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A Demographic Analysis of Greenspace Exposure Requirements in Self-Sustaining Space Settlements

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Abstract

The design of space settlements presents unprecedented challenges to human factors, particularly regarding the exposure of inhabitants to "green" natural elements and environments. Prolonged absence from nature induces significant psychological and physiological degradation, and targeted exposure to nature results in stress reduction, cognitive restoration, immune system support, and decreased risk of mood disorders for some individuals. Through an integrative review of relevant literature, this paper evaluates the specific wellbeing requirements of key demographic groups – including children, students, working adults, and elders – within hypothetical space habitats. The analysis indicates that exposure requirements vary across life stages, with hands-on interaction, passive viewing, and immersion in greenspace environments offering benefits such as mitigating solipsism syndrome, relieving work-induced mental fatigue, and restoring attention. To optimize the health, productivity, and operational resilience of space inhabitants, future settlement designs must strategically incorporate real physical greenspaces and plant-interaction opportunities tailored to demographic routines.

1 Introduction

Early space settlers will have fewer amenities than we do on Earth. Specifically, they will have severely restricted access to nature. Most people on Earth can go outside and immediately be immersed in biodiversity currently known to be unique to our planet. For the initial generation of space settlers, their emigration will come with a sense of loss and longing for what they may have taken for granted.

Even on Earth, where nature surrounds us, we can get into situations where we are away from natural environments for weeks, months, or longer. During these periods, humans are deprived of the multifaceted benefits of nature exposure. Psychologically, nature can reduce stress and anxiety and improve mood, cognitive function, attention, and more. Physiologically, it can lower blood pressure and reduce mortality from cancer and cardiovascular and respiratory issues. In current in-space habitats, these benefits are largely lost due to the low intensity and diversity of the natural elements found there.

Using integrative methods [1], this paper will review the state of theory and study about how human health depends on exposure to nature and what these needs will be in a self-sustaining space settlement. To reduce selection bias, two researchers (Calloway and Krishnamurthy) will screen the results of literature discovery. The research question to be answered is: *In a first-generation* *space settlement, what are the psychological and physiological needs of prominent demographic categories for "green" nature exposure to maintain personal wellbeing?* The findings will inform the future design of such space settlements so they may better accommodate inhabitant wellness.

2 How Nature Exposure Affects Human Psychology and Physiology

There is much evidence, and many theories, connecting human health and physical nature exposure. Studies have demonstrated the benefits of natural elements and environments on our psychology and physiology. These studies inform the exposure requirements for the optimal performance and wellbeing of prominent demographic categories.

2.1 Benefits from Nature Exposure

The psychological benefits from nature exposure will be discussed first. Across demographics, short-term exposure to greenspaces and other natural environments has positive effects on mood, self esteem, and emotions, and reductions in the negative effects of depression, stress, and attention fatigue [2–7].

Certain demographics are shown to benefit differently. Because the brains of children and adolescents are impressionable and developing, it is especially critical to maintain their psychological health. In children, contact with nature may improve their mood and cognitive functioning, increase their social interactions, and improve ADHD symptoms [8]. Also, in children and adolescents, high levels of "green time" (engagement with nature), as opposed to "screen time" (engagement with screen-based technologies), were associated with more favorable psychological outcomes [9].

College and university students are a demographic known to be especially encumbered by chronic psychological effects including stress and depression. For people of college age, studies show that sitting or walking in natural settings may significantly and positively impact psychological wellbeing, including a reduction of stress symptoms [10,11].

Working adults are a much more numerous demographic than children, adolescents, or college students. Day-to-day employment activities vary in intensity and psychological effect, and much of the workforce faces negative psychological effects from their employment at some point in their career. Outdoor nature contact during the workday was shown to correlate with higher task performance and prosocial behavior [12]. Adults who spend time in greenspace shortly after their workday may show improvements to positive emotion, subjective vitality, and restoration [13].

While exposure to natural environments is shown to have several benefits, absence from such environments for extended periods is shown to reduce psychological wellbeing. On Earth, urban environments expose inhabitants to noise, pollution, commuter traffic, high task frequency, and other stressors. Entering a natural environment reduces access to digital screens, distancing people from digital media relating to global crises like climate change and war, which if consumed excessively may negatively affect the viewer's health. Even the view of greenspace through windows of a residence or confined space is associated with a lower risk of psychological illnesses like anxiety and depression [14,15].

In children, a lack of interaction with nature in early life has been associated with multiple emotional and cognitive difficulties, termed "nature deficit disorder" (NDD) [16 (citing Louv, 2005)]. At post-secondary academic institutions, it was found that counseling directors frequently must reduce the number of visits for non-crisis patients to handle an overall increase in their number of clients [17]. This implies that alternative modes of psychological amelioration should be accessible to students of such institutions. In working adults, confinement to nature-bare urban environments over extensive labor periods can lead to stress accumulation, reduced task performance, reduced socialization, and other modes of psychological depletion [12,13].

People are affected not just psychologically by nature exposure, but physiologically as well. Natural environments are shown to reduce mortality related to cancer and respiratory and cardiovascular issues, and the “greenness” of mothers’ neighborhoods was positively associated with higher infant birth weight [16]. Walking in a forest, or even sitting in a room with a natural view, was shown to cause a decline in blood pressure compared to walking or sitting in an urban environment [18]. Physical exposure to biodiverse plants and microbiota has been associated with better immune-system performance [2,16,19]. Children with higher access to greenery were shown to have lower blood pressure [20]. Exposure to sunlight is well known to correlate with the body’s creation of vitamin D3. It should be pointed out that studies on the effects of indoor plants on wellbeing have been reviewed to have mixed results, but a strong relation has been made between the presence of plants and pain management [21].

Thus far, the discussion has been on exposure to real natural environments. However, there have been several studies on the effects of simulated natural environments on psychological health. Immersion of individuals in a simulated natural environment through a virtual-reality (VR) headset was conducted to test the effects on stress, respite, and other psychological characteristics in highly fatigued frontline workers, hospital patients under critical active treatment, and people with limited access to nature (such as people with reduced physical mobility) [22–24]. Because of the differences in reality and perception between simulated and real natural environments, this study will focus on the latter while recognizing that future research should be done on the former.

2.2 Nature-Exposure Requirements for Human Satisfaction

These benefits imply that natural elements should be integrated into urban environments and that natural environments (distinct from urban environments) should be accessible to everyone per common humanitarian ethics. On Earth, there are relatively few instances where it is prohibitive to enable such access. However, in addition to physical accessibility, there are other considerations to maximize the effectiveness of greenspace: opportunity of

Table 1. Categorization of demographics and associated type, intensity, and effects of nature exposure

Category	Demographic	Type of Exposure	Intensity (Period or Frequency)	Experiment Results	Source
Children	Middle-school pupils	Access to a renovated schoolyard with greenery, water features, and wooden furniture	Regular daily access during school breaks	Proven: a greener schoolyard related to reduced physiological stress, as well as improved psychological wellbeing and perceived restorativeness	Kelz et al. (2013)
	Preschool pupils	Outdoor playtime in natural environments	Variable (averages of outdoor hours throughout the year)	Proven: more daily outdoor hours related to reduced inattention and hyperactivity in the following years	Ulset et al. (2017)
Studying or working adults	University students	Self-chosen natural environment	20 minutes once a week, for three weeks	Proven: restorative natural environments related to wellbeing and reduced stress and burnout	Payne et al. (2020)
	Full-time office employees	Physical contact with nature outside the office during the workday	Variable	Proven: exposure to nature at work related to improved task performance and prosocial behavior	Tang et al. (2023)
	Healthy working adults	Urban natural environments (a park and a woodland)	15 minutes of viewing while sitting, followed by a 30-minute self-paced walk	Proven: increased perceived restorativeness, subjective vitality, mood, and creativity, while decreasing negative mood (compared to city-center control)	Tyrväinen et al. (2014)
Adults with restricted mobility	Male prisoners under pandemic-related isolation	Viewing greenspace through cell windows	Variable	Proven: visibility of nature related to life satisfaction, wellbeing, distress tolernance, and reduced loneliness, depression, and anxiety symptoms	Li et al. (2021, "Prisoners")

use (e.g. having the time to use it), personal motivation and reasons for use (e.g. having multiple outlets of value extraction, such as walking the dog, birdwatching, and using it as a shortcut), and ease of use (e.g. appropriate weather conditions and lighting) [25]. Biodiversity is another factor being explored [16].

It has also been shown that different demographics benefit differently from nature exposure varied by magnitude, period, frequency, and type. Data exemplifying this were collected from a scoping sample of literature and summarized in Table 1.

3 Characterization of Space Settlements and Inhabitants

For this study, we define a space settlement as a self-sustaining settlement of people outside the biosphere of Earth. The settlement is assumed to be operating in a steady state, thus fully constructed, operational, and with appropriate population and demographic ratios.

In *The High Frontier*, one of the foundational works on space settlement, O'Neill proposes several types of space settlement [26], with one such being a long-term roving research community. The population of such would be thousands, about 25% of whom would be school- or college-aged individuals and about 50% would be an active workforce. Prominent categories in such a workforce would be composed of community service workers, equipment servicers and technicians, and researchers. The large student population implies that schools, universities, and/or training programs would be present to educate upcoming members of the workforce. Earlier embodiments of settlements would require intensive workload, so there may be little to no unemployment. In later, more optimized settlements, on-site retirement of elderly populations would be possible.

A "starship" capable of a successful 5-generation interstellar migration is estimated to require about 40,000 people [27]; about 13,600 would be "subadults" (children and adolescents); 23,400 adults; and 3,000 elders. Across the generations, it is obvious that the children would need to learn, and the adults would need to maintain the spacecraft and operations.

Another settlement, smaller in scale, is proposed of about 491 people, most of which would come from large cities to source the technical expertise necessary to operate such a complex space structure [28].

If a catastrophic event were to occur on Earth prompting an emergency extraterrestrial settlement operation, Mars is a proposed location [29]. Such a settlement would be composed of individuals selected for their value to the continuation of the race: "astronauts, science engineers, space policy experts, and, most importantly, average citizens with general or specific skills". Depending on the purpose of the settlement, other specific roles may be required, such as doctors, medics, miners, and soldiers.

Table 2. Demographic categorization of space settlement models

Source	O'Neill (1976)	Smith (2014)	Covey and Faber (2017)	Szocik et al. (2020)
Settlement Characterization	Long-term roving research community	A "starship" capable of a successful 5-generation interstellar migration	A small-scale, first-generation space settlement (4 rotations per minute)	An early, high-risk Martian outpost
Demographic	**Prominent Roles**			
Children and adolescents	School-aged children	"Subadults"	Children	Children
Studying or working adults	College-aged adults; active workforce (community services, equipment servicers, researchers)	"Adults"	Adults with technical expertise	Adults with general and specific skillsets
Elders	Working elders; compensated retirees	"Elders"	Not reported	Not reported

The demographic distributions per cited model are summarized in Table 2. These case-based demographics are categorized into children, studying or working adults, and elders, which relate to the categories of study cited in Section 2.

4 Nature Exposure for Space Inhabitants

There has been prior research evaluating the nature-exposure needs of space dwellers, and there are numerous anecdotes of astronauts and cosmonauts expressing affection for plants while on space missions. These resources in addition to those collected in the previous sections will be synthesized to suggest recommended nature-exposure conditions for prominent demographic categories expected to be found in self-sustaining space settlements.

4.1 Existing Research and Discussion

Some evaluation has been done to predict the needs of future space inhabitants for nature exposure and interaction. NASA released a report titled *Space Settlements: A Design Study*, which includes an appendix on the "Psychological and Cultural Considerations" of "Human Needs in Space" [30]. The appendix mentions "solipsism syndrome", "the state of mind in which a person feels that everything is a dream and is not real". The NASA researchers suggest the highly controlled and organized environment of a space settlement would be conducive to this state. They also suggest the risk can be alleviated by introducing unpredictable elements, such as plants and animals with some independence from "human planning".

In contrast to the nature-bare urban environments and deserts on Earth, O'Neill envisioned free-flying space settlements with diverse natural environments composed of grass, trees, flowers, and animal species [26]. He also mentioned that the first humans living in space will experience a "future shock" that should be quelled in part by familiar and natural environments. He noted that sunlight is quite accessible but suggested a day/night cycle should be implemented to align with natural human circadian rhythms. He also suggested that his proposed communities would be well populated with greenery for the purpose of inhabitant wellness: "Within, I suspect that the traveling laboratory would be landscaped in a manner expressive of the inhabitants' need for the psychological solace of lush vegetation." [26, p. 244].

He also suggested that the elderly or infirm population, which on Earth would normally be confined to beds or other limited-mobility situations, would have opportunities to mobilize freely at higher "elevations" in the spacecraft (closer to the rotational center). This implies that such demographics would be more freely able to explore the greenspace of the settlement compared to people in similar situations on Earth. However, greenspace implementations at such elevations may be limited, for example, to hydroponic growth and vertically climbing species.

In addition to ambient nature exposure, hands-on interactions with plants are shown to have benefits, and several anecdotes exist of astronauts and cosmonauts showing affection to handling plants. It is suggested that gardening or caring for plants can restore "directed attention" used for complex cognitive processes [31] such as those common to the daily research activities of astronauts on long-duration space missions [32] and which will surely be prominent in space settlements, especially in early embodiments. An early indication of the positive psychological effects of growing plants in space is given by the spaceflight diary of cosmonaut Valentin Lebedev: "we feel sad and uncomfortable without our garden and without our dear plants. It was such a pleasure to take care of them. Man probably has a need to take care of things and without those things feels empty." [33]. Peggy Whitson, Don Pettit, Scott Kelly, and other astronauts have also quoted sympathies for plants they cared for in space [32].

4.2 Exposure Suggestions for Inhabitants

The models cited in Section 3 for future space settlements support the assumption that a majority percentage of the population of such a settlement would be working or learning. Due to the complex and underdeveloped nature of early space settlements, the workload of such would likely be especially intense. An intense workload implies mental and physical stress, the effects of which are negative in chronic amounts. Stress may lead to further psychological or physiological issues. Even for inhabitants not exposed to intense workloads, it's assumed that there will be some with chronic mental or physical illnesses that affect similar people on Earth today.

Zeroth-generation settlers (i.e. those who formerly lived on Earth) may have more intense needs for nature exposure due to homesickness. Sufficient nature exposure is also important to prevent the recession of human-nature interactions across generations [34], which could be detrimental to the population and prohibitively difficult to recover from. In addition, for the long-term health of the immune system and microbiome of humans living in space, a sufficiently biodiverse environment may be necessary [35]. This may reduce health risks in the settlement population and in any individual returning to the biodiversity of Earth (refer to David Vetter, the "bubble boy").

Virtual-reality (VR) simulations of nature exposure have been studied as a compromise for demographics without feasible access or opportunity to use real natural environments. However, simulated exposure is assumed to not be as effective at mitigating solipsism syndrome as exposure to real nature in part because simulation code is ultimately human-controlled. However, simulated natural environments are still an active area of study, and the benefits and applications of such in space settlements should also be a topic of future study. Useful cases for a simulated natural environment such as via VR headset include situations of intense work in constrained environments (e.g. missions on a confined spacecraft or isolated section of the habitat) or for analogous purposes as are currently proposed on Earth (e.g. during intense extended medical procedures).

As on Earth, nature exposure needs in a self-sustaining space settlement will differ across demographics. However, the most obvious general implementation is to insert natural elements and environments into the routines of individual people. For working people, it would be beneficial for natural environments to be accessible or in view during the work period [12,14]. For workers commuting between their residence and their workplace, it would be beneficial for them to be able to pass through a natural environment for an extended period (at least 15 minutes) [13], though this may be infeasible for space-constrained settlements. People with a shorter commute or an absence of one should have access to easily usable greenspace for at least 20 minutes a week [11].

There should also be opportunities to handle plants (e.g. via gardening or light care) and to have them indoors [21,32]. For children, prolonged access to natural environments during the school day should be possible and encouraged [20,36], but the effective embodiments of such (e.g. green schoolyards) should be studied further.

The implementation of all such embodiments of nature exposure would allow the most inhabitants the greatest ease to obtain the benefits relevant to their demographic. It is currently unclear whether each of these embodiments would be feasible and to what extent they would be redundant relative to each other, so further research is called for.

5 Conclusions

Research on the benefits of "green" nature exposure on human health was collected and categorized by demographic category, showing the variation of exposure type, intensity, and effects. Typical space settlement models were collected and compared, highlighting historical mentions of nature-exposure benefits and needs to the hypothetical inhabitants. Finally, a demographic categorization of a typical self-sustaining space settlement was performed, the need for nature exposure in such a settlement was validated by prior research and anecdotes, and suggestions were made for the exposure requirements of future space inhabitants, with special needs suggested for early settler generations and on early settlement embodiments.

It is suggested that, if feasible, all correlating beneficial natural elements and environments should be designed for and implemented in future space settlements to yield maximum positive effects on the psychological and physiological wellbeing for the greatest number of inhabitants. Since such an ideal is unlikely, more research is needed to determine the most feasible and effective embodiments of natural elements and environments.

Nature-exposure needs of the initial settlers (i.e. the zeroth generation, coming from Earth) should be predicted and compared to the predicted needs of later generations (i.e. those born in the settlement). Of the exposure types found to benefit various demographics on Earth (green-space access, passive elements, viewing, handling, digital simulation, etc.), those relevant in space settlements should be ranked – by factors like effects on wellness, effects on productivity, difficulty of design, cost of implementation, and sustainability – to determine priority and feasibility, which would in turn inform future space-settlement mission designs. In addition, since leisure and choice are expected to be more restricted in space settlements than generally on Earth, the characterization and effects of these restrictions should be applied to the design of realistic nature access in such settlements. The case for no nature exposure at all for space inhabitants should also be studied (i.e. "If we can function without it, should we?").

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