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Psychological and biological challenges of the Mars mission viewed through the construct of the evolution of fundamental human needs

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ABSTRACT

The environment of a deep-space Mars mission represents a genetic, epigenetic, and psychological mismatch to the terrestrial environment in which humans evolved. Potential psychological and biological challenges of this mismatch have been gleaned from simulations in space-analog facilities, polar expeditions, and missions served on the International Space Station. Optimal performance and welfare of crew members will depend on successful adaptation to these challenges, which in turn depends on the satisfaction of fundamental human needs. These fundamental human needs – drawn from Maslow's hierarchy of needs – include physiological, security, relationship, and existential needs. The satisfaction of each need over the course of a protracted space mission will require the crew to overcome novel psychobiological obstacles for which they must be prepared. Of particular concern will be the rigors of an isolated environment out of sight from the travelers' terrestrial home, leading to stress-induced depression of the immune system and potential psychological pathologies. A rationally designed mission environment that utilizes technology and measures such as biophilia to optimize the fulfillment of each human need could bolster the psychobiological resilience necessary for a successful odyssey.

1. Introduction

The practical psychological and biological requirements of participants on a human deep-space mission are rarely, if ever, discussed in the context of human evolution. Reference to evolution for such a mission may at first glance seem to be of little value or relevance – the technological challenges of such a mission may seem to be so much more immediate. An evolutionary context for such a mission might encompass the challenges concomitant with a deep-space environment that is mismatched with the one in which the genomes and epigenomes of crew members developed, or it may refer to a set of speculations about the possible future evolutionary progress of humankind. Evolution in the form of continued biological adaptations to the spaceflight environment theoretically could be possible, but would require conditions such as isolated communal living in small groups, intensive selective pressure on a given function or trait, and very limited inter-group migrations.

In this paper, we initially consider how the human evolutionary past might impact a manned Mars missions. The obvious and in some sense trivial statement – that humans are not evolutionarily adapted to live in space – has serious consequences when the idea of future human space missions is considered and postulated as the next step of human expansion. Crucial decisions will need to consider the nature, means, and purposes of such a mission. If such a deep-space mission is treated only from a short-term perspective, we do not have to concern ourselves with human adaptability as much as in the case of a long-term mission. Careful considerations and studies are required when human life and health are at stake. Because space is an extremely unfriendly environment to humans, even short missions require careful preparation in the medical and technological sense. When we consider the idea of a deep-space mission only from a short-term perspective, we do not have to discuss and have in mind the human evolutionary past and human adaptability in general, except in the context of how such a past affects performance and survivability in the mismatched environment of space. When a long-term deep-space mission is considered, concerns regarding past and future human evolution should be explicitly taken into account. For our purposes here, in the majority of the paper, we assume that the first human deep-space mission will be a mission to Mars, and that such a mission will be longer than the currently planned approximately three year mission. (A short-term human Mars mission

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refers to a mission that will last about three years, including transit and surface operations. We define a long-term Mars mission as one where a primary objective consists of building and maintaining a permanent human settlement. A long-term mission will follow after a series of short-term missions.) This distinction refers here only to human missions to Mars, where the shortest variant of the mission is estimated at 2.5–3 years, when compared with a long-term – including research base, semi-permanent or permanent human settlement – scenario. In the space medicine and psychological literature, even the shortest human mission to Mars has a status of a long-term mission, while a short duration mission is defined as a mission no longer than 2 weeks [Kanas and Manzey 2004]. But for the purpose of this paper, we apply short-term and long-term distinctions only to the human mission to Mars.

This means that astronauts during the first Martian missions will stay there through many years, or perhaps they will stay there forever. In the light of such a long-term deep-space mission, an evolutionary context must include knowledge about the human evolutionary past, and speculation about the possible future evolution of a human colony on Mars. In addition, it must also engender predictions about the effects of an artificial, accelerated evolution that might be deliberately affected and modified by the most advanced human knowledge and supported by the ethical and philosophical idea of human physiological and psychological enhancement as a necessary and perhaps unique way to cope with the challenge of living in space.

The goal of this paper is to discuss challenges of human missions to Mars in the light of fundamental human needs. We propose the model in which we treat human astronauts – and possibly future Mars settlers in the long-term mission scenario – in a complex bio-psychological way. We start from the study of space hazards and the deleterious impact of space environment on human physiological needs. Then, we discuss the importance of security, relationship and existential needs. We discuss the interconnectedness and synergy of all four human needs. We propose that the space environment comprise an extreme mismatch from the terrestrial environment ideally suited to satisfy human needs. We then consider possible solutions based on the idea of biophilia or various forms of human enhancement. We argue that the concept of human deep-space missions is challenging in a way incomparable with previously realized human space missions.

2. Fundamental needs in human evolution

The genesis of the psychological and biological challenges individuals will face on a Mars mission stems from the universal human needs that must be satisfied for optimal performance and welfare. One conception of these universal human needs was postulated by the psychologist Abraham Maslow [1] and provides a useful framework for the psychobiological challenges of a Mars mission, since the necessity of their satisfaction remains constant regardless of place and time. If we slightly rework Maslow's framework, we essentially have four categories of human needs: physiological needs, safety or security needs, relationship needs, and existential needs. We intentionally eliminate a fifth category of needs of Maslow, that of his conception of the need for esteem, since we morph it into the categories of relationship and existential needs. We do this since, in our opinion, his division of esteem into lower esteem (esteem dependent on others) subsumes with relationship needs, and his conception of higher esteem (self-respect) subsumes with existential fulfillment.

2.1. Physiological needs

The first of these, physiological needs, relates to all the biological needs of the organism including energy intake (adequate food and nutrition), energy conservation and restoration (rest and sleep), and maintenance and growth (through stressing the body through exercise, for instance).

Space travel results in challenging physiological issues for the human organism including muscle atrophy, bone demineralization, occasional degraded vision, impaired cardiovascular function, and redistribution of fluids to the upper parts of the body [2]. The most effective single countermeasure to these changes has been exercise. Exercise increases mitochondrial protein synthesis and preserves telomere length, two areas of concern gleaned from the recent twin study comparing -omics changes between astronaut Scott Kelly (who spent 340 days aboard the ISS) and his identical twin Mark (a former astronaut, who remained on Earth) [3,4]. Although exercise compliance is generally good, on longer flights with non-professional crews this might be a problem due to the time requirements and boredom of extensive exercise [2]. Exercise compliance might be improved through the use of virtual and augmented reality games that involve body movement. In 2016, a terrestrial augmented reality game, Pokemon Go, increased the activity level of participants by 1473 steps a day on average, a more than 25% increase. In only 30 days, the game added a total of 144 billion steps to U.S. physical activity levels [5]. Exercise involving the learning of new complex movements involving bilateral coordinative functions, such as dance, martial arts, sports, and yoga, might not only improve compliance through increased enjoyment but also enhance cognitive function [6].

Other physiological challenges result from space radiation, which can damage DNA directly or indirectly through the production of free radicals. Radiation risks include cancer, central nervous system disorders, degenerative diseases, and acute radiation syndromes. Microgravity can impair DNA repair mechanism resulting in increased double strand breaks, chromosome aberrations, and micronucleus formations [7,8]. Nutritional interventions may modulate some of these effects: in one study, rats on a diet supplemented with 2% strawberry extract for two months prior to exposure to 1.5 Gy of 1 GeV/n 56Fe particles performed better on behavioral tasks than non-supplemented animals [9].

The magnitude of the dangers of cosmic radiation is illustrated by the fact that the Martian rover Curiosity has absorbed during its 8.5 month trip to Mars as much radiation as an organism would absorb during 90 years on Earth [10]. Radiation damages cells, leading to cancers and death. For obvious reasons, scientists cannot test space-like radiation exposure on living humans. Comparative studies on non-human animals do not guarantee reliable conclusions due to species differences [11]. Scientists study astronauts on the International Space Station who are exposed to increased radiation levels compared to being on Earth (although less than in deep space); these studies suggest that the risk of cancer may increase during cumulative ISS and deep-space missions of more than 18 months, depending on solar conditions [12]. It is worth noting sex differences in the context of radiation exposure: women are more susceptible to cancers caused by radiation [13]. Female health and, consequently, the perpetuation of life itself, seem to be more endangered during space missions than are the lives of males. This is a challenge of the highest import for deep-space colonization missions for future human settlement in space. Wickman [14] argues that radiation exposure affects human reproduction. There are real concerns about the feasibility of human reproduction under space environmental conditions [15].

The impact of living in the earthly gravity field is deeply embedded in the genome of all animal species [16] and is the frame through which terrestrial biological adaptations have occurred. For that reason, leaving earthly gravitational conditions causes various risks and dangers including, among others, bone loss. Bone density and strength might not be protected in Martian gravity without additional interventions such as exercise. Implementation of artificial gravity has great promise but would be difficult on a large scale for many people, either on the journey or on Mars itself [16]. Exercise and pharmaceuticals have proven to be effective for professional astronauts on ISS, but might be insufficient for larger numbers of colonists without the same high levels of discipline and motivation [17]. Some estimates predict that a three-year Mars mission may cause up to a 50% loss of strength in some muscle groups [18] if the most modern countermeasures are not used regularly. Various aspects of the space environment cause alterations in the human immune system that might increase the risk of acquired diseases. Exhausted and immune-weakened astronauts could be exposed to infections. Extended space flight also produces deficits in cognitive and perceptual abilities [19].

In the light of these many and varied physiological challenges, we have great concerns about the viability of something as ambitious as a Mars colonization effort with current countermeasure concepts. Obviously, humans did not evolve to live in space [17]. For technical reasons we cannot precisely emulate, here on Earth, the wide range of space-environmental conditions, and for ethical reasons we cannot study humans in some of the more demanding conditions of a deep-space mission such as radiation exposure. However, we can study the physiological performance of astronauts on ISS. According to some estimations, an initial exploration mission to Mars may last three years [20]. The longest human mission in space belongs to Valeri Polyakov who stayed on the Mir space station for 437 days in 1994/1995. Recently a “one-year” ISS mission was conducted by Scott Kelly and Mikhail Kornienko in 2015/2016 [21,22]. For obvious reasons, even such an extremely long space mission does not simulate all of the conditions and factors that are relevant to a real deep-space mission to Mars. Nevertheless, some partial conclusions and estimates about physiological challenges are possible on the basis of current missions to ISS.

The NASA Human Research Program enumerates the major risks to health and performance in long-duration space flights. These include “Risk of Adverse Health & Performance Effects of Celestial Dust Exposure, Risk of Adverse Health Outcomes & Decrements in Performance due to Inflight Medical Conditions, Risk of Bone Fracture due to Spaceflight-induced Changes to Bone, Risk of Ineffective or Toxic Medications Due to Long Term Storage, and Risk of Renal Stone Formation” [23]. In addition to this list, we might also consider the broad set of medical problems that might require surgery or other dramatic action. Abadie et al. [24] mention risks including gravity, isolation, closed environment, radiation, and awareness of remoteness from Earth. Among directly physical deteriorations many authors mention bone loss and deficits in the musculature or cardiovascular system. Health troubles might be exacerbated by lack of a normal 24 h light-dark cycle which could also lead to motor and cognitive deficits during technical tasks and scientific experiments [17]. Wickman [14] enumerates such space ecological challenges as microgravity, radiation, isolation, noise, and stress. Living in space will engender many challenges that encompass one large complex of physiological, psychological, and ecological deteriorations [25].

2.2. Security needs

Next in the hierarchy of needs are those related to safety or security, which encompass all the concerns that humans have about remaining secure from the perils of their environment, whether such dangers come from natural or created hazards, the malevolence or dominant hierarchy-reinforcing intentions of other humans, the nutrient needs of other organisms, or the self-propagating directives of microorganisms, viruses, or prions. As the philosopher Thomas Hobbes once wrote, in the absence of a protective authority, the life of man is ”solitary, poor, nasty, brutish and short”. Thus, a centralized and responsive protective authority, a deterrent legal framework, or a decentralized self-protective framework should be contemplated in any situation where humans interact with one another and their environments.

Although professional astronauts undergo a rigorous screening process, the possibility of violence is always present as long as human beings interact with one another. In 2007, an unfortunate incident took place in which an astronaut on Earth confronted a romantic rival with possibly harmful intentions. Although this did not occur in space, it indicates that even after rigorous screening there can be problematic outcomes. Large colonies with a wider range of expertise, background, and discipline might be expected to yield even greater problems. The possibility of violence on a space mission was predicted a half century ago by psychiatrists [26–28]. A Mars mission will be the first in which humans will have to deal with the ”Earth-out-of-view” phenomenon [White 1987]. The psychiatrists predicted that this separation from Earth could lead to an extremely pathological case of separation anxiety that could trigger an existential crisis and lead to suicide and even a desire to destroy the space vehicle and the rest of the crew. This must be tempered with the understanding a great many dire predictions were made at that time about the ability (or lack of such) of humans to survive in space, few if any of which turned out to be true. Nevertheless, NASA has developed guidelines for the potentiality of a violently agitated crew member including a protocol for physically restraining them [29]. However, an objective is different from a well-practiced plan, and until astronauts repeatedly simulate restraining a crew member through non-violent methods, security vulnerabilities remain. The human factor, as always, remains the fly in the technological ointment.

2.3. Relationship needs

The third category of fundamental human needs is the area of relationship needs, the satisfaction of our innate desire for love and belonging. Interpersonal communication training, including assertiveness training and conflict resolution training, as well as a well-reasoned environmental design to maximize both respect for personal space and positive interpersonal interactions, can help minimize these concerns.

Games and activities on a Mars mission that involve human touch will likely be important for the satisfaction of relationship needs. Some nonhuman primates spend up to 20% of their time grooming to facilitate interpersonal bonds, and in a recent study of sports teams, those that spend more time touching one another perform more successfully [30]. fMRI studies show that touch dampens the stress response, and other studies demonstrate that it increases levels of oxytocin and decreases blood pressure [31,32]. Therefore, activities involving touch such as partner yoga, dance, martial arts, or massage may be beneficial on a Mars mission.

One potential hazard of the relationship connections between individuals on a Mars mission is the possibility of the spread of a mass psychogenic illness: the spread of aberrant behaviors with no apparent external biological agent. Behaviors and conditions such as depression and obesity spread through social networks, and mass psychogenic illnesses may comprise extreme pathological manifestations of this phenomena [33,34]. On a 1976 Russian mission to the Salyut 5 space station, the crew was brought back to Earth early after they reported an acrid smell aboard the station; no source of the supposed odor or technical problems were ever found [35]. Other cases of mass psychogenic illness in the modern era include the Tanganyika laughter epidemic of 1962 and a series of incidents between 1973 and 1978 in Singapore factories [36,37].

Obviously social connection is essential for human health, and a rational environmental design of a Mars mission living space must maximize positive connections while minimizing the potential for aberrant ones. Artificially intelligent systems could potentially detect pathological behaviors early to minimize the dangers to the rest of the crew.

2.4. Existential needs

Last in the hierarchy are needs related to existential fulfillment, which might be satisfied through adherence to various goal-achievement training methodologies. Our *telos*, or purpose, can be the essential driver to stave off debilitating conditions such as anxiety and depression. A key method of satisfying this need on a Mars mission could be psychological diagnostics beforehand which identify a number of subgoals (apart from the overall mission) which give the participants’ lives meaning, and the facilitation of goal-achievement methods to engage in the pursuit of these sub-goals on the mission.

The previously discussed physiological challenges may only be a prelude to these more troublesome psychological and existential concerns. The physical health of astronauts has largely had priority over psychological studies in deep-space missions [14]. The space environment, however, produces various psychological threats and risks including "confinement, limited habitation volume, compromised quality/conditions of habitation environment, absence of fresh air, reduced sensory stimulation, boredom, regimented work/rest schedules, [and] strangeness of [the] environment" [14]. Some of these are not unique to the domain of the space environment and include, among others, confinement, or the effects of high levels of stress. Other psychological ills are specific to the space environment and include a delay in communication with ground control (and family support), and possible mental and psychological deprivation caused by radiation and microgravity [19]. Other types of psychological challenges include operational mission stressors like workload and time pressure, and psychosocial factors including crew tension, cohesion, leadership issues, and cultural and language differences [38]. In the Russian but not the American space program and space health care system, asthenia has the status of serious psychiatric syndrome [38].

There are a few possible strategies that may be used to cope with space psychological health issues, although much remains to be done and this could be a substantial concern for colonization missions. Beyond screening and training, mainly these strategies consist of tools to maintain well-being, such as sensory stimuli that mimic natural features of Earth, training for group and inter-cultural dynamics, and monitoring to detect problems early so that interventions can be taken (crew coaching, sociometric badges).

3. Synergy between fundamental human needs

These four fundamental human needs synergistically affect each other, which compounds the effects of their satisfaction or deprivation. For instance, consider existential fulfillment needs and physiological needs. If one is deficient in basic physiological needs, one's psychology is impacted and that can severely affect the existential state of being and goal-achievement ability. How well the maintenance tasks underlying a physiological state are satisfied can adversely or beneficially affect an individual's emotional state and psychological outlook. This in turn can affect the self-efficacy that is so crucial to successful goal achievement and which helps give us a sense of purpose and accomplishment.

Mechanistically this might occur when exercise produces the hormone atrial natriuretic peptide (ANP). When heart rate increases during exercise, more ANP is produced which counteracts stress hormones, resulting in a decrease of stress and anxiety. Additionally, exercise boosts the production of natural opiates called endorphins, which fight pain and boost mood. Not only does exercise boost ANP and endorphins, it raises levels of the neurotransmitters targeted by antidepressant medications, including dopamine, norepinephrine, and serotonin. All three of these monoamines increase mood and are part of the mechanism of action of various antidepressant medications. Exercise also boosts brain-derived neurotrophic factor (BDNF). Chronic stress raises cortisol levels, which cause neurons and their connections to shrink in the hippocampus, a cluster of brain cells essential for learning and memory. BDNF, conversely, causes connections between neurons to sprout and grow, creating the neural infrastructure through which the monoamines can exert their affects [39]. This may be essential to breaking out of the repeating negative thought cycle indicative of depression. So the exercise that aids physiology is inextricably linked to a boost in mood which aids the goal achievement that satisfies our existential needs for purpose and accomplishment. Numerous other synergistic affects emerge from the actions engaged in to satisfy various existential needs.

4. Magnification of synergistic effects through environmental mismatch

These synergistic effects are magnified further by environments that are mismatched to those in which our genes evolved. For instance, our modern obesity epidemic is hypothesized to originate from a mismatch between our pre-agricultural genomes (which developed in times of food scarcity to be pro-adipogenic) and our modern environment of food surplus [40]. Analogous mismatches will inevitably arise on a Mars mission.

A catch-all preparation approach would be to strengthen each fundamental human-need category through a targeted program of biopsychological training. The rigorous selection process for the mission will increase the likelihood that exceptional individuals with strength in these fundamental areas will be chosen. However, because of the mismatch between the Mars environment and the primordial environment in which our genes developed, as well as the Earth environment in which our epigenome developed, it seems to us imperative to strengthen the areas encompassing the four fundamental human needs through specialized training. The greater the mismatch, the greater the potential disruption to the genome, epigenome, and psyche. Cracks in the psychobiological foundation become more evident the greater the strain. Therefore, a specialized psychobiological diagnostic program to identify these cracks with targeted proscriptive training to remedy any deficits would appear to be wise.

What are some mismatches stemming from the novel environment of the Mars mission that we can identify up front? While an exhaustive survey is beyond the scope of this paper, we can identify a few of the most pressing challenges by focusing on the effects of prolonged isolation in the next section.

4.1. *Psychological challenges of an isolated environment*

A key psychological challenge (encompassing the relationship need) is isolation, which will be compounded by extreme alienation from the natural surroundings of Earth. Earth is 0.239 million miles away from the moon but 140 million miles away from Mars. Such a divorce from the travelers' terrestrial home will engender novel challenges as the psyche seeks to adapt to the surroundings of oblivion. The history of human exploration on Earth lends us useful examples of similar expeditions when missionaries or colonizers left their homelands, often forever, and explored new and dangerous environments. Their indomitable motivation to explore was likely essential for the success of their missions. We expect the same in regard to future Mars astronauts. The extreme distance from Earth to Mars tests the limits of our analogies and introduces a new milestone in the history of human exploration and risk assessment. It is imperative that the existential needs of the voyagers are firmly aligned with their missions of exploration.

Although the map can never recreate the territory, simulations in space-analog facilities are an important and necessary means to characterize some of these challenges. The HI-SEAS analog, for instance, has conducted several simulated missions of four, eight, and 12 months. This is an isolated facility below the summit of the Mauna Loa volcano in Hawaii, which can hold up to six crew members. Various Mars-like scenarios can be simulated, including communication delay with "mission control." Valuable information on team performance, autonomy, and psychological function is acquired during these missions, including that from various biosensors [41,42].

A central limitation of many such simulations is their short duration compared to that of an actual Mars mission. The shorter duration, as well as the awareness that help will arrive if a crisis occurs, drastically changes the psychological dynamics. Survival in a challenging environment might be eased somewhat if one knows when help will arrive, but is not so easy if there is no such knowledge. A telling example is the current series of six-month missions to ISS. Astronauts can be evacuated within hours in case of emergency, they see Earth constantly, and being in low-Earth orbit enables live contact with ground control without delay. None of these conditions will be the norm on a deep-space mission. Lack of evacuation capability, significant communication delay with Earth, and the constantly diminishing view of mother Earth, might all contribute to psychological stress.

Psychological problems have occurred on some simulated analog missions. During the Biosphere 2 simulation, which encompassed a greenhouse-like habitat, two crew members did not speak to each other for 18 months, apart from mission-critical exchanges [43,44]. During a simulated four-month Mars exploration mission at the Flashline Mars Arctic Research Station (FMARS) in the Canadian High Arctic on Devon Island, participants reported interpersonal conflicts and an episode of unreciprocated sexual attraction [45]. The Russian Mars 500 mission (which also consisted of European and Chinese crew members) came closer to replicating the duration of a Mars mission by isolating participants in a test chamber in Russia for 520 days. Members suffered from depression, sleep irregularities, boredom, and loss of motivation. A female was not included to avoid possible psychological issues inherent in group dynamics of a mixed-gender crew [46,47]. Personal journals kept by astronauts aboard ISS from 2003 to 2016 (as part of a research project) could provide a useful model, although again the shorter mission durations impact extrapolation to a Mars mission [48,49]. Journal entries were extracted and coded as positive, negative, or neutral. On future simulations, such data could be improved by coding in terms of explanatory style which is correlated with increased performance in multiple domains [50]. Polar expeditions present a valuable model from which lessons for Mars can be drawn. This is because of the higher levels of isolation and danger compared to other simulations. In addition, the larger number of people, even in a winter-over situation, means that all will not have the very high degrees of training, motivation, expertise, and dedication as in current professional astronaut crews; in this sense also it may better approximate a Mars colonization. Approximately 5% of participants on these expeditions develop psychiatric disorders. Interpersonal conflicts, depressed mood, sleep disturbances, and impaired cognitive ability are common [51].

While the discussed analogue simulation missions have some analogical value, it is worth keeping in mind limitations of these kinds of studies. First, the crew of these missions are comprised mostly from volunteers who even if trained and guided by space agencies differ from professional astronauts in longevity and intensity of their training and expertise. Professional astronauts selected for real mission to Mars may be better adapted to psychological challenges met by participants of terrestrial simulations. They can be recruited from the former ISS astronauts and they can have experience which is not available for terrestrial volunteers. However, the study of volunteers in analog missions may lend more useful insight if space missions become a more available and commercialized undertaking. Depending on which different possible scenarios of future missions become a reality, there may be need for non-professional astronauts. Their selection due to financial and logistical reasons may be less stringent than the current selection of professional astronauts.

Second, space analog simulations conducted on Earth cannot imitate critical conditions. Space radiation, which is the most hazardous during interplanetary journey, and altered gravity, are not simulated on Earth. For this reason, missions on the ISS are currently the best and the most reliable way of testing human performance in space. Terrestrial simulations are not able to imitate real psychological challenges. Missions on the ISS also differs in a psychological sense from real missions to Mars. Last but not least, terrestrial analogs cannot simulate the complex and interconnected hazardous impact of the physical factors of space environment and real psychological stress. This is the objection to overextending the findings from some expeditions realized on Earth. This fact illustrates how challenging and unpredictable the first human mission to Mars will be.

Measures to improve psychological resilience on a Mars mission are especially important due to depression of the immune system in space flight. Astronauts on ISS for six months have reduced T-cell function, and reactivation of latent viruses including Epstein–Barr, varicella-zoster, and cytomegalovirus has been reported. Psychological stress increases the risk of reactivating these viruses [52].

The long duration of a Mars mission increases the possibility of psychological stress due to the death of a loved one on Earth. Understandably, this ranks at the top of human stressors [53]. Moreover, death rates for bereaved persons under age 65 increase significantly within the first two years after the death of loved ones, for reasons not fully understood [53–58].

For all these challenges, it would be prudent to implement a focused multi-faceted regimen to decrease stressors and increase resilience for a Mars mission. One aspect of this regimen might consist of infusing the mission with connections to nature such as natural imagery and green plants. Biophilia is a field of study proposed by E. O. Wilson [59] to describe the innate tendency of humans to seek out nature and other forms of life, and the effect that this tendency has on their psychology and biology. Within this overarching field, the “savanna hypothesis,” proposed by Gordon Orians, states that we are hardwired via evolution to experience beneficial biological and psychological states in the presence of beneficial primordial habitats [60]. Studies show that viewing nature scenes significantly decreases fear arousal [61]. One study that measured alpha brain waves (Electroencephalography, EEG-a/EEG-b) and forehead electromyography (EMG) showed decreased anxiety in natural settings [62]. Another using gEEG and EMG showed that activities with plants (especially flowering plants) promote physiological relaxation [63].

These stress-reducing effects may be responsible for the enhanced immune function of those immersed in natural settings. An analysis of a decade of stays at one major hospital showed that surgical patients assigned to rooms with windows overlooking natural scenery had shorter postoperative hospital stays and took fewer potent analgesics than patients in similar rooms with windows facing a brick building wall [64]. In another study, appendectomy patients in hospital rooms with plants and flowers had significantly less intake of postoperative analgesics, more positive physiological responses evidenced by lower systolic blood pressure and heart rate, and lower ratings of pain, anxiety, and fatigue [65]. Natural Killer Cells (lymphocytes which play an integral role in the innate immune system) and intra-cellular anti-cancer proteins are elevated for more than seven days in city-dwellers who took a day trip to the forest [66].

Pets can also have anti-stress and immune boosting effects. In one study, patients recovering from heart disease who had pets had greater one-year survival rates than those who did not [67]. Immunoglobulin A (IgA) levels were boosted in participants who petted a dog, while those who petted a stuffed toy dog, or simply relaxed on a couch, didn't experience significantly increased IgA [68,69]. Pet ownership, but not ACE-inhibitor therapy, decreases blood pressure responses to mental stress [70]. Recent archeological findings show that dogs have been buried alongside humans, complete with items such as decorative collars and spoons which they would utilize in this afterlife [71]. This evidence points to a close relationship with our canine companions in our evolutionary past.

New wearables, brain-computer interfaces, virtual and simulated reality devices, and other computer technologies could also potentially alleviate stress by providing sources of distraction and engagement, in addition to “low tech” technologies of plants, natural scenery, pets, and so on. Enhancements such as social media platforms may modify brain and behavior, possibly by expanding Dunbar's number – how large one's social group can be – which is hypothesized to be dependent upon prefrontal lobe functionality, with implications for behavioral contagion. However, the psychological and sociological effects of these new technological devices would have to be evaluated before adoption for a Mars mission [72–75]. A rational architectural design of personal quarters and common space that maximizes positive interactions while preserving privacy will also be important for psychological health [76].

Simple interventions such as scheduling a viewing party of a particular entertainment event at (roughly) the same time those on Earth are watching may psychologically ground the crew away from the abyss through a shared connection of time and space [77].

5. Conclusion

Optimal planning to account for the physiological, security, relationship, and existential needs in an environment mismatched with the one in which humans evolved is imperative on a deep-space Mars mission. We emphasized the gap between human adaptive space on Earth and the space environment of a mission to Mars, which is considered by mission planners as a new target for humans in the near future. We suggested treating the future deep-space missions human astronauts in a complex biopsychological way which will include human connectedness with natural environment through thousands of years of evolution on Earth. As we suggested, biophilia is a promising area for future studies. We wanted to show that mission planners should consider various avenues of human enhancement. As we showed in the first part discussing space hazards for human physiology, human mission to Mars will introduce new qualitative and quantitative hazards for human health. Exposure to space radiation and microgravity will be incomparable with previous crewed missions. For these reasons, while human - Mars analogs on Earth offer valuable data, there are useful mostly for psychological insight. As we showed in the paper, we should always consider humans in an integral way, in which physiological stress affects psychological stress, and vice versa. While we cannot predict precisely all hazards and threats for human astronauts during a mission to Mars, it is worthwhile to consider all possible countermeasures including human enhancement.

The suggestions in this paper may help in developing a starting point for such discussions. Contemplation of the issues regarding human evolution on a longer-term Mars mission, as well as how this evolution will proceed in the context of technological and biological interfaces and enhancements, also deserves our attention and will be the focus of future papers. If it is an imperative of humans to know ourselves, as that ancient oracle at Delphi counseled, we must learn who we will become as we evolve to face our futures.

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