in the form of countermeasures allows for better performance and well-being in the individuals.

Stress, both chronic and acute, has been linked to a wide variety of physiological and psychological outcomes. Physiological changes to the neural structure of the brain are evident in the research, such as the over-functioning of the stress-response systems that have been described by Lederbogen and colleagues (2011). Stress affects the hypothalamic-pituitary-adrenocortical axis, particularly through the production of cortisol, and the sympathetic-adrenal-medullary system through the release of catecholamines (Cohen, Janicki-Deverts, & Miller, 2007). These activations, in turn, mediate the relationship between stress and outcomes such as depression, cardiac disease, and autoimmune diseases. Within the brain, hippocampal shrinkage in the size and number of neurons occurs in individuals with mood disorders and prolonged stress (Otto, 2007). Additionally, the number of terminals and branches within the neuron available to make connections with other neurons decreases. Furthermore, under adverse conditions, the brain stops producing new neurons, termed neurogenesis. In cases of sensory deprived environments, neurogenesis does not occur, simply because the brain is not stimulated (Otto, 2007).

The psychological outcomes of prolonged stress include a buffet of negative affective, behavioral, and cognitive outcomes. As described by Cohen and colleagues, physiological changes associated with chronic stress are related to depression (Cohen et al., 2007). Additional research has linked chronic stress to anxiety and insomnia, among other mood disorders (Otto, 2007). While most mood disorders found in individuals in ICE environment occurs at a lower rate than the normal population, the potential outcomes of major mood disorders in an ICE environment could have more detrimental consequences (Stuster, 2010; Suedfeld & Steel, 2000).

Studying ICE Environments

Because living in space is a unique experience, there are no perfectly transferable studies that can predict the impact of long-duration space flight on human health and psyche. Instead, we use several types of analogues to construct a picture of what might occur. These analogues include, but are not limited to: Antarctic winter-over expeditions, NASA Extreme Environment Mission Operations (NEEMO) underwater settings, experiences of astronauts in low-Earth orbit (e.g., International Space Station [ISS], Mir, Skylab), bed rest studies, Biosphere II, submariners, and involuntary penal commitment. No one study is a complete representation of the challenges that astronauts will likely face; however, these studies provide some guidance to inform our procedures and potential countermeasure development. Each analog fits only part of the complete long-duration experience. For example, in Biosphere II, six crew members were kept in self-sustained isolation for 2 years, the longest social isolation experiment to date. However, the enclosure that the crew lived and worked in was colossal, over 3 acres in size and stocked with many different types of terrain and plants. By comparison, a long-duration space craft will be much more confined and sensory deprived. The NEEMO studies are more analogous to the confined and sensory deprived environment that will be experienced in long-duration space-flight, but the duration of time spent in NEEMO is severly limited (couple of weeks, at most). Antarctica provides a more high-fidelity analog for long-duration space flight. Winter-over expeditions in the Antarctic are extended duration and there is a lack of sensory stimulation and social isolation with the limited light and small crew.

Using analogs to predict the likely outcomes of sensory deprivation and social isolation, we now move beyond the description of negative outcomes toward remediation tactics to prevent adverse effects. An in-depth discussion of biomarkers and outcomes of sensory deprivation is beyond the scope of the present research; however, countermeasures will be proposed with a brief rationale for each countermeasure and an implementation strategy. We will describe countermeasures for sensory deprivation first, countermeasures that address sensory deprivation and social isolation second, and countermeasures specific to social isolation third. Each countermeasure is presented as a stand-alone proposal, but the integration and combination of multiple countermeasures will provide the greatest positive impact on crews for long-duration space flight.

Sensory Deprivation Countermeasures

As noted previously, sensory deprivation is a major stressor, both psychologically and physiologically and will likely prove to be a significant problem in implementing long-duration space flight. As such, countermeasures to mitigate the negative impact of sensory deprivation—to minimize the stress it will put on crew members—are necessary in designing the long-duration vehicle. Three potential countermeasures for sensory deprivation—novelty, virtual reality, and a greenhouse—will be described both in terms of their importance in mitigating the negative effects of sensory deprivation and in implementation strategies.

Perhaps the most critical countermeasure for the experience of sensory deprivation on board a long-duration space flight vehicle will be the introduction of novelty. Our preference for novelty in an environment allows humans to learn and interpret their environment and a lack of novelty introduces a situation of sensory monotony, in which the senses are not stimulated by the surrounding environment. Without appropriate countermeasures, sensory monotony will be present in the sterile, learnable habitat during long-duration space flight. As noted previously, the sensory deprivation that occurs as a result of monotony leads to a decline in the neural plasticity of the brain (Otto, 2007). As neural plasticity decreases, decrements in performance follow. These physiological changes manifest as behavioral, cognitive, and affective decrements.

Novelty gained from the natural environment contributes to sensory stimulation. Our ability to gather information from our environment and interpret novel stimuli has an evolutionary basis that has contributed to our success as a species (Kellert & Wilson, 1993). We have a preference for natural and visually complex environments, a preference known as biophilia. More than just visual, nature stimulates our olfactory, tactile, kinesthetic, and auditory senses in addition to the gustatory sense, which is stimulated in the quest to find edible food. Natural environments exhibit movement, growth, and limitless variation, all of which will be lacking in space. Left to our own devices, individuals seek out nature or nature substitutes in situations of sensory monotony (Bringslimark, Hartig, & Patil, 2011; Leather, Pyrgas, Beale, & Lawrence, 1998). In planning a long-duration vehicle, taking cues from nature by installing novelty will allow crew members to compensate for other stressors in their environment as well as remove a critical stressor: sensory monotony.

Implementation of novelty can and should occur via several avenues. The end goal should be to provide interesting and novel stimuli whenever possible. For example, many crew members, even in the relatively short-duration 6-month ISS missions, complain of menu fatigue (Stuster, 2010), which occurs because individuals are bored with the food selections given to them in orbit. They experience gustatory monotony. In long-duration flights, food should be as variable as possible, with customizability and a large menu selection. Another way to integrate novelty into the environment is through audio and visual routes. Crew members should have access to a wide variety of media for use in the vehicle and visual stimulation should be incorporated into all tasks, not left to recreation hours. In designing the habitat, keeping the vehicle from looking too clinical and "learnable" will help counteract sensory monotony. The form of the vehicle necessary for successful functionality should be harmonized with the needs of the crew members for their performance and well-being.

Video screens and virtual reality headsets present a method for delivering sensory stimuli as a countermeasure for stress. As noted previously, one of the challenges associated with long-duration space flight will be sensory monotony. This countermeasure will address visual monotony in particular. Virtual reality devices provide a mode for increasing novelty in the environment and impart a sense of movement in the environment. Nature-based stimuli should be considered for the primary use of virtual reality devices. Previous research has shown that even limited time (10 minutes) of explorable, nature-based virtual terrain lowered stress for individuals in stress-inducing situations (Valtchanov, Barton, & Ellard, 2010). Nature in particular has a restorative effect beyond colors and familiarity. Abstract paintings with colors commonly found in nature do not have the same soothing effect (Valtchanov et al., 2010). Most likely, the restorative effect of natural settings harkens back to our biophilic preferences. Virtual reality devices offer a way of incorporating nature surrogates into the vehicle. Explorable environments may be particularly beneficial in terms of restorative effects and visual stimulation.

Another potential use of virtual reality devices could be as a means of communication between the space craft and Earth and leisure. Virtual reality devices can be used as a way of sharing home and personal videos from family and friends. They could also be used to make exercise more enjoyable. Videos of favorite running trails, hikes, or landscapes could be played during a workout to make recreation more immersive.

In creating virtual reality devices and content, designers should pay particular attention to making the experience as immersive and integrated as possible. Nature scenes, for example, should not be left only to recreation time, but rather should be incorporated into the background of work operations. Having a screen with digital landscapes might provide a restorative effect in the same way that having a window in an office would. Additionally, videos that incorporate advances in 3D video technology would provide visually appealing stimuli and offer crew members the ability to explore the environment.

The necessity for humans to interact with nature inspired another countermeasure for sensory deprivation: a greenhouse. A greenhouse would provide multiple benefits on board a long-duration flight and stimulate several senses. The mere presence of flora enhances neural stimulation and increases the production of mood-enhancing chemicals in the brain. The act of gardening has many benefits (Kaplan, 1995) and has been noted to provide valuable, novel, and interesting recreation activity for astronauts (Stuster, 2010). Gardening provides a connection to Earth-bound flora, cultivates nurturing skills, provides tangible benefit to the community (i.e., fresh produce), and provides a source of novelty.

The implementation of a greenhouse would take space and energy from the rest of the vehicle, but even a small greenhouse would be beneficial. Astronauts describe the psychological benefit and attachment that they formed to plants on board flights (Stuster, 2010). A greenhouse the size of a typical ISS rack would be sufficient. The structure should be large enough to hold several plants, be stocked with edible plants, and be tended by more than one crew member; however, it should be small enough so as not to intrude on other vehicle functions. In windowless environments, nature surrogates such as plants can counteract some of the negative effects of sensory deprivation (Bringslimark et al., 2011). Providing crew members with a greenhouse will allow for visual, olfactory, kinesthetic, and tactile stimulation as well as restorative benefits inherent in nature.

Sensory Deprivation and Social Isolation Countermeasures

Countermeasures that apply to both sensory deprivation and social isolation are summarized in two specifically proposed countermeasures: 1) the need for private quarters on a long-duration space flight vehicle and 2) recreation. These two countermeasures deal with basic human needs—the need for safe shelter and activity. Successful countermeasures will reduce the social isolation that individuals experience and allow for sensory stimulation by giving crew members an outlet to release stress and participate in energy-diffusing activities.

Private quarters provide crew members with more benefits than just a place to sleep. Instead, having private quarters allow individuals the time they need to disconnect from other people so that they can rejuvenate. In any ICE environment, the other individuals who are present in the environment themselves become stressors. People need time to relieve stress after a situation that induces strain, even if the social interactions are positive overall. Temporary withdrawal is the primary way that people can interrupt the stress-strain cycle that could otherwise be very harmful if allowed to persist. Without an outlet, stress continues to build over time (Otto, 2007). The inability to "get away from it all" produces stress over time and can precipitate progressively negative and confrontational interactions between crewmates (Poynter, 2006).

Additionally, personalization is a compensatory strategy, which allows individuals to have a sense of control over their environment and a place to reflect and relax away from other crew members. Personalization would be well-suited to private quarters, as it would be out of the way for other crew members. Crew members could add personal pictures and mementos from home without intruding on others' space. A sense of autonomy in a stressful and rigorous environment provides a useful outlet for crew members to relieve stress. As such, crew spaces should never be shared or swapped during space flight.

Another countermeasure for social isolation and sensory deprivation is recreation. Recreation can be broken down into active and passive forms. Active recreation, particularly exercise, has been studied extensively and is a primary countermeasure utilized by NASA to maintain the bone density and muscle mass of astronauts. Additional psychological benefits occur during exercise as well, including the release of brain derived neurotrophic factor and biogenic amines (Otto, 2007). An exercise regime, including the virtual reality countermeasures described previously, should be incorporated into the crew members' routines.

Another form of active recreation that could be incorporated into a long-duration space flight vehicle would be a physical game. Games provide an outlet for aggression and tension in a structured and focused way that can alleviate the more abstract forms of stress (Hauplik-Meusburger, Aguzzi, & Peldszus, 2010). Games in space would provide a method for forming team cohesion and encouraging crew members to spend time together. Additionally, game pieces that can be rearranged and moved freely address some of the issues involved in sensory deprivation by providing tactile, kinesthetic, and visually stimulation.

Other forms of recreation on board a space craft are more passive in nature, meaning that they do not require sustained movement on the part of the crew member. Passive recreation in past flights has included movie nights, journal writing, and photography (Stuster, 2010). Many astronauts have acknowledged the stress-relieving benefits of such hobbies, particularly photography of Earth from orbit. However, when the Earth is no longer in view, photography will not be a likely form of recreation. Recreation countermeasures should be customizable and able to be accomplished alone or in a group. Individuals seeking an outlet for stress may prefer to recreate on their own, but group recreation encourages team cohesion. For sensory forms of recreation such as movie viewing or listening to music, crew members should be given a substantial library of content to choose from, some personalized to their individual preferences. Whatever form it takes, recreation should be viewed as a necessary part of mission planning, not as optional or auxiliary to the mission.

Social Isolation Countermeasures

Social connectedness may become even more important once visual reminders of Earth are no longer readily apparent. Although the astronauts assigned to the long-duration mission will not be operating individually in perfect isolation, as a group they will be cut off from the extended social networks that provide emotional and instrumental social support. In many of the analogue studies that we have used to predict performance in long-duration space flight, individuals have been cut off from extended networks, but still operate in sizable groups (i.e., 80 individuals in the Antarctic or 150 individuals on a submarine). The social environment on a long-duration space flight is much more desolate. It is likely that only four to six individuals will make up the entire crew on board the spacecraft. As has been recorded in analogue studies, tensions with available others will escalate over time (Otto, 2007; Poynter, 2006). Importantly, individuals in the spacecraft crew will need to operate autonomously during some parts of the mission, as Earth-based support will be out of radio contact. Therefore, these individuals must depend on one another for their survival, making it crucially important that they work together as a team. The negative effects related to the relative social isolation of crew members should be addressed. Three potential countermeasures for long-duration space flight are 1) in- and out-bound communication, 2) psychiatry, and 3) observance of holidays and events.

In- and out-bound communication with ground-based support will take on new significance in long-duration space flight. In addition to the logistical and mission-specific support, ground control will also need to offer a high level of social support to crew members to lessen the feelings of isolation that will occur in deep space. As social beings, most of us have a strong need for connectedness. When we are isolated from those around us, either physically or mentally, we suffer from performance decrement and compromised well-being (Cacioppo & Patrick, 2008). In terms of performance, individuals who experience isolation are higher in state negative affect, perform worse on cognitive tasks, and attempt complex assignments for less time than do those who are not socially isolated (Baumeister, DeWall, Ciarocco, & Twenge, 2005; Baumeister, Twenge, & Nuss, 2002; Twenge, Baumeister, Tice, & Stucke, 2001). In the long run, feelings of social isolation have been linked to depression—perhaps due to neurological changes in the brain (Cacioppo & Patrick, 2008; Otto, 2007).

During times when it is available to them, crew members should be able to communicate with Earth and important social support networks. Communication with family, friends, and mission control will likely be sporadic during some parts of the mission, with latencies lasting 20 minutes each way, but connection should go on for as long as possible and be used for both work and recreation. Although communication home can be a stressor for astronauts, many also report enjoyment in connecting with significant others on a regular basis (Stuster, 2010). Communication in the form of digital "care packages"—videos of important life events (i.e., the birth of a child, a wedding) and milestones and correspondence from home could be delivered regularly to keep crew member morale high.

Another countermeasure that should be available to crew members during long-duration space flight is some form of psychiatry or counseling. Social isolation is a predictor of mood disorders, including depression and anxiety, which in turn have been linked to performance decrements, poor motivation, lack of attention—all of which are important for successful operation of a spacecraft (Cacioppo & Patrick, 2008). Incidence of depression, anxiety, and other psychological issues are likely to rise over the duration of confinement. Research in analog environments notes a positive linear trend for depression over time (Otto, 2007). Although the risk of a serious mood disorder is low—lower than the baseline population, in fact—a serious episode could pose a serious risk for everyone on board.

Currently, astronauts have access to psychiatric and psychological support through communications with those on the ground. While mission control should continue to provide regular private psychological conferences between crew members and mission psychologists, additional measures should be taken for situations in which communication with ground control is limited. Pre-flight, crew members can be trained in strategies that will allow them to be their own emotional support system. Critical counseling skills in active listening, empathy, and conflict mediation can provide a stop-gap measure to keep psychological crises from manifesting or at least controlled until expert assistance is available. Additionally, crew members should be trained in the use of pharmacological remedies for psychological discomfort. With limited communication and extreme social isolation, it is important to arm crew members with tools to manage their own behavioral health.

A final countermeasure to counteract the negative impact of social isolation in long-duration space flight is the observance of important holidays and milestones. The celebration of such events will not only link the crew members with Earth, but also maintain a feeling of normalcy for the crew and provide an outlet for stress relief. With Earth out of view, there is potential for the astronauts to feel isolated from the rest of mankind. To maintain the bonds that the astronauts have with home, holidays and important events should be celebrated. Additionally, celebratory events can ease tension among crew members and contribute to a sense of well-being (Otto, 2007). Milestones that could be celebrated on board include birthdays, religious and cultural holidays, and mission milestones (i.e., a 100 days party). Astronauts should be able to communicate with significant others at home during important life events. Crew member morale can be maintained by infusing a sense of celebration during scheduled points in the mission.

Additional Considerations

Additional considerations before and during flight include selection criteria, experience, and training. Certain personality types may be better able to adapt to the strenuous environment caused by sensory deprivation and social isolation. Individuals with a predisposition toward positive group interaction and teamwork should be preferable. Furthermore, astronauts with successful previous experience in long-duration confinement such as the Antarctic winter-over stations or 6-month flights on the ISS should be considered. Individuals with experience in isolated, confined, and extreme environments may be better able to set realistic expectations regarding long-duration space flight. In terms of training, individuals without long-duration ICE experience may consider subjecting themselves to such an experience and to train in tactics and countermeasures to mitigate possible negative effects.

Another risk in space-flight is poor sleep. Interrupted or poor sleep is both an indicator and result of stress. An individual experiencing strain in a stressful situation may have trouble falling asleep and staying asleep. Insomnia is one of the signals for depression in individuals. Furthermore, poor sleep can cause irritation and fatigue, which can cause decrements in performance, including impaired learning and motor tasks. Such performance decrements could be catastrophic in a high-stakes setting, such as long-duration space flight. The relationship between stress, strain, and sleep is cyclical and has the potential to cause continually worsening decrements. Poor sleep can be a response to stress and depression, but can also cause irritation and fatigue, which themselves cycle through into behavioral decrements. Journals from astronauts listed interrupted sleep as a major stressor while in flight (Stuster, 2010).

Countermeasures to ensure proper sleep can have a positive interaction with the sensory deprivation and social isolation countermeasures described previously.

Conclusions

Long-duration space flight is not without serious cognitive and performance threats to the astronauts. Mitigation tactics for combating the negative effects of long-duration space flight is unexplored territory, as no one has ever been isolated to the same degree that the astronauts on a long-duration space flight will be. Based on the results of analog studies and previous experiences with space flight, we can predict what might occur to individuals in this scenario without adequate countermeasures (see Otto, 2007; Suedfeld& Steel, 2000). To avoid potentially disastrous consequences, countermeasures for sensory deprivation and social isolation must be planned as part of the mission, not treated as auxiliary or optional operations. Several potential countermeasures have been proposed here based on the available literature, but need to be tested in high-fidelity environments.

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Long-duration space flight presents several challenges to the behavioral health of crew members. The environment that they are likely to experience will be isolated, confined, and extreme (ICE) and, as such, crew members will experience extreme sensory deprivation and social isolation. The current paper briefly notes the behavioral, cognitive, and affective consequences of psychological stress induced by ICE environments and proposes nine countermeasures aimed at mitigating the negative effects of sensory deprivation and social isolation. Implementation of countermeasures aims to maintain successful crew performance and psychological well-being in a long-duration space flight mission.

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