Bringing Nature into Space: The Restorative Potential of Virtual Environments for Long-Term Space Travel

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For a human mission to Mars, prolonged isolation and confinement poses one of the greatest risks to the well-being of the crew, and can threaten the overall success of the mission. Numerous studies have documented the range of psychological, sociological, and behavioral problems that can result from long durations in isolated and confined environments, but to date, little research has examined how environmental conditions themselves could attenuate, or even pre-empt, negative effects such as stress, monotony, and under-stimulation that are associated with isolated, confined, and extreme environments.

Exposure to the outdoors, and to natural landscapes in particular, has proven to be beneficial in reducing stress, improving cognitive skills, boosting work performance, and accelerating recovery. Though being out in nature is not possible on a mission to Mars, the use of virtual reality (VR) technologies to provide the experience of a simulacrum may be able to provide similar benefits. VR has the potential to not only reduce symptoms that can lead to pathology, but may even have measurable salutogenic effects on the crew. They could offer alternate settings for social interaction; provide opportunities for leisure, relaxation, and creativity; increase sensory stimulation and creativity; reduce feelings of isolation and confinement through Earth-like environments; and promote a greater affinity for the Mars environment.

Keywords: isolation and confinement, nature, virtual environments, psychosocial well-being

photo: courtesy of www.hi-seas.org

Nomenclature

The language of architecture and the language of astronomy both include the word 'space' in their respective lexicons; there is some overlap in their meaning, but also some critical subtle differences. In order to preserve the nuances of each, the two terms will be distinguished as follows: 'space' represents the general condition of emptiness, absence, or void; and 'Space' represents what we commonly refer to as outer space or the cosmos.

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I. Introduction

PSYCHOSOCIAL problems that arise from isolation and confinement in extreme environments (ICEs) present one of the most significant obstacles to the success of long-duration human missions in Space.[1,2,3] Some of the adverse effects that have been associated with ICEs include stress, boredom, monotony, loneliness, anxiety, irritability, aggression, uncooperativeness, social splintering, withdrawal, and performance impairment.[4,5] While adverse psychosocial effects are not exclusive outcomes of ICEs, nor are they universally experienced, they may however, lead to the disintegration of crew cohesion or decrements in crew performance, which can in turn undermine the success of the mission.

Psychological and social problems associated with prolonged isolation and confinement have been primarily addressed through crew selection and training, taking into consideration factors such as crew size, cultural background, gender, and heterogeneity.[6-10] While the threats that ICEs present to a crew's psychological health and social cohesion have been rigorously documented,[11-18] less consideration has been given to managing environmental factors that could ameliorate these effects,[19] or even promoting salutogenesis.[20,21] There are a number of environmental conditions which contribute in particular, to the subjective experience of confinement, such as minimal access to the outdoors; constrictive, compartmentalized spaces; inflexibility in reconfiguration of interior space; lack of mobility and limited range of physical activity; limited choice or control over personal surroundings, and lack of sensory stimulation.[22]

The potential for how environmental interventions can positively impact behavioral and mental health is clearly illustrated by the crew interaction with the cupola installed at the ISS [Figure 1]. In a study conducted on the crew's activity, eighty percent of astronauts' leisure time was spent sitting by the viewing portal Earth-gazing.[23] This phenomenon, which later came to be known as the Overview Effect, had a profound salutogenic influence on the crew—well beyond the simple pleasure of a window view. The window allowed crewmembers to have a visual connection to 'home' that also imparted a phenomenological sense of place and proprioceptive location. Moreover, the cupola created an intimate niche that was conducive to reflection: crewmembers reported that gazing at the Earth gave them a heightened appreciation of the fragility of our planet and of the interconnectedness between all living things and their environment.[24]

photo: courtesy of NASA

Figure 1. Astronaut Karen Nyberg gazing at the Earth from the cupola on the ISS

Environmental interventions may not only reduce stress experienced by crewmembers, but may also diminish those very stressors which arise from confinement in the first place. It can also provide the possibility for aesthetic experience—to have occurrences of beauty in day-to-day life—which is often underestimated as an essential determinant of well-being. The potential for both pre-emptive and restorative effects of environmental interventions is an area of study that should be investigated further in the context of human Space travel.

II. Restorative Benefits of Nature

There is abundant research in the field of environmental psychology that shows that exposure to the outdoors—that is, perceptual awareness of conditions beyond the confines of the habitat enclosure—can provide restorative benefits and is crucial to psychophysical well-being; in particular, views of natural landscapes. Restoration is understood as the renewal of diminished social, physical, psychological and social capacities to meet adaptive needs.[25,26,27] While studies on restorative benefits have focused predominantly on addressing stress, cognitive fatigue, and mood, in the context of ICEs, restoration could also address feelings of satisfaction (with colleagues, mission, and habitat), as well as arousal and stimulation to counter boredom and monotony.

There are two theoretical foci in the literature on restorative environments: Ulrich's model based on affective response as the catalyst for restoration,[28-31] and Kaplan's model which posits that cognitive response precedes affect, and hence, precipitates restoration.[32,33]

Ulrich's research on hospital patients recovering from surgery revealed that they experienced a range of benefits, both emotional and physiological, when they had windows that allowed them to view nature—as opposed to those patients who either had no access to a window, or had views only to adjacent buildings. When exposed to views of trees in particular, surgery patients reported less stress and anxiety, required less pain medication, and required shorter recovery time and hospital stays.[34] Similarly, Barton and Pretty's research found that people who exercised with exposure to nature, especially water features, enjoyed improved self-esteem and mood.[35] Moreover, exposure to natural scenery has also been found to influence aspirations, with participants placing more importance on intrinsic values (e.g., personal growth, intimacy, sense of community) over the extrinsic ones (e.g., wealth, status, power).[36]

Ulrich's framework is predicated on the assumption that preferences for natural environment stem from our evolutionary history, eliciting positive feelings and a sense of well-being that have been encoded by conditions that are favorable to our survival.[35] In contrast to Ulrich's emphasis on affect and mood as the antecedent for restorative effect, Kaplan argues that preferences for natural settings are based on their ability to replenish depleted attention capacity, caused by the distracting and chaotic stimuli of our busy urban settings.[37,38] Kaplan's body of research has thus concentrated on the impact of nature exposure on cognitive processes. Numerous studies have demonstrated that students taking exams in a classroom with a window to a view performed consistently better than students in classrooms with no outdoor view or natural light.[39-42] Other studies have correlated higher quality of work performance and increased productivity when workers had offices with views to natural features and intake of natural light.[43-46]

It should be noted that views to outdoor 'scenery' should not be equated with the presence of indoor 'greenery'. While the inclusion of plants in living spaces also has its benefits on psychological well-being,[47-49] it is not a substitute for the multi-sensory experience of sweeping and expansive landscapes.

III. Natural vs. Simulated Environments

More recent research has examined whether the same restorative effects of direct or indirect exposure to nature can be elicited through simulated environments. Studies showing promising results have been conducted on a range of demographic populations: groups living in isolated and confined conditions (e.g., prison, Antarctic research stations, space habitat simulations), subjects who are experiencing stress-induced pathology (e.g., PTSD), and hospital patients who are in treatment for illness or injury.

Studies conducted on prison inmates showed that 15-20 minutes of exposure to nature videos positively impacted relationships with inmates and prison staff; and that these effects lasted for hours after the exposure.[50,51] Even exposure to static nature imagery (e.g., poster, photos) was found to significantly reduce stress, anxiety, aggression and irritability—especially in conditions where there is little or no access to ambient nature.[52-55]

All scene types however, do not have the same degree of restorative effects. Viewing nature imagery was found to be more effective in alleviating stress than viewing urban landscapes, watching television, or looking at abstract art.[57] Exposure to simulated natural environments—compared to exposure to simulated urban environments—gave rise to increased positive affect, and accelerated recovery from stress and directed attention fatigue.[26,56,57] Of the types of nature imagery used in the studies, exposure to trees was most strongly correlated with feelings of relaxation,[58] with subjects displaying a preference for gardens, flowers, and open landscapes.

The presence of scenic pictures and dioramas in conditions of confinement has been reported as soothing to geographically isolated explorers and scientists. Crews at the Antarctic research stations displayed images of idyllic places that they have either visited in the past (evoking nostalgia) or dreamed of visiting in the future (evoking chimera).[7] Reflecting "a desire to view landscape-type scenes and simulate the exercise of distant vision," it has been observed that "false windows [were] installed in personal quarters and common areas to display various types of dioramas…reportedly, some individuals enjoy staring at the dioramas for long periods of time".[1]

Biologist E. O. Wilson theorizes that humans have a deeply entrenched genetic predilection for these types of views: "There is an evolutionary foundation for the common human preference for sweeping views from an elevated perspective, especially for views involving bodies of water…natural selection has predisposed members of the human species to favor views and scenes that in many ways replicate optimal living conditions during the millions of years of human evolution: an unobstructed view of a plain and a nearby pond, lake, or seashore".[1]

When removed from surroundings in which a species has thrived, the captive organisms cease to flourish; this phenomenon has been observed in labs where animals are used for experimentation. It can be inferred not only that *access* to nature provides measurable benefits but also that the *absence* of nature in isolated and confined spaces can actually hinder the behavioral and mental health of its occupants. Given the constraints of Space travel, virtual reality offers possibilities that could enrich the lives of the crew by providing a surrogate experience of nature.

IV. The Potential of Virtual Reality

Virtual reality, a term that was popularized in the late 1980's, has actually been in development for over a century. Broadly defined, virtual reality creates the impression that the subject is somewhere other than their physical location. Within this interpretation, full-scale panoramas, 3D movies, and flight simulators constitute the earliest forms of virtual reality, and are precursors to the more advanced cybertechnologies that have recently emerged.

The potential for the current generation of VR to promote psychological benefits is greater than previous types of simulations because of its higher capacity for immersion and interactivity. Immersion refers to the objective physical properties of the representation, such as fidelity, screen size, eye-tracking, or resolution. Presence, on the other hand, refers to the feeling of 'being there'. The more immersive a simulation is, the greater the sense of presence it can evoke. Although immersion is a pre-condition of presence, presence refers to the subjective experience of the viewer, measured by the human response to the simulation. Because computer-generated imagery is more immersive than posters or photos, virtual reality can come much closer to achieving a simulacrum.

A burgeoning field of research suggests that when subjects are immersed in surrogate landscapes (in most cases the stimuli is exclusively visual), similar effects as those with direct exposure to nature have been observed. In Valtchanov's work on virtual settings, subjects experienced a range of restorative benefits, such as reduced cognitive fatigue, decreased stress levels, increased focus and attention, increased positive affect, and decreased negative affect.[59] Greater restorative effects were correlated with higher degrees of immersion: the greater the capacity of the medium to appeal to the senses, the more psychological impact it had.

Virtual reality technologies can achieve what deKort refers to as 'experiential isomorphism', which focuses on the replication of the *experience* of nature in simulated environments rather than on the degree of realism of the simulation. Whereas pictorial realism is a condition of immersion, experiential realism is key to presence. Studies in treating phobias have demonstrated that experiential realism is more therapeutically effective than pictorial realism.[60] A study by deKort et. al, examined specifically how the degree of immersion affected subjects' response, recording a high correlation between immersion (differentiated by screen size of the medium) and self-reported positive/negative affect. It was found that immersion, more so than interactivity, was essential for producing restorative effects.[60] While the study did not look at the responses as a correlative measure of presence, they hypothesized that the outcomes were tied to increased feelings of presence.

Besides the types of landscapes viewed, other factors influence the ways in which simulations are perceived. Depledge found in his research that design of the content is far more critical in achieving immersion than the actual VR medium itself, and deKort posits that the validity of simulations depends on an array of factors, including type of representation, environmental content, and the assigned task or experimental objective.[60, 61]

VR using multiple modalities (visual, audio, olfactory, and haptic stimuli) is an area that has even greater potential for producing restorative effects. To maximize their effectiveness, VEs should be multi-sensory and highly immersive.[62] Depledge argues for the need for a multivariate approach to study the modulation of the five senses to produce ambient effects in virtual environments, especially olfactory stimuli which has been largely ignored.[63] The more senses that are engaged simultaneously to reinforce a perception, the more powerful the experience—especially when our olfactory sense is aroused.[64] Scents and other olfactory signals in particular are potent in evoking memories because unlike the other senses, they are sent to both the frontal cortex (which is responsible for recognition) and the limbic area (which is responsible for emotion) of the brain. Stimulation of multiple senses create a synergistic, or crossmodal effect; however, it does not require that all senses be aroused with equal intensity—only that they are synchronized with and reinforce one another.[65] Valtnachov's research integrated a rumble platform which provided somatosensory input, head-tracking to alter the view of the landscape in real-time, and synthetic scents from air fresheners to mimic forest smells.[59]

Annerstadt's study using a virtual forest showed greater stress recovery with combined visual and audio stimuli (when congruent forest sounds like birds, wind, and rustling leaves were synchronized with the imagery) over visual stimuli alone (no sound accompanying the imagery). Moreover, the absence of sound in conjunction with high-fidelity visual stimuli may have produced an uncanny valley—a sense of creepiness stemming from a strong resemblance that does not quite achieve realism[66,67]—which could imply that multiple modalities may be in fact, necessary to achieve a stronger sense of presence that is more conducive to restorative effects. An example of multi-modality that could be recreated to produce a highly immersive simulation is a fireplace: a high-fidelity video of logs burning, combined with audio of crackling flames, the aroma of burning wood and pine smoke, and the thermal sensation of radiant heat. Responses to such a multi-sensory simulation could be studied in comparison to the experience of an actual fireplace.

V. Applications for Space Missions

The use of VR technologies in long-duration Space travel has considerable potential for addressing deficiencies in meeting the crew's psychological needs. The most promising studies to date indicate that they could be effective in relieving stress through the simulation of natural and familiar environments like those on Earth; but they could also serve to create a wide spectrum of varied experiences through the invention of environments that are entirely new, imagined and exotic.[68-70] Beyond simulating bucolic vistas to induce feelings of tranquility, virtual environments serve to create conditions of perceptual exteriority that may be pivotal in mitigating the adverse effects that stem from confinement. Simulations that impart to the user a sense of expansiveness, an infinite horizon—in other words, a phenomenological reality beyond the confines of the habitat—could potentially alleviate many of the problems posed by prolonged seclusion: feelings of captivity, loneliness, monotony and tedium, sensory under-stimulation, solipsism, and homesickness, to name a few.

Other types of virtual environments beside simulations of nature have also been shown to support crewmembers' psychosocial adaptation in ICEs. Recent research at the HI-SEAS habitat simulation examined Second Life as an interface for social interactions, in which crewmembers could manipulate virtual objects in a shared virtual environment with family and friends 'back on Earth'. Preliminary results from the study indicated improved communications, increased social satisfaction, and reduced social monotony.[71-73]

Combined visual, auditory, and olfactory input may be able to create a perception of a larger reality beyond the immediate habitat. Such manufactured environments may help crewmembers' adjustment to the Lunar or Martian landscape, and reduce feelings of alienation.[74] By fostering a visceral connection to the extraterrestrial environs through sensory input, VEs could help establish a sense of place and belonging, and this feeling of being 'at home' could have a profound positive impact on crew well-being during an extended mission in Space.[75]

If they are to adapt, migrants to Mars or the Moon must be able to adjust to, and eventually develop an affinity for, the foreign surroundings of their new home.[76] Living in ICEs is especially challenging because it severely limits an occupant's relationship to the outside world, thus inhibiting the ability for a habitat to be perceived as a place of dwelling.[77] The ability to psychologically acclimate to Mars will depend, in part, on crewmembers' exposure and opportunities to familiarize themselves with their new environment—both qualitatively through sensory input, as well as quantitatively through the acquisition of information. The use of virtual interfaces could serve to establish and mediate a connection to the Martian environment. (How the crew's preferences for Earth v. Mars scenes impact psychological adjustment could be a topic for further study. Future research could also explore whether frequent exposure to the Martian geography through virtual environments can actually cultivate a deeper empathetic disposition towards its environment.) Moreover, because the habitat is a highly automated environment where the element of choice in many aspects of daily life is limited and there is little flexibility to reconfigure interior spaces, the ability for the crew to select or even create their own virtual environments may also help return a semblance of control over their living spaces.

Of the two available delivery vehicles for VR, Head-Mounted Display (HMD) and Cave Automatic Virtual Environments (CAVE ™), HMD would be far more practical in Space habitats than CAVE ™ —though each has its advantages and disadvantages [Figure 2]. HMD is more feasible from a pragmatic standpoint because it requires minimal equipment, the device itself is relatively lightweight and compact, it is inexpensive, and is easy to operate. In comparison, CAVE ™ requires sophisticated projection apparatus, is costly, and its operation requires much more space for operation. HMD allows individual crewmembers to participate at will, with a scene of their own choosing, and for any length of time without disturbing other members of the crew; however, because it is a solitary endeavor (though others can participate through avatars inserted into a shared scene), it could exacerbate feelings of disengagement or social isolation from rest of the crew. Because it substitutes the physically occupied environment with an entirely new fabricated one, it could also cause the user to feel disengaged from their actual surroundings.

In contrast to the HMD, the CAVE ™ format is a form of augmented reality that does not cleave the users from their immediate physical surroundings. However, given the challenges of employing an equipment-intensive system in a spatially constrained interior, a more primitive version could instead be implemented, which could retain some of the characteristics of the cave environment. An interactive, dynamic, high-fidelity panorama depicting a stationary landscape—combined with other multi-sensory input—could be enjoyed by any number of crewmembers at one time;

and by integrating them in both dining and exercise areas, it would also allow the crew to take their meals or do their physical training in other scenic locales if they so choose. To enhance their mealtime or workout experience, the crew could develop themes such as a 'picnic in the woods' or a 'jog along the seashore'. Celebratory themes (e.g., fireworks) could be offered to mark special occasions. The ability to 'meander around the Martian terrain' could be employed for both leisure and research purposes. A cave-like system enhances the existing surroundings rather than severing them, thus allowing occupants to experience their habitat in a variety of ways, either individually or communally. A potential drawback is that a surface-consuming panorama could be disruptive for crewmembers if they are engaged in other tasks, do not want to participate at that time, or would prefer to experience another type of scenery than the other users.

HEAD-MOUNTED DISPLAY	CAVE-TYPE ENVIRONMENT
Removes user from immediate surroundings	Augments/transforms interior environment
Requires less equipment and space	Requires more equipment and space
Lower cost	Higher cost
Use does not require crew consensus	Requires crew consensus (scene, scheduling)
Can be used privately; less disruptive	Can be used communally; create events
Limited to singular activity	Multiple simultaneous activities possible
Isolated or limited social interaction	Offers wider options for social interaction

Figure 2. Comparison of VR formats

There are three types of virtual scenery that would have potentially relevant applications for a Mars mission: Earthscapes, Mars-scapes, and Artscapes [Figure 3, shown in HMD format]. Landscapes from Earth depicting nature may be used to relieve stress and anxiety in response to overstimulation, and conversely to elicit arousal and exhilaration in response to under-stimulation. Depictions of the Martian landscape may be used to promote acclimation to the unfamiliar surroundings, overcome feelings of hostility or alienation, and facilitate adaptation. And finally, abstract environments may be employed to stimulate creativity, or as a means of momentary escapism.

Scenic preferences of crewmembers would be assessed in advance in order to establish the types of virtual landscapes to be developed for a Space mission. In any case, there should be sufficient variety so that not only can individual preferences be satisfied, but also so that crewmembers don't become bored of viewing them over the duration of the mission. (The importance of scenographic novelty in long-duration applications is another factor to be studied.) How users react to the various outdoor landscapes will depend not only on the scenographic types themselves, but also on the user's personal history and personal preferences.

Earth scenes [Figure 3a] can provide psychological comfort by recalling memories of familiar things and of past events. They can connect the user to nature, as well as to places that are known to them. They satisfy the yearning for nostalgia while offering a respite from the foreign and alien surroundings far from Earth. Landscape options could include bodies of water (e.g., ocean shore, waterfalls, river); snow-covered mountains; woods, rainforest or jungle; and expansive vistas, such as a meadow or pasture. But it could also provide other soothing amenities, such as a fireplace, an aquarium, or various weather phenomena (e.g., sunset, thunderstorm, northern lights). However, if virtual environments were only to present comforting, nostalgic experiences of familiar geographies of Earth, and become a means by which to avoid the physical realities of life on Mars, they could end up serving as a mechanism for maladaptation. This could, in turn, lead to increased feelings of disengagement from their less hospitable surroundings. Frequent virtual 'trips' to Earth may even come to serve as a reminder that their new Space abode is not their home.

Mars environments [Figure 3b] could afford opportunities to establish a visceral connection with the outdoors and to learn more about the physical geography. Experiencing the Martian environment through VE might help attenuate feelings of anxiety and detachment. If the crew is to feel at home beyond Earth, a process of empathetic acclimatization is essential. One possible strategy would be to locate virtual "windows"—to recreate an experience similar to that of the ISS—so that crewmembers could view the Martian landscape at full scale and in real time using head-tracking software. Options could include: viewing of a static immediate location (virtual window showing the adjacent surroundings of the habitat); viewing of a static remote location with changing climatic conditions or other dynamic element (live camera/video feed); or a mobile, roaming view (from Rover or drone). Users would be able to dictate the vantage points and be able to traverse the exterior terrain through the operation of remote drone cameras. Given that the primary purpose of the built habitat is to protect its occupants from the hazardous conditions of Space, it becomes even more critical that virtual technologies provide an experiential dimension of the Martian environment.


Figure 3a. Virtual Earthscapes


Figure 3b. Virtual Mars-scapes

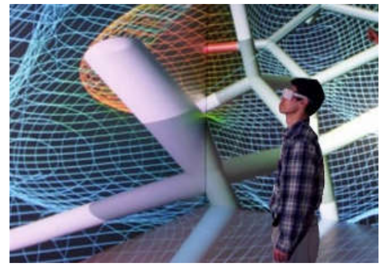
Figure 3c. Abstract Artscapes

Artscapes [Figure 3c] provide the opportunity to engage the imagination and creativity of the user. They could be either randomly generated by a program algorithm or entirely invented by the user. Options for image creation are: computer-generated, the nature of which would be random, unpredictable, and spontaneous; or user-generated, which would be characterized by design, control, and interactivity. Whereas Earth scenes recall memories and satisfy the need for comfort and familiarity, and Mars scenes can establish interfaces for research or affective connection, the purpose of artscapes is to offer the experience of the fantastical.

VI. Conclusion

The negative effects of long-term isolation and confinement in Space travel can impair crew performance, undermine social cohesion, and inhibit the ability to adapt; this is due in part to the fact that living in ICEs severely limits an occupant's relationship to the outside world**.** Developing cognitive and affective connections to exterior environments beyond the habitat is one of the critical factors in the process of psychological adaptation. This is especially challenging however, given the hazardous conditions of the Space environment and the stringent requirements of the habitat structure.

Multi-modal virtual environments could offer an infinite selection of simulated, and otherwise inaccessible, environments for the crew to experience. They can be used to foster a deeper relationship to the planetary landscape that would otherwise not be possible, and potentially provide other myriad benefits for psychosocial well-being. The use of VEs could reduce symptoms that lead to pathologies, such as feelings of isolation and confinement, sensory monotony, boredom and tedium, under-stimulation, solipsism, personal and social stress, and feelings of anxiety towards the extraterrestrial surroundings. In addition to providing more options for leisure and recreation, it is possible that the integration of VEs as part of the crew's routine could induce salutogenic effects that would result in greater social cohesion, increased creativity, improved work performance and productivity, and feelings of satisfaction.

How different scenes would be experienced in the HI-SEAS habitat using the CAVE™ format:


Baseline condition *photo: www.hi-seas.org*

Earthscape *Mars-scape*

Figure 4. Transformation of the HI-SEAS habitat interior

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