BIOPHILIC INTERVENTIONS IN CREW QUARTERS FOR DEEP SPACE TRANSIT HABITATS TO IMPROVE COGNITIVE AND PHYSIOLOGICAL HEALTH MEASURES

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BIOPHILIC INTERVENTIONS IN CREW QUARTERS ON

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COGNITIVE AND PHYSIOLOGICAL HEALTH MEASURES

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Abstract: While the concept of biophilic design has been around for many decades, new methods for studying and quantifying the effects of biophilic design in virtual reality present unique opportunities for interior designers and architects, while exploring design concepts for spacecrafts and space habitats. When a person experiences a space with biophilic design, it can result in both cognitive and physiological benefits. There is a *critical need* to not only integrate biophilia into the design of the interiors of spacecraft but to study the benefits of this as well. The *purpose* of this study was to assess if the integration of biophilic design in a virtual simulation of personal crew quarters on the International Space Station (ISS) can help improve emotions and feelings while also improving cognitive responses in individuals. The *specific aims* of the study include the following: a) Determine if virtual biophilic crew quarters result in an improvement to overall feelings and emotions when compared to the current design; b) Determine if virtual crew quarters designed with the integration of biophilic design result in an improvement in cognitive load when compared to the current design; c) Determine if virtual crew quarters designed with the integration of biophilic design result in an improvement in satisfaction and intent to spend more time in the space when compared to the current design; d) Determine if virtual crew quarters designed with the integration of biophilic design result in an improvement in cognitive responses when compared to the current design. The participants answered survey questions to assess specific measures related to feelings and emotions, task load, and cognitive responses and heart rate and pupil dilation were also measured. The study found that there were significant differences in feelings and emotions, pupil dilation, performance, and effort, and moderate to strong correlations between satisfaction with the space and intention to spend more time in the space. This study has important implications for the design of space habitats to help improve the health and wellbeing of astronauts and space travelers.

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CHAPTER I

INTRODUCTION

1. INTRODUCTION

On July 20, 1969, two people, Neil Armstrong and Buzz Aldrin, became the first two human beings to ever step foot on the moon (Fewer, 2007). This was followed by decades of innovative space exploration and research. One area of research that has received attention in the 1980's and continues to receive attention is the design of spaces and habitats in spacecrafts and space stations (Clearwater, 1988; Broyan, 2010). Research on design of spaces while addressing human factors issues and exploring the relationship between 'habitat design' and 'crew psychology' has also been explored (Mohanty, Jorgensen & Nystrom, 2006). To address challenges with navigation in partial gravity environments, interior design elements were explored and improved, including You-Are-

Here Maps for the international space station (Marquez, Oman, and Liu, 2004). Architectural designs for space tourism are also being explored (Martinez, 2009), along with human friendly architectural designs for a base on Mars (Kozicki and Kozicka, 2011). With highly advanced and innovative emerging technologies and the collaboration of SpaceX and the National Aeronautics and Space Administration (NASA), the possibility of going to Mars in mid-2030's is no longer an idea found only in science fiction (Simon et al., 2017).

While it is important to have functional spaces for space missions with long durations, companies like SpaceX could value aesthetics also. When designing, aspects of form, color, pattern, and texture could all play a key role in aesthetics (Bushnell, 2006). One approach to improving aesthetics of space habitats while also improving the health and wellbeing of individuals who use these spaces could be the integration of biophilic design. By incorporating strategies of biophilic design into the crew quarters, the transit habitat becomes not only a tool for survival but also a tool for keeping the occupants happy, healthy, and satisfied. The first chapter of the thesis presents the background of the study, specifies the problem of the study, describes its significance, and presents a brief discussion of the methodology used. The chapter concludes by noting some key terms used in the writing.

2. THE BACKGROUND OF THE STUDY

The following section provides a discussion on the various elements of biophilic design and how it can be implemented and studied in different situations. The concept of biophilic design has been around for many decades, but new methods for studying biophilic effects in virtual reality and methods for quantifying the effects of biophilic design present unique opportunities for interior designers and architects. By designing with elements and patterns of nature in mind, designers have the capabilities to create a built environment that supports the health and wellbeing of the end user, as well as create spaces that foster creativity and collaboration.

Biophilic design first originated from the term “biophilia,” coined by Erich Fromm, and meaning “love of life” (Söderlund, 2019). Edward Wilson then took Fromm’s preliminary findings and developed a broader, more comprehensive meaning to biophilia and biophilic design. There are many elements and aspects of biophilic design and three categories that are widely accepted: nature in the space, natural analogs, and nature of the space (Ryan et al., 2014). Of these categories, there are 14 patterns for implementing biophilic design into the built environment: visual connection to nature, non-visual connection to nature, non-rhythmic sensory stimuli, access to thermal and airflow variability, presence of water, dynamic and diffuse light, connection with natural systems, biomorphic forms and patterns, material connection with nature, complexity and order, prospect, refuge, mystery, and risk or peril. These elements help satisfy the innate needs human beings have for living things and natural systems and can benefit individuals cognitively, emotionally, and physiologically (Ryan et al., 2014).

According to Gillis and Gatersleben (2015), biophilic design has been widely accepted in recent years for the contributions it makes to the health and well-being of the end-user. Biophilia is now being so embraced that there are two globally recognized building standards that incorporate biophilic design and its principles- the Living

Building Challenge and the WELL Building Standard. Human beings typically encounter three spaces- those that are stressful, those that are not, and those that actively work to reduce stress and improve mental fatigue. Urban environments are one example of the high-stress environment humans encounter, but biophilic design can help combat this stress by providing a built environment that has beneficial effects on its occupants. Studies have shown that by incorporating biophilic design patterns and principles into the built environment, users can experience the restorative effects of nature.

When a person experiences a space with biophilic design, it can impact them both cognitively and physiologically. Cognitively, biophilic design can improve productivity, creativity, well-being, job satisfaction, mood, and self-esteem (Sanchez, Ikaga, & Sanchez, 2018). From a physiological standpoint, biophilic design leads to a more relaxed brain, ocular muscles, and lenses, while also reducing diastolic blood pressure, stress levels, and cortisol levels (Ryan, et al., 2014). Biophilic strategies could also be integrated with the design of greenhouses for instance. While a greenhouse on a space craft or space station plays a key role in providing added life support, the design of greenhouses can also be beneficial from a spatial enhancement and sensory standpoint (Hauplik-Meusburger, Peldszus & Holzgethan, 2011). Thus, by incorporating strategies of biophilic design into the crew quarters, the transit habitat becomes not only a tool for survival but also a tool for keeping the occupants happy, healthy, and satisfied.

3. THE NEED FOR THE STUDY

The long-term goal of this proposed research study is to better understand the role that biophilic design plays in the physical and mental wellbeing of individuals who spend long durations of time in a space station or on a spacecraft. The objective in this study was to assess if the integration of biophilic design in a virtual simulation of personal crew quarters in a space analogue helps improve emotions and satisfaction as well as cognitive and physiological measurements. The rationale for the study is that virtual interior spaces with biophilic patterns embedded in the design will result in improvements in physiological and cognitive performance in individuals who use these spaces.

It is the expectation that the successful completion of this study will show that space analogues designed with the integration of biophilic design will result in improvement in physiological and cognitive measures when compared to virtual interior spaces of space analogues without the integration of biophilic design. It is expected that exposure to the biophilic environment will lead to a reduced heart rate and improved skin conductance measurements and an improvement in mood and well-being. The findings from this study could have a significant impact on the health and wellbeing of individuals including astronauts or commercial space travelers who use spacecrafts or space stations in the future.

4. SPECIFIC AIMS

The aims of the study were divided into different sections to study distinct aspects of the individuals' cognitive and physiological measurements as they related to the study

- **Specific aim 1**

Determine if virtual crew quarters designed with the integrations of biophilic design will result in an improvement to overall feelings and emotions when compared to virtual interior spaces of crew quarters without the integration of biophilic design.

- **Specific aim 2**

Determine if virtual crew quarters designed with the integration of biophilic design will result in an improvement in cognitive load when compared to virtual interior spaces of crew quarters without the integration of biophilic design.

- **Specific aim 3**

Determine if crew quarters designed with the integration of biophilic design will result in an improvement in satisfaction and intent to spend more time in the space when compared to virtual interior spaces of crew quarters without the integration of biophilic design

- **Specific aim 4**

Determine if crew quarters designed with the integration of biophilic design will result in an improvement in cognitive responses when compared to virtual interior spaces of crew quarters without the integration of biophilic design

5. THE SIGNIFICANCE OF THE STUDY

With plans of orbiting Mars in the 2030's (Simon et al., 2017), the idea of long-distance space travel is becoming more of a reality. In missions such as these, the design of the transit habitat and the crew quarters play a vital role in the overall safety and productivity of the mission. Currently, most of the existing designs for transit habitats are created by architects, engineers, or industrial designers. Interior designers offer a unique perspective to the design of these habitats as interior designers focus specifically on how the individual interacts within the space. Designing in this way provides a unique human-centered approach to design that creates spaces from empathic design and evidence-based design (Leonard & Rayport, 1997; Hamilton & Watkins, 2008). While previous short-term space habitats have been designed for functional and utilitarian purposes, a long-term space flight poses unique challenges for the design to not only keep the occupants safe but to also impact the health and well-being of the crew beneficially. As there are limited data supporting interior design and biophilic design in transit habitats, studies in this area are vital to the development of the space architecture field.

6. OVERVIEW OF METHODOLOGY

This study determined if biophilic design in personal crew quarters can help improve feelings, emotions, and physiological and cognitive responses during a virtual simulation. As biophilic design has been demonstrated to improve cognitive performance (Browning, Ryan, & Clancy, 2014), it also offers further opportunities for improving crew wellness and safety during missions. In this study, participants observed and interacted with two differing virtual reality environments. The virtual reality environments were designed using Sketchup and measured participants' opinions on simulated existing and proposed crew quarters. Both crew quarters applied design techniques similar to those used within the aerospace industry, including current technological innovations and prior research on spacecraft environments. This research aimed to better understand through the current knowledge about living in space what the crew might expect on a deep space mission within crew quarters.

In this study, participants started by entering a neutral virtual environment to orient participants to the technology and allow for training of the controls and system before being introduced to the other environments. In the non-biophilic condition, the crew quarter environment was based on the existing crew quarters currently used on the International Space Station and remained as realistic as possible using appropriate materials, colors, lighting, and dimensions. Participants virtually entered each space using a virtual reality headset. In the treatment condition, the crew quarters had the same dimensions as the control, but incorporated design elements based off various biophilic principles: Material connection to nature, Visual connection with nature, Non-visual connection with nature, Biomorphic forms and patterns, Dynamic & diffuse lighting, and Sense of refuge. Quantitative data of heart rate, task load, pupil dilation, and emotions and perceptions were collected. While participants encountered each environment, they were asked to "think aloud" (Jääskeläinen, 2010) in order to become fully immersed in each environment and to better express how they feel about the experience in each environment. More information on the study methods will be provided in Chapter Three of the thesis proposal.

7. SCOPE OF THE RESEARCH

The research project discusses the redesign of the current crew quarters on the International Space Station (ISS) by adding elements of biophilic design. By redesigning these crew quarters, it can be used as a precedent for long term, deep space missions, such as a mission to Mars. The research does not aim to study the redesign of other areas of the ISS or other space craft, but strictly the redesign of the crew quarters on the ISS.

Any other locations, areas, or habitats are beyond the scope of this project. Additionally, the designs will only implement visual elements of biophilic design, such as biomorphic forms and patterns and material connection to nature. Any other biophilic elements, such as biophilic soundscapes are out of the scope of the project.

8. PROBLEM STATEMENT

The problem statement for the study is that while the current design for the ISS crew quarters do adequately meet the needs of its occupants, a redesign while integrating biophilic elements could be more beneficial for occupants who use the crew quarters for long term or commercialized space travel.

9. DEFINITION OF TERMS

Biophilia: a hypothetical human tendency to interact or be strongly associated with other forms of life in nature: a desire or tendency to commune with nature

Biophilic Design: a concept used within the building industry to increase occupant connectivity to the natural environment through the use of direct nature, indirect nature, and space and place conditions

Crew Quarters: the single occupancy, private quarters on a space vehicle used by the crew for sleeping and relaxing.

Evidence-Based Design: the deliberate attempt to base building decisions on the best available research evidence with the goal of improving outcomes and of continuing to monitor the success or failure for subsequent decision-making

Empathic Design: a user-centered design approach that pays attention to the user's feelings toward a product, place, or space

Transit Habitat: a spacecraft used for long duration, deep space flight missions

CHAPTER II

REVIEW OF LITERATURE

1. INTRODUCTION

The following review of literature includes the negative environmental factors experienced by astronauts while living in space, as well as some of the barriers to maintaining physical and mental health, and research on better supporting astronauts while on deep-space missions through the incorporation of biophilic design strategies.

2. EFFECTS OF LIVING IN SPACE

The effects of living in a space craft or space station have been studied for as long as people have been going to space. Researchers have found that human beings can experience many negative side effects of living in a space environment, such as feelings of isolation, confinement, crowding, and sensory deprivation (Clearwater, 1988). Living in a microgravity environment can also lead to feelings of disorientation, which could be dangerous during emergency situations (Marquez, et al., 2004). Coupled with the fear of a constant risk and danger, space craft environments can be detrimental to the occupants living in those spaces (Clearwater, 1988). In extreme cases, astronauts can develop dysfunctional psychological responses ranging from depression and fatigue to interpersonal conflict and decreased alertness and motivation (Clearwater, 1988). This could potentially lead to feelings of nervousness and indecisiveness.

As far back as 1998, researchers have been studying sleeping disruptions in orbiting astronauts (Monk, et al, 1998). According to Monk et al, the second most commonly used medications during space shuttle missions are hypnotics that are used for sleep improvements. One cause for concern is the disruption of circadian rhythms, which is the body's natural 24-hour day-night cycle (Toh, 2008). Toh further discusses how this sleep-wake cycle consists of alternating intervals of activity and restfulness and affects the body physiologically and biochemically. One aspect of this is the regulation of melatonin levels, which affect sleep and wakefulness. This process affects the human body in biochemical, behavioral, and metabolic ways, and is important in understanding human functioning (Toh, 2008).

According to Guo et al (2014), an astronaut's circadian rhythm, if deregulated, can put their mission in jeopardy, effecting their physical and mental health along with their job performance. One effective way of maintaining circadian rhythm is through zeitgebers, which are external time-giving cues that help determine the stage of a person's natural circadian rhythm. The researchers discuss how exposure to bright light that is greater than 2,500 lux can be utilized to treat various disorders relating to circadian desynchronization (Guo, 2014). However, if these deregulations go untreated then it could potentially lead to obesity, cardiovascular disease, various cancers, and sleep disorders, as well as mood disorders relating to attention deficits and depression (Guo, 2014).

When a person is living and working in outer space, they experience numerous disruptions to their natural sleeping patterns. Dijk et. al (2001) found that on average, astronauts only sleep for 6-6.5 hours each night. When compared to a typical work-rest schedule, the researchers found that astronauts also experienced higher workloads and more wakefulness, resulting in sleep loss and circadian rhythm disorders. After prolonged sleep deprivation and abnormal sleep schedules, astronauts additionally experienced decreases in neurobehavioral performance and daytime alertness. When comparing scheduled sleep times to actual sleep times, the study found that astronauts often went to bed later than scheduled and occasionally took naps during the day. It was determined that this could be due to the high workload expected of astronauts, resulting in these individuals staying up later than scheduled to complete work tasks.

In an article by Wu et. al. (2018), specific sleep problems encountered by astronauts during spaceflight, as well as certain countermeasures to combat these issues, are discussed. Some common causes of negative sleeping habits are environmental aspects of the crew quarters, abnormal sleep schedule and work schedule, circadian rhythm disorder, and mental and physical discomfort. Due to the environmental factors of living and working in space, astronauts do not get enough quality sleep, which affects their psychological and physiological performance. Physical health and cognitive health decrease, as well as operational performance and visual alertness (Wu, 2018). These features can not only harm the astronaut, but they can also put crew relations and the mission in jeopardy. Several countermeasures have been proposed to increase safety and wellbeing, including sleep environment improvements, work-rest schedules modification, pharmacological interventions, light treatment, and others (Wu, 2018). Some of these aspects must be implemented by administrative personnel, while designers can implement others.

While some measures have been taken to help with feelings of spatial disorientation and motion sickness, such as virtual reality training, more can be done to help individuals living in a space craft (Shebilske et al., 2006). It is because of the negative effects experienced by astronauts that designers, architects, and engineers are starting to take into consideration the human-environment fit of the spacecraft (Clearwater, 1988). By designing the built environment with human factors in mind, space stations and space craft can better promote feelings of comfort, safety, and productivity for the astronauts who live and work in these environments (Clearwater, 1988). A meticulously designed environment that uses biophilic elements could help reduce the negative effects of living in space and leave occupants feeling calmer and more content (Design, B).

3. OVERVIEW OF BIOPHILIC DESIGN

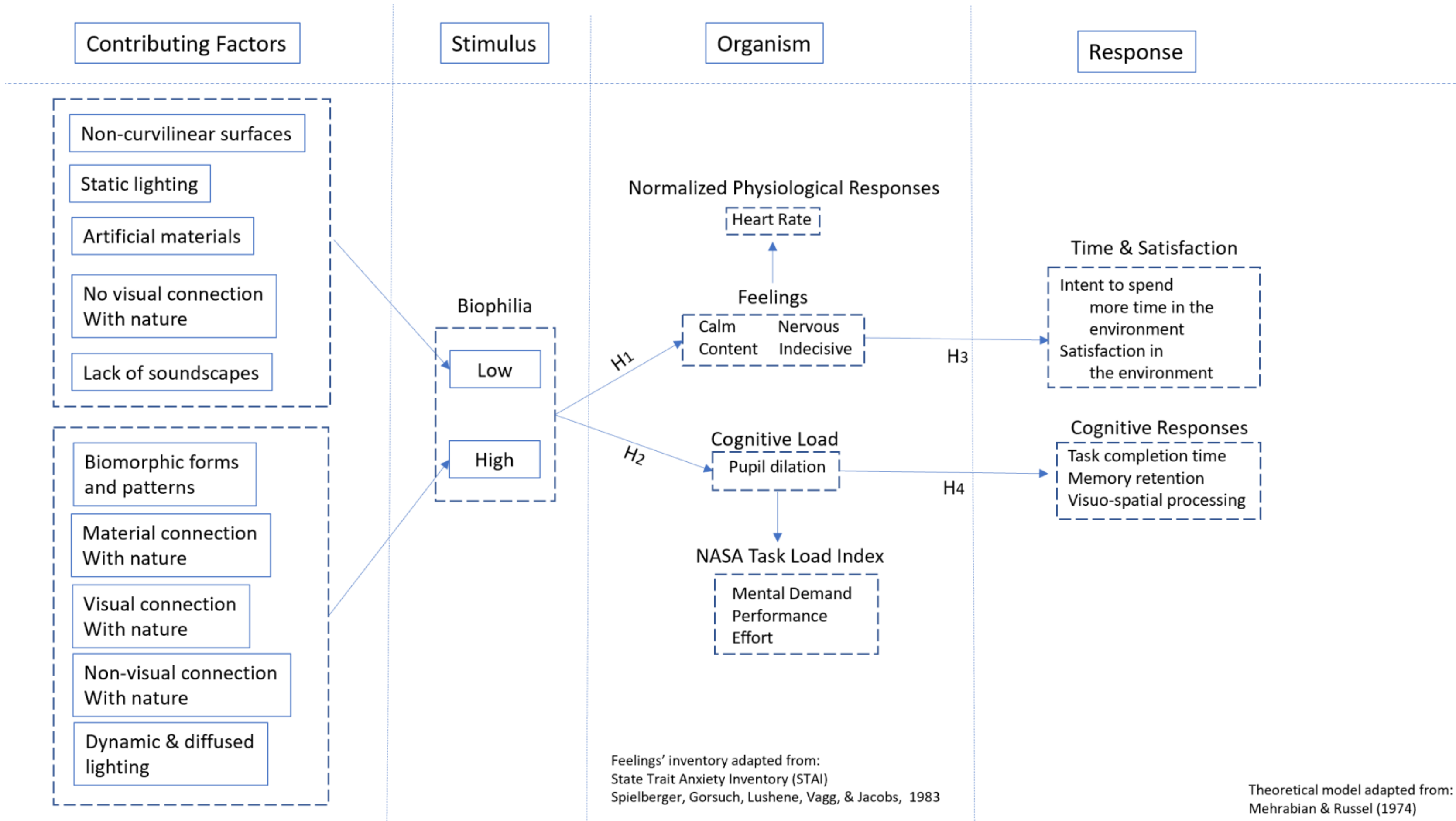
Biophilic design is a concept that has existed for millennia but has only been scientifically studied in the last few decades (Sanchez, Ikaga & Sanchez, 2018). For nearly as long as humans have existed, they have been trying to relate to the world around them and have found comfort in the association with other living things. The innate love of life that people have is what is known as Biophilia and embracing this concept through patterns in the built environment is known as Biophilic Design (Söderlund, 2019).

Various theories and matrices have helped quantify biophilic design and study its effectiveness and impact. Attention Restoration Theory has been used in various studies to help determine some of the therapeutic qualities of biophilic design (Yin et al., 2020).

Attention Restoration Theory (ART) is the concept that natural environments are filled with “soft fascinations” that help lower mental fatigue, restore cognitive capacity, and therefore increase attention and focus (Yin et al., 2020). Another theory called Stress Recovery Theory (SRT) states that humans have evolved to have preferences toward the natural environment and therefore when humans are exposed to nature, it engages the nervous system and leads to stress recovery (Yin et al., 2020). The proposed theoretical model as seen in Figure 1(adapted from Mehrabian & Russel, 1974) demonstrates how there are various contributing factors that can affect the level of stimulus in an environment. This, in turn, can affect how an organism feels in each space and can lead to one feeling calm and content, or nervous and indecisive (adapted from Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). This can correlate to an organism’s physiological responses, such as heart rate. Additionally, the level of biophilic stimulus in an environment can affect the cognitive load of an organism, which is demonstrated through pupil dilation (Gavas, et. al, 2017; Zagermann, et. al, 2018; Krejtz, et. al, 2018) and correlated through NASA Task Load Index (Noyes, et. al, 2007; Wang, et. al, 2014) which will measure mental demand, performance, and effort (Galy, et. al, 2018). These factors can lead to an individual’s level of satisfaction and their desire to spend more time in the given environment (Mehrabian & Russel, 1974; Robert & John, 1982). Furthermore, it can affect cognitive responses such as task completion time, memory retention, and visuo-spatial processing (Wang, et. al, 2014; Braly, et al, 2015; Camos, et. al, 2015; Castro-Alonso, et. al, 2019; Naert, et. al, 2018).

Figure 1

Proposed Theoretical Model



ART and SRT are helpful tools for understanding certain effects of biophilic design, but other measurements could be used to develop a wholistic understanding of how to implement biophilic design in the most effective way. McGee et al. (2019) propose a systematic testing and evaluation for biophilic design known as the Biophilic Interior Design Matrix (BID-M). The matrix provides a tool for designers to evaluate interior spaces for their use and effectiveness of biophilic design. This model uses clear and easy-to-understand language in way that encourages the adoption of more biophilic design practices. The researchers propose that by providing designers with the knowledge of biophilic design in the matrix, designers not only obtain a useful tool for assessment, but also a guide for biophilic design throughout all phases of the design process.

Designing for transit habitats holds unique implications as the built environment is used in various ways. The habitat is not simply a transient space where occupants patiently await their destination, but rather a space for working, socializing, relaxing, sleeping, and exercising. As the environment is unique and dynamic, it is important to understand the various implications biophilic design can hold in various scenarios. Biophilic design has unique implications for workplace design as it can improve productivity and creativity (Sanchez, Ikaga, & Sanchez, 2018). One effective strategy for implementing biophilic design into the workplace is through the combination of greenery and daylight-like technologies. The workplace of any individual can strongly impact their health and well-being, so it is crucial to design those spaces in a way that supports the occupant. Studies have shown that if the building is not properly designed or maintained, it can lead to sick building syndrome and be damaging to the occupant's health (Sanchez, Ikaga, & Sanchez, 2018). Workplace environments can contain stressors such as noise level, excessive thermal factors, chemical compounds, particulate fluctuations, and even radiation. By introducing natural plants into the built environment, air quality can be improved, and feelings of fatigue can be reduced (Sanchez, Ikaga, & Sanchez, 2018).

Various papers and studies embrace biophilic design, but some principles and patterns may be flawed for their inability to adapt to abnormal or extreme environments. Parsaee et al. (2019) state that in extreme environments, such as those climates that are inordinately hot or cold, people spend the vast majority of their lives inside. The article presents that in extreme environments the design and function of the built environment can largely impact the end-user. In Nordic and sub-Arctic environments, the biological needs of Nordic occupants have had to adapt to abnormal light levels and strong seasonal photoperiods as these individuals spend more than 90% of their time indoors. This results in an extremely limited connection to nature, but it presents a unique opportunity for interior designers and architects. By embracing patterns of biophilic design, the built environments can be restorative and therapeutic while still maintaining a highly functioning space. The article proposes that biophilic design should be more flexible and easily replicated no matter what the environmental conditions are. In the same way that humans and nature are both adaptive and dynamic, biophilic building envelopes should be too. By creating a built environment that can readily change to meet the needs of its occupants, biophilic, nature-inspired spaces can be brought into harsh environments.

Another extreme environment that largely benefits from biophilic design could be prisons (Söderlund & Newman, 2017). While research in this particular field is much smaller, preliminary results are promising. The beneficial effects of biophilia present added benefits in the prison environment as the decreased levels of stress and improved mental health led to safer living situations and more altruistic emotions in prison residents. The restorative and healing effects of biophilia potentially lead to reduced healthcare visits and lower levels of recidivism (Söderlund & Newman, 2017). Biophilic design also produces the added benefits of rehabilitation services by providing residents with opportunities for food production and employment through gardening and groundskeeping. A main issue with the design of prisons revolves around the safety and security of the residents and staff, but the article proposes several ways to implement biophilic design in a secure way. Using a speaker system for nature sounds, adding nature scents to the airflow, and creating a sense of refuge in the resident's cell, elements of biophilic design can be present throughout the facility.

4. HEALTH BENEFITS OF BIOPHILIC DESIGN

When a person experiences a space with biophilic design, it can impact them both cognitively and physiologically. Cognitively, biophilic design can improve productivity, creativity, and feelings of well-being (Sanchez, Ikaga, & Sanchez, 2018). It can result in lower workload sensations, higher job satisfaction, lower levels of perceived fatigue, and a decrease in the concentration of saliva amylase, which means a decrease in stress levels (Sanchez, Ikaga, & Sanchez, 2018). Furthermore, it can improve one's mood and increase their levels of self-esteem (Sanchez, Ikaga, & Sanchez, 2018). Ryan et al. (2014) state that from a physiological standpoint, biophilic design leads to a more relaxed brain, ocular muscles, and lenses. Furthermore, biophilic design reduces diastolic blood pressure and cortisol levels, which in turn reduces stress. Exercise within biophilic spaces can also produce desired outcomes of a more positive mood and self-esteem (Ryan, et al., 2014).

5. THE 14 PATTERNS OF BIOPHILIC DESIGN

Biophilic design can be achieved in many ways, but one of the most common and effective strategies for implementing biophilia into a design is through the use of what is known as the 14 patterns of biophilic design. These patterns are a series of tools for designs, architects, and the like to effectively understand how to design with biophilia in mind and how to understand the science behind each individual pattern (Design, B). There are aspects of biophilic design that can focus on aesthetics and appearances, but these 14 patterns focus solely on the benefits to the users psychological, physiological, and cognitive health (Design, B). The 14 patterns of biophilic design are divided into three categories: Nature in the Space, Natural Analogues, and Nature of the Space (Design, B).

a. NATURE IN THE SPACE

The first category, Nature in the Space, has seven patterns of biophilic design. This category means that the design uses biophilia through direct use of in a space or a place. Examples of this could be indoor plants and greenery, water features, gentle breezes, or smells or sounds found in nature. The first pattern is a visual connection with nature, which means that the user or occupant has a direct view of natural elements, living systems, and natural processes (Design, B). This can be achieved through artwork or videos that depict natural scenery, a living wall, or indoor plants, and can be either real or simulated nature. The second pattern consists of a non-visual connection with nature and relates to the user's relationship with nature through auditory, haptic, olfactory, or gustatory stimuli (Design, B). This can be achieved through mechanically released natural plant oils or recordings of nature sounds, such as birds chirping, rain falling, or the sound of a waterfall.

The next pattern is non-rhythmic sensory stimuli and can be difficult to simulate. This pattern provides individuals with a sense that what that are experiencing is something ethereal or special, such as unique shapes found in clouds as they pass by or a glimpse of deer gently grazing on vegetation (Design, B). This can be achieved through nature sounds with unpredictable intervals, reflections of water on a surface, or shadows that slightly change with either movement or time. The fourth pattern relates to thermal and airflow variability and can be achieved through cross ventilation or window operability, deliberate HVAC delivery strategies, and systems control (Design, B). When properly designed, this pattern allows users to experience a space that feels refreshing, active, and invigorating while providing the user with a sense of control and flexibility. Another pattern involves the presence of water, which can be either physical or simulated. A place with a presence of water can be either stimulating, restorative, or both and can be achieved through reflections of water, artwork with images of water, or constructed waterfalls or streams (Design, B).

The sixth pattern uses dynamic and diffuse light to achieve biophilic design. This pattern can be naturally occurring, or it can be simulated in a space, such as the crew quarters. The dynamic and diffuse lighting can be simulated through personal user dimming controls, task lighting, ambient diffuse lighting on the walls or ceiling, the presence of illuminance, and tunable lights that produce white lighting during the day while minimizing blue light during the night (Design, B). The last pattern in the Nature in the Space category is in regard to a connection with natural systems. This pattern can also be difficult to simulate, but when properly designed it can provide users with a sense of relaxation, nostalgia, and enlightenment by evoking a sense of seasonality and cycles of life (Design, B). This pattern can be achieved through designs that simulate daylighting systems that transition with diurnal cycles, natural patina of materials such as leather, copper, and wood, and wildlife habitats such as flowers plants, hedges, or birdhouses.

b. NATURAL ANALOGUES

The next category of biophilic design consists of natural analogues, which are design elements that may not be as direct or straightforward as biophilic patterns in the nature in the space category. This means the design may use indirect evocations of natural systems and elements, such as organic forms and structures, natural looking materials or colors, and even common sequences or shapes found in the natural world (Design, B). One example of this is biomorphic forms and patterns, which are more symbolic representations of nature. This can be achieved through designs that follow the Golden Mean or the Fibonacci series (Design, B). Additionally, biomorphic forms and patterns are different than common manmade structures, meaning that these biophilic elements are not strict right angles and straight lines but more curvilinear and sculpturesque forms.

Material connection with nature is the next pattern and it relates to the creation of a distinguished sense of place through seemingly natural materials or elements (Design, B). This can be achieved through interior design details that appear to be wood, stone, leather, bamboo, rattan, cork, or fossil textures. While many designers may use real, natural materials, laminated or veneered materials with a natural pattern will still provide the same biophilic benefits to the end user. The last pattern in this category is complexity and order. This pattern mimics nature through a perfect harmony of complex shapes and structures that are patterned in a naturally recurring order (Design, B). While overcomplicated designs can increase stress levels and lead to nausea, certain fractal geometries found in nature can positively impact the end user. Examples of this would be buildings, spaces, or artwork that have a perfect balance between an information rich design that is not only interesting but also restorative, such as the geometries found in the Eiffel Tower in Paris (Design, B).

c. NATURE OF THE SPACE

The final of the three categories is nature of the space and uses spatial configurations found in natural environments to evoke the positive effects of biophilia, allowing the user to have a deliberate and engaging experience with a seemingly natural space (Design, B). The first biophilic pattern in this section is the idea of prospect, meaning that the occupant has an uninterrupted view over a distance for either surveilling or planning. The next pattern, sense of refuge, provides occupants with a place for withdrawal, either from a flow of activity or the environmental conditions. If the space provides a sense of refuge, the user will feel protected and safe, which can be achieved when they are covered from overhead and behind, similar to a covered seating area at a bus stop. The crew quarters would be an example of this as the user is able to seek direct refuge from environmental stimulation, whether that be physical stimulation or loud machinery or mental stimulation of a strenuous workload.

The idea of mystery is the next pattern, and it works in contrast to prospect, meaning that some views might be obstructed in a way that encourages the occupant to travel deeper into the environment (Design, B). An example of this would be the pleasant scent of food in a store where the individual cannot yet see a bakery or restaurant. This can also be achieved through winding paths, curvilinear edges that are only partially visible through peek-a-boo windows, deliberate placement of light and shadow. The last pattern is the concept of risk or peril. While this idea may seem contradictory to the calming and restorative effects of biophilia, this pattern provides a small element of excitement to the individual (Design, B). The risk pattern could be anything from a double height atrium to an infinity edge in a pool, but it must present a noticeable threat but is also coupled with a reliable safeguard.

6. DESIGN FOR A MISSION TO MARS

For decades, scientists and engineers have been studying the effects of the environmental design in spacecraft and how it can affect the health and wellbeing of the crew. Researchers have found that the human body and mind are strong and can be quite resilient in harsh environments (Clearwater, 1988). For short periods of time, motivated and disciplined individuals can adapt to nearly any living situation, no matter how poorly designed the built environment is for the occupant (Clearwater, 1988). Research on polar research stations, submarines, offshore oil platforms, and hyperbaric chambers has shown that human beings are capable to adapt and work in extreme and isolated environments for short periods of time (Clearwater, 1988). However, if the human body is exposed to harsh or extreme living conditions for prolonged periods of time, then people can expect to see physiological and mental damage to the occupants of those spaces.

The negative aspects of spacecraft have led to the development of more habitable spacecraft with a higher emphasis on human factors (Dudley, 2003). The term "habitat" in regard to space architecture has broadened over the years to encompass a variety of needs of the astronauts living on space stations and various space craft. In the initial beginnings of research, a habitat was defined as “spacecraft that were intended for the transport of humans, space stations, and planetary surface stations” (Dudley, 2003). This then led to a more comprehensive meaning to the term, defining habitability the “degree to which an environment promotes the productivity, wellbeing and performance of its occupant” (Clearwater 1988). This led to the development of the Habitability Research Group, which is a complex and interdisciplinary team involving psychology, physiology, industrial design, architecture, interior design, perception, and various fields of engineering (Clearwater 1988). The team focuses on the development of human factors in the aerospace industry and has determined that there is a critical relationship between an individual’s wellbeing, their performance, and the environment that they are in (Clearwater 1988).

There are two main routes an interior designer could take when approaching the design of a space craft or space station: the “Man in a Can” model and the “Quality of Life” model. In the first model, the design of the spacecraft focuses purely on meeting only the manifest challenges, maintaining tight deadlines, and using limited resources (Dudley, 2003). The Man in a Can model is dedicated to the minimal comfort of the crew and designs only for what the crew can tolerate. The second model, the Quality-of-Life model, focuses on the overall comfort and wellbeing of the crew (Dudley, 2003). It also focuses on meeting manifest challenges, in addition to taking human factors interfaces into consideration. This type of model is common to more mature scientific expeditions, such as those in current Antarctic research conditions (Dudley, 2003).

Moving forward, the Quality-of-Life model will be more suitable for long duration, deep space missions, such as a mission to Mars. This scenario poses unique implications for the crew as it will be unlike any other space mission. It will be different than a typical tour of duty on a space station in that the occupants of the space craft will not be able to look out a window and see the earth (Dudley, 2003). These individuals will not have easy or quick access to needed supplies, repair parts, or new equipment. In the case of an emergency, the likelihood of returning to earth or sending a rescue spacecraft is much lower. The sheer psychological pressure of this could weigh heavily on the crew and lead to increased levels of stress (Dudley, 2003).

There is a critical relationship between the built environment and the health and wellbeing of its occupants. The interior design of the spacecraft environment can largely affect the physical and psychological health and comfort of the end user, specifically through the use of colors (Schlacht, 2006). In the case of long-term isolated missions, the user's wellbeing can be positively impacted through light levels, colors, changes in wind direction, and hot and cold temperatures, which are all characteristic of earth's natural environment (Schlacht, 2006). Further additions of artwork depicting natural landscapes can help reduce levels of stress, balance heart rate, and relax ocular lenses (Schlacht, 2006).

The interior design of long duration, deep space flights is more than an accomplishment of an aesthetically pleasing environment. The thoughtful, intentional design of spacecraft can help aid the end users in visual orientation, maximize judged spaciousness, and support specific functions of both individual and group work, meetings, mealtimes, and recreation (Clearwater, 1988). The adequate design of the interior of a space craft on a long duration mission can no longer be seen as a favorable add-on, but rather a vital tool to promote the safety and health of the crew.

7. RESEARCH QUESTIONS

   1. How does the environment affect feelings experienced (calm, content, nervous, and indecisive) when in the environment? (H1)
   2. How does the environment affect cognitive load (pupil dilation) when in the environment? (H2)
   3. How do feelings and emotions experienced in the environment (calm, content, nervous, and indecisive) affect intention to spend more time in the environment and satisfaction in the environment? (H3)
   4. How does cognitive load (pupil dilation) affect cognitive responses of task completion time, memory retention, and visuo-spatial processing? (H4)

8. HYPOTHESES

- H_1: The type of environment (biophilic vs non-biophilic) affects the feelings.

  Paired t-test

  H_{01}: μ biophilic = μ non-biophilic

  H_{11}: μ biophilic ≠ μ non-biophilic

- H_2: The type of environment (biophilic vs non-biophilic) affects the cognitive load.

  Paired t-test

  H_{02}: μ biophilic = μ non-biophilic

  H_{12}: μ biophilic ≠ μ non-biophilic

- H_3: Feelings affect satisfaction and intent to spend more time in the environment.

  Correlational hypothesis

  H_{03}: $\rho = 0$

$H_{13}: \rho \neq 0$

- H_4: Cognitive load affects cognitive responses in the environment

  Correlational hypothesis

  $H_{04}: \rho = 0$

  $H_{14}: \rho \neq 0$

9. CONCLUSION

Based on the aforementioned factors, there is a critical need to better understand the role biophilia can play in affecting individuals living in space, particularly on long term or deep space missions. It is anticipated that the successful completion of this study will show that space analogs designed with the integration of biophilic design will result in improvements in physiological, emotional, and cognitive measures when compared to virtual interior spaces of space analogs without the integration of biophilic design. It is also anticipated that there will be a statistically significant difference in measurements in the control environment compared to the biophilic environment. It is probable that there will be a reduced heart rate and improved emotions, along improved pupil dilation and task load in the biophilic environment. The central hypothesis of the proposed study is that virtual interior spaces of crew quarters designed with the integration of biophilic design will improve physiological, emotional, and cognitive measures when compared to virtual interior spaces of crew quarters without the integration of biophilic design.

In conclusion, the literature suggests that there are some gaps in the current understanding of how biophilic design can affect astronauts in crew quarters. Based on the concepts mentioned in the literature review, novel methods must be developed to better understand the positive impact of biophilia in space analogues. The table below demonstrates some issues relating to the research topic that have been addressed in the past, as well as some issues that need further exploration.

Table 1.

Issues related to the biophilic design of spacecraft crew quarters

Issues addressed in the past	**Issues that need further exploration**
• Design of space habitats addressing human factors • Design that explores the relationship between habitat and crew psychology • Using You-Are-Here maps to address challenges with partial gravity • Designs for space tourism- human-friendly architectural designs for a Mars base • The impact of biophilic design in virtual reality environments • Design of spacecraft from an architectural, engineering, or industrial design point of view • Biophilic design in various environments that share comparable	• **Design of spacecraft from an interior design point of view** • **Design for space tourism- transit habitats for the common person** • **Interior design specifically for a transit habitat, such as those for a Mars mission** • **Interior design for spacecraft on long term missions** • **If and to what extent biophilia can improve psychological, cognitive, and physiological measurements in astronauts**

properties (workplace, prisons, arctic regions) ● The negative effects of living in space- psychological, cognitive, physiological ● Improvements to sleeping patterns and circadian rhythms in earth environments due to biophilia	

CHAPTER III

METHODOLOGY

1. INTRODUCTION

This study aimed to determine if biophilic design in personal crew quarters could help improve physiological and cognitive measures. As biophilic design has been demonstrated to improve cognitive performance (Browning, Ryan, & Clancy, 2014), it could also offer opportunities for improving crew wellness and safety during missions. In this study, participants observed and interacted with two differing virtual reality environments to determine the effects of biophilia in a space analogue. The virtual reality environments designed in Sketchup and measured perceptions of the space and physiological, emotional, and cognitive responses to virtual non-biophilic and biophilic crew quarters. The environments that were used apply design techniques which are similar to those used within the aerospace industry including current technological innovations and prior research about spacecraft environments. This research aimed to better understand through the current knowledge about living in space what the crew might expect on a deep space or long-term mission within crew quarters. In the non-biophilic condition, the crew quarter environment was based on the existing crew quarters currently used on the International Space Station. In the treatment condition, the quarters were designed using the concepts of biophilic design.

2. PARTICPANT SAMPLE

The participant sample consisted of a sample of students, staff, and faculty at a large midwestern university. Participants were selected on a voluntary basis through email, snowballing, and personal connections of the researcher. Participants received no monetary compensation for participating. The inclusion criteria for the study were that participants must be 18–60 years in age, which reflects potential typical age ranges of astronauts who have experienced space flight or might experience space flight in the future. Participants who had abnormal heart rate, such as arrythmia or heart murmur, were excluded from the study. Additionally, participants who had significant cognitive challenges that could inhibit their participation were also be excluded from the study. While no participants experienced nausea or dizziness when using a virtual reality headset, they were told that they were allowed to discontinue the study if physiological distress occurred. This study included 40 participants.

3. PROCEDURES

The study obtained institutional review board approval (IRB-21-379), and guidelines for social distancing and sanitizing pertaining to the CoViD-19 pandemic were accounted for in the data collection process. Data collection started in November 2021 and ended in January 2022. The data were collected in the Mixed Reality Lab at Oklahoma State

University. Participants interacted in two virtual reality environments using the Vive Pro Eye virtual reality headset, with one environment being the non-biophilic model and the other one being the proposed biophilic model. The non-biophilic environment is solely based off the existing crew quarter conditions on the International Space Station (Figure 2) while the treatment condition is designed with patterns of biophilic design (Figure 3).

Figure 2

Virtual Model of ISS

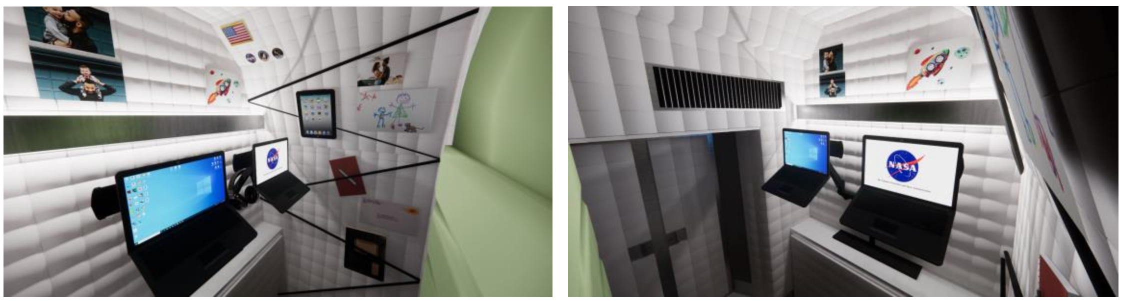


Figure 3

Virtual Model of Proposed Biophilic Environment

The study consisted of participants interactions with two virtual reality environments. To better understand the experience of virtual reality, participants first encountered a “practice” environment that was modeled to resemble a small apartment.

Participants were asked to wear the headset for approximately 5 minutes while locating certain items throughout the room and verbalizing anything that comes into their mind. Once participants felt comfortable with virtual reality, they were then randomly placed into one of two environments. In each environment, participants were asked to answer various questions that prompted them to interact with the space, such as counting the light sources, reading text on a laptop, describing a wall and the view of a window, locating the sleeping bag and iPad, reading an address on an envelope, finding certain elements in a photograph, and counting icons on a laptop. Once participants successfully completed these tasks, they were then asked to take a moment to further explore the space on their own. While participants were in each space, they used the think aloud protocol, where they were asked to verbalize anything that comes to mind (Jääskeläinen, 2010). If participants were silent for more than 20 seconds, they were prompted by the researcher. When experiencing each environment, measurements for heart rate and pupil dilation, were recorded. In addition, after experiencing each environment participants immediately took a survey that assess feelings and emotions (calm, content, nervous, and indecisive), satisfaction with the space and intent to spend more time in the space, task load (mental demand, performance, and effort), memory retention, task completion time, and visuo-spatial processing.

4. BIOPHILIC DESIGN CONSIDERATIONS FOR THE CREW QUARTERS

The biophilic environment had the same dimensions as the existing non-biophilic model but incorporated use of design elements based off the following biophilic principles: Material connection to nature, Visual connection with nature, Non-visual connection with nature, Biomorphic forms and patterns, Dynamic & diffuse lighting, and Sense of refuge. While a large window in space craft might not be physically doable, this "window" could be simulated through an electronic light panel. The image would be customizable and, in this case was set to a forest/jungle view for the study. Thus, participants had a "view of nature" in a simulated crew quarter. While it is out of the scope of this project, it is important to consider additional design considerations of materials, such as flammability, off-gassing, cleanability, weight, durability, and acoustics.

5. INSTRUMENTS

Measurements for feelings and emotions (calm, content, nervous, and indecisive), heart rate, pupil dilation, task load (mental demand, performance, and effort), satisfaction, intent to spend more time in the space, task completion time, memory retention, and visuo-spatial processing were studied both in the non-biophilic and biophilic models. Heart rate was taken at a resting rate and for the entirety of the participants exposure for the non-biophilic and biophilic environment. Heart rate was taken using Biopac Systems equipment, model MP160. To get a baseline measurement for resting heart rate, participants sat with their eyes closed for three minutes before entering either of the virtual reality environment. Measurements were taken for an average of the three-minute period. Pupil dilation was measured using the VR headset when experiencing both environments. Participant's feeling and emotions (calm, content, nervous, and indecisive) in the spaces was measured using a modified version of the State Trait Anxiety Inventory (STAI) which can be seen below in Table 2 (adapted from

Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Task completion time of specific tasks was measured using a digital timer for a post-test survey for each environment.

Additionally, participants were asked questions relating to memory retention and visuo-spatial processing. For memory retention, participants complete a survey asking them to recall certain aspects of each environment, such as the location of specific items or the color of certain elements. For visuo-spatial processing, participants completed two tasks. The first task (the tic-tac task) consists of a 3x3 block matrix where three to five squares briefly illuminated (Hart, et. al, 2001). Participants were then instructed to indicate which blocks contained the illuminated squares by selecting numbers on a keypad. Next, participants were then presented with clock faces with hands indicating the time, but without hour markings. There were blank boxes available for participants to type the clock's time (Hart, et. al, 2001). To measure task load of each environment, participants answered questions from a modified version of the NASA Task Load Index (Hart, 2006). This consisted of three questions to help determine the difference in task load of each environment (Table 3).

Table 2

Modified State Trait Anxiety Inventory Questionnaire

Read each statement and select the appropriate response to indicate how you feel right now, that is, at this very moment. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.			
1 Not at all	2 A little	3 Somewhat	4 Very much so

1. I felt calm in the space	1	2	3	4
2. I felt nervous in the space	1	2	3	4
3. I felt indecisive in the space	1	2	3	4
4. I felt content in the space	1	2	3	4

Lastly, participants were asked about their intention to spend more time in the space and their overall satisfaction with the environment.

Table 3

Modified NASA Task Load Index

Read each statement and select the appropriate response to indicate how you feel right now, that is, at this very moment. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.	
Mental Demand	
How mentally demanding were the tasks?	Very Low Very High
Performance	
How successful were you in accomplishing what you were asked to do?	Very Low Very High
Effort	
How hard did you have to work to accomplish your level of performance?	Very Low Very High

6. DATA ANALYSIS

For the analysis, heart rate, pupil dilation, task completion time and results from the survey were recorded and analyzed using the software Microsoft Excel and IBM SPSS. A one-tailed paired t-test was conducted for hypotheses 1-2, and a Pearson correlation for hypotheses 3-4. The significance level was set at 0.05. Descriptive statistics were also reported.

CHAPTER IV

RESULTS & DISCUSSION

1. INTRODUCTION

As stated in Chapter 1, the study examined the effects of biophilic design in a virtual simulation of the crew quarters on the International Space Station (ISS). To do so, pupil dilation and heart rate were measured while participants experienced each environment and a post-test was immediately administered after exposure to each environment to measure feelings and emotions, mental demand, effort, and performance (NASA TLX), time and satisfaction, and cognitive responses. This chapter is organized in terms of the research questions and hypotheses stated in Chapter 2.

RQ 1: How does the environment affect feelings experienced (calm, content, nervous, and indecisive) when in the environment? (H1)

RQ 2: How does the environment affect cognitive load (pupil dilation) when in the environment? (H2)

RQ 3: How do feelings and emotions experienced in the environment (calm, content, nervous, and indecisive) affect intention to spend more time in the environment and satisfaction in the environment? (H3)

RQ 4: How does cognitive load (pupil dilation) affect cognitive responses of task completion time, memory retention, and visuo-spatial processing? (H4)

- H_1: The type of environment (biophilic vs non-biophilic) affects the feelings.

  H_{01}: μ biophilic = μ non-biophilic

  H_{11}: μ biophilic ≠ μ non-biophilic

- H_2: The type of environment (biophilic vs non-biophilic) affects the cognitive load.

  H_{02}: μ biophilic = μ non-biophilic

  H_{12}: μ biophilic ≠ μ non-biophilic

- H_3: Feelings affect satisfaction and intent to spend more time in the environment.

  H_{03}: $\rho = 0$

  H_{13}: $\rho \neq 0$

- H_4: Cognitive load affects cognitive responses in the environment

  H_{04}: $\rho = 0$

  H_{14}: $\rho \neq 0$

The study first examined how the environment affects the feelings experienced when in the environment and how the environment affects cognitive load. It then examined how feelings experienced in the environment affect intention to spend more time in the environment and satisfaction with the environment. Lastly, the study examined how cognitive load affects cognitive responses of task completion time, memory retention, and visuo-spatial processing.

2. BASIC DEMOGRAPHICS

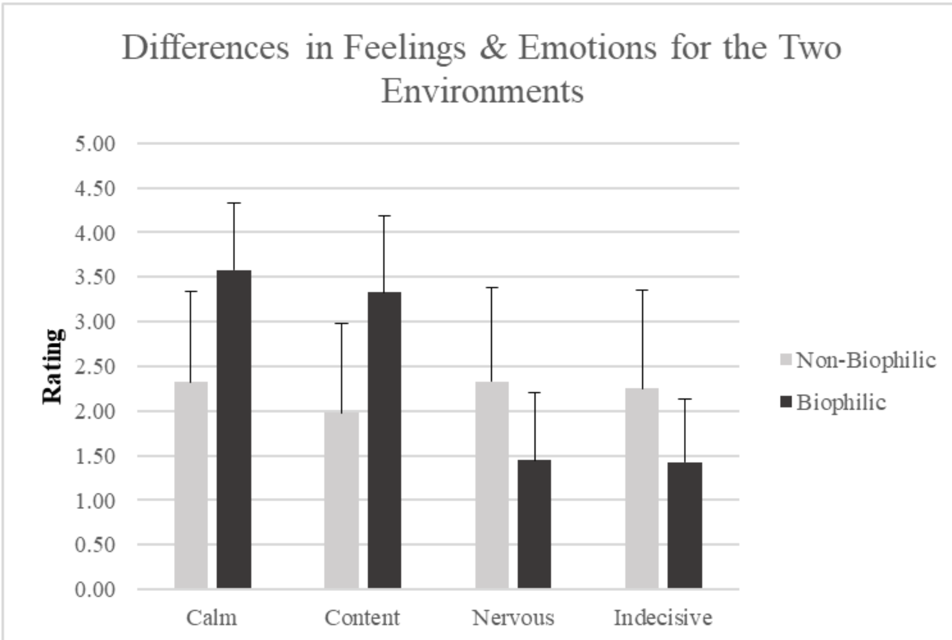
All participants were adult students, staff, or faculty in a midwestern university located in the United States. A sample size of $n = 40$ was obtained, composed of 25% male, 72.5% female, and 2.5% non-binary. The ages of participants ranged from 18-57 with an average of 25.5 ± 10.2 years. All participants were invited for a 1-hr period to conduct the experiment without time constrictions. This time was established through a pilot test run with six participants before starting the data collection process. These six participants' data were not included in the data analysis presented here.

3. FEELINGS AND EMOTIONS

Participants experienced differences in perceptions of feelings and emotions when experiencing the two different virtual reality environments. As indicated in Figure 4, participants felt higher feelings of nervousness and indecisiveness in the non-biophilic environment and higher feelings of calm and content in the biophilic environment. Analysis of the data found statistically significant differences in all four of the emotions with the following p-values: Calm ($p < 0.0001$), Content ($p < 0.0001$), Nervous ($p < 0.0001$), Indecisive ($p < 0.0001$).

Figure 4

Differences in Feelings & Emotions for the Two Environments

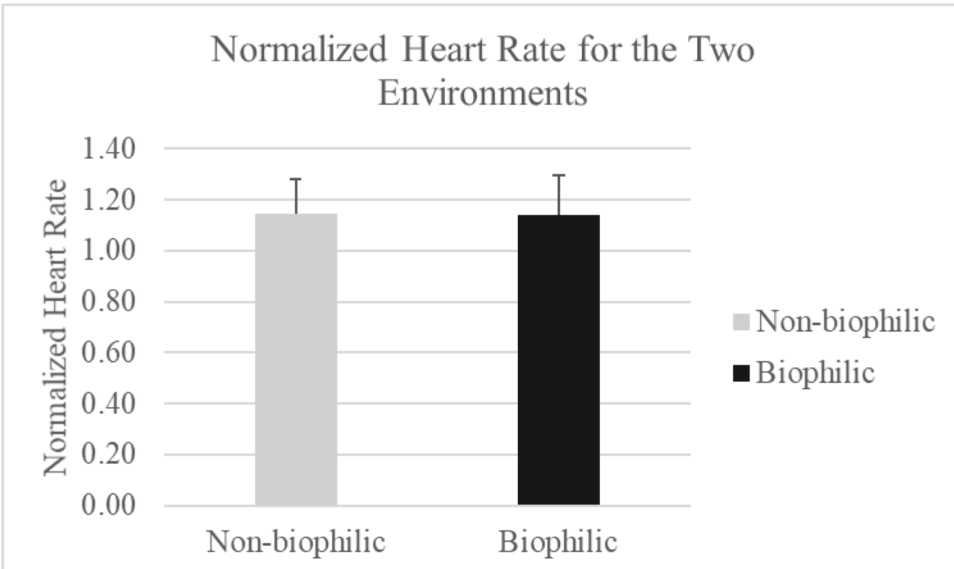


Based on these results, it is concluded that the type of environment affects the feelings experienced when in that environment. Participants felt calmer and more content in the biophilic environment and more nervous and indecisive in the non-biophilic environment. Therefore, the null hypothesis (H_1) was rejected as there was a difference in feelings experienced when in the two different environments. These findings are in agreement with other studies that have demonstrated how biophilic design can have a positive impact on one's mood (Sanchez, Ikaga & Sanchez, 2018; Yin et. al, 2020).

As for the heart rate, there was no significant differences in heart rate when experiencing the two different virtual reality environments. As shown in Figure 5, the normalized heart rate for the non-biophilic environment (1.14 ± 0.14) and the biophilic environment (1.14 ± 0.15) were not statistically significantly different (p=0.3).

Figure 5

Differences in Normalized Heart Rate for the Two Environments



The study also found that there was a weak correlation between feelings experienced in the environment with heart rate (Akoglu, 2018). As demonstrated in Table 4, the correlation between feelings of calm, content, nervous, or indecisive and heart rate were not statistically significant. The highest correlation value was between indecisive and heart rate (r^2=0.25), but the correlation is weak (Akoglu, 2018). The was a very weak correlation for feelings of calm, content, and nervous when compared to normalized heart rate. The current findings are not in agreement with other researchers who have found a stronger relationship between heart rate and emotional responses (Pollatos et. al, 2007; Quintana et. al, 2012).

Table 4

Correlation Between Feelings Experienced and Normalized Heart Rate

Feelings Experienced	Normalized Heart Rate	
	r^2	p-value
Calm	0.01	0.916
Content	-0.10	0.387
Nervous	-0.02	0.828
Indecisive	0.25	0.023

The weak correlation between feelings and emotions experienced, and heart rate could be due to a variety of reasons. The study showed that there was no significant difference in heart rate among the two environments. As many factors can affect one's heart rate, it is important to discuss how the participant's heart rate might have been affected in this study. First, heart beats per minute (bpm) might not have been the most appropriate measurement as many of the participants were college students who could have been sleep deprived or might have consumed alcohol or coffee within 24 hours prior to the experiment, all of which could potentially affect heart rate.

Secondly, participants were randomized for each experiment, so some participants experienced the non-biophilic environment while others experienced the biophilic environment first. Analysis of the data showed that the average bpm of participants during the first exposure was higher (92.21 bpm) than their bpm during the second exposure (90.38). Therefore, bpm was higher in the first exposure regardless of whether the first exposure was to the non-biophilic space or the biophilic space. This demonstrates that over the course of the experiment, participants might have been more relaxed, which might not have any relation to the environment to which they were exposed. This could be due to the nature of the experiment as not every participant was familiar with virtual reality or the feeling of having electrodes and wires attached to their ribcage and wrist. Participants may have experienced an initial discomfort or nervousness during the first exposure but then calmed down during the second exposure. The researcher aimed to prevent this occurrence by having each participant experience a virtual practice environment before exposure to either environment. As there was a higher heart rate during the first exposure, future researchers should consider doing a between-subjects study or aim to prevent the feelings of nervousness, excitement, or discomfort for future participants. This could be achieved by having participants spend more time in the practice environment, preferably more than the 5 minutes spent in the current study. Additionally, researchers could have participants come to the experiment for a practice session where each participant can familiarize themselves with the testing equipment and experience the practice environment. Then, on a later date participants can experience the actual virtual reality environments. While participants were screened for abnormal heart rate (heart arrythmia, etc.), future researchers might consider screening for caffeine or alcohol consumption.

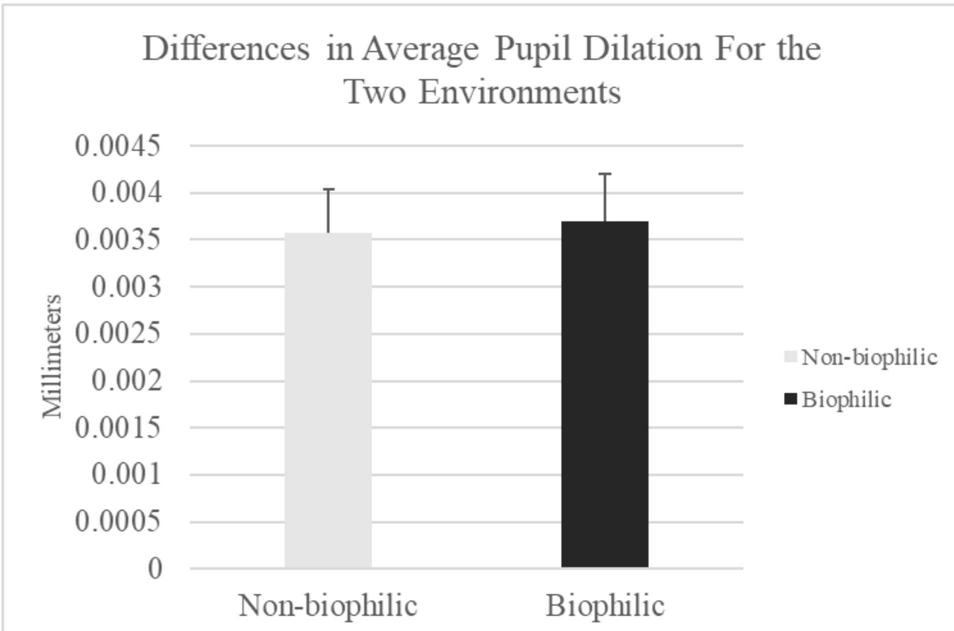
4. COGNITIVE LOAD

Participants experienced differences in cognitive responses for the two environments. As demonstrated in Figure 6, there were differences in average pupil dilation for the non-biophilic environment and the biophilic environment. The pupil dilation for the non-biophilic and biophilic environments were 0.0035 ± 0.00046mm and 0.0036 ±

0.00050mm, respectively. The analysis of the data showed a statistically significant difference for pupil dilation ($p=0.0001$).

Figure 6

Differences in Pupil Dilation for the Two Environments

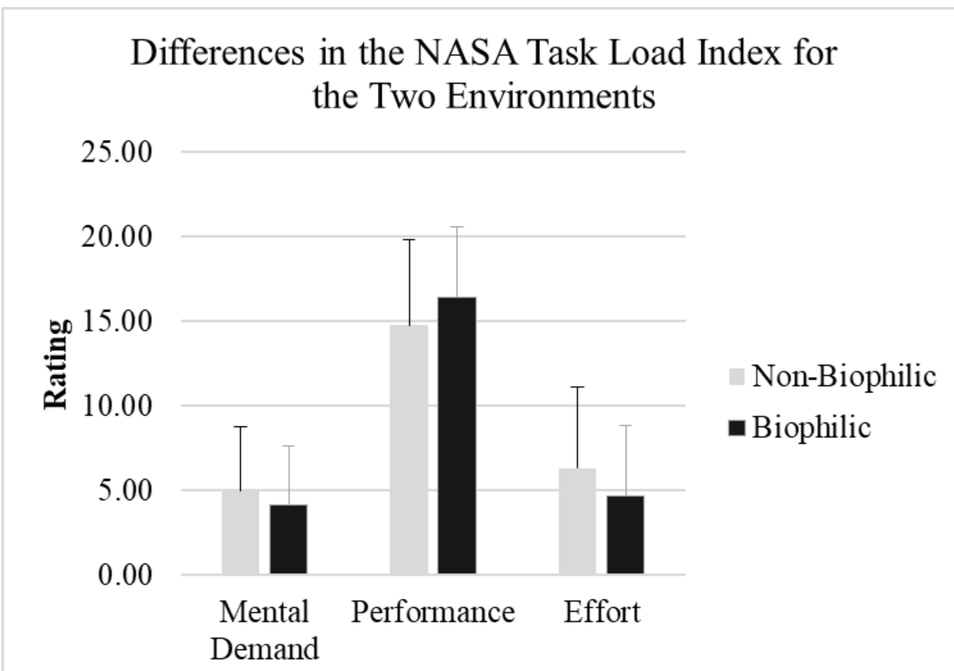


Based on these results, it was found that the type of environment affects pupil dilation. Participants experienced an increase in pupil dilation in the biophilic environment. Therefore, the null hypothesis (H_2) was rejected as there was a statistically significant difference in pupil dilation between the non-biophilic and biophilic environments. These findings are in agreement with other researchers who have found that pupil dilation changes in response to exposure to distinct types of environments (Janisse, 1974; Kahneman, 2011; Nunnally, 1994).

Additional measurements for cognitive load were measured through the participants survey responses. As depicted in Figure 7, participants felt that they performed better in the biophilic environment and that the tasks in the biophilic environment were less mentally demanding and required less effort. While the differences in mental demand were not significant (p=0.07), the differences in performance and effort were significantly different with performance having the larger difference (p=0.006) followed by effort (p=0.02).

Figure 7

Differences in Measures for the NASA Task Load Index for the Two Environments



Based on these results, it can be concluded that the type of environment can have an impact on an individual's task load perception. The study also determined if there were any correlations between the modified NASA TLX variables (mental demand, performance, and effort) and pupil dilation, as shown in Table 5. The data showed that there was a weak relationship between the NASA TLX variables and pupil dilation (Akoglu, 2018).

Table 5

Correlation between Modified NASA TLX and Pupil Dilation

NASA TLX	**Pupil Dilation**	
	r2	p-value
Mental Demand	0.06	0.598
Performance	0.03	0.781
Effort	-0.04	0.781

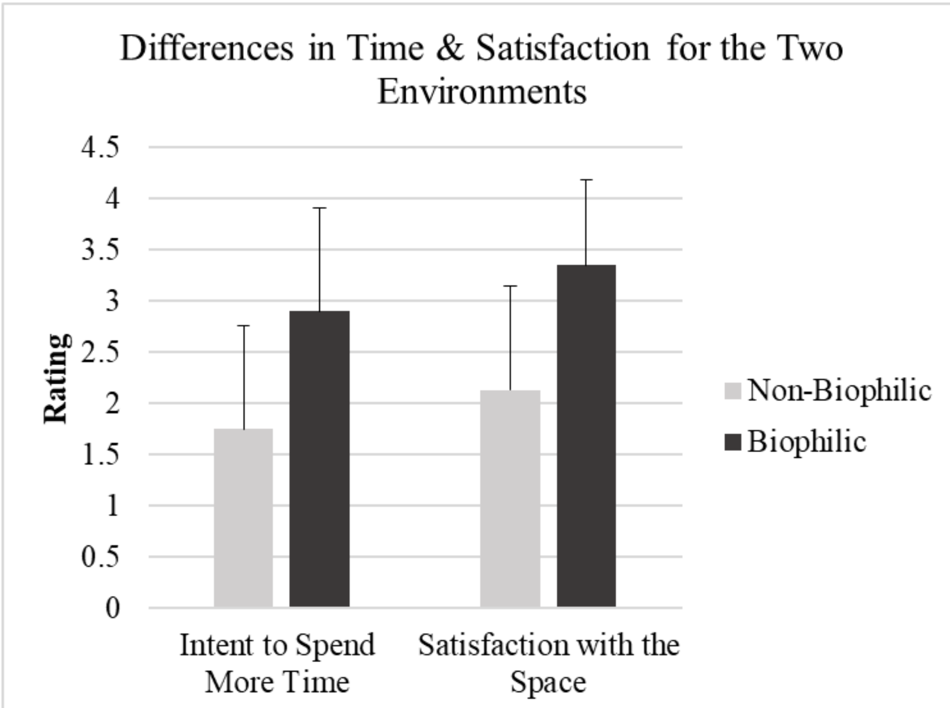
Based on the aforementioned results, it can be concluded that the type of environment does impact the participant's cognitive load. While there was not a significant difference in mental demand, there was a significant difference in performance, effort, and pupil dilation.

5. THE EFFECT ON TIME AND SATISFACTION

The study found that there were further differences in perceptions of the two spaces. Overall, participants felt that they had a higher intent to spend more time in the biophilic environment ($p < 0.0001$) and had a higher satisfaction with the biophilic environment ($p < 0.0001$), as seen in Figure 8.

Figure 8

Differences in Responses for Time and Satisfaction for the Two Environments



The study aimed to determine if there was a correlation between the feelings experienced by a participant in an environment and a participant's intent to spend more time in a space and their satisfaction with the space. The study found that there was a moderate relationship between nervous and indecisive and intent to spend more time in the space. There was a strong correlation between intent to spend more time and feelings of calm and content. For satisfaction with the space, there was a moderate relationship with nervous and indecisive, and a strong relationship with calm and content (Akoglu, 2018). These findings are summarized in Table 6.

Table 6

Correlation Between Feelings Experienced and Time and Satisfaction

Feelings Experienced	Intent to spend more time		Satisfaction	
	r^2	p-value	r^2	p-value
Calm	0.68	$p < 0.001$	0.77	$p < 0.001$
Content	0.72	$p < 0.002$	0.78	$p < 0.002$
Nervous	-0.51	$p < 0.003$	-0.47	$p < 0.003$
Indecisive	-0.57	$p < 0.004$	-0.50	$p < 0.004$

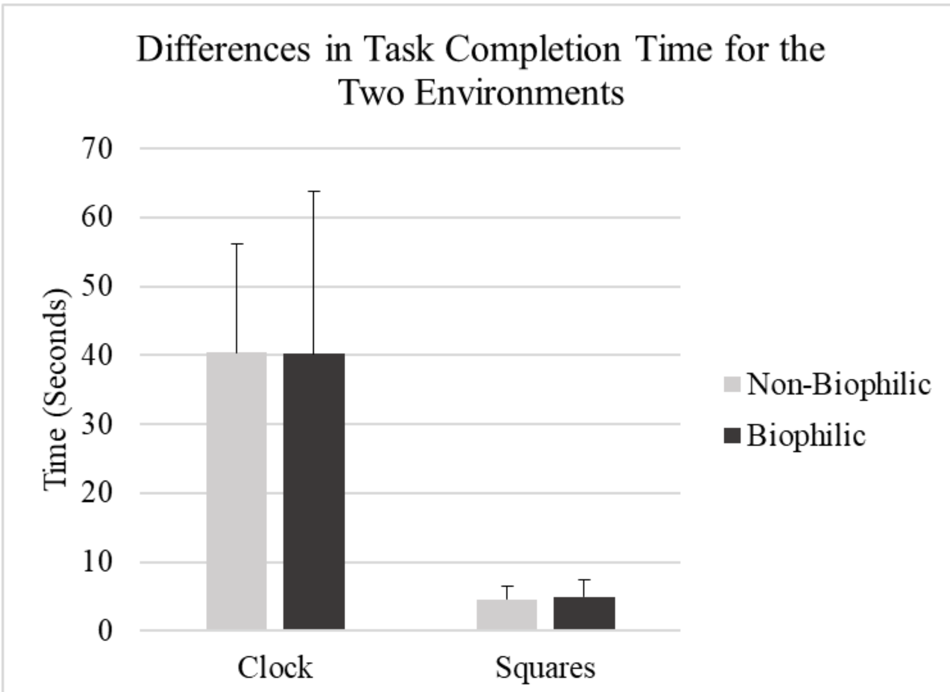
Based on this data, the null hypothesis (H_3) was rejected as there was a correlation between the feelings and emotions experienced and the participants satisfaction and intent to spend more time in the environment. These findings are in agreement with Robert and John (1982), who found that emotional perception affect user's enjoyment and their intention to spend more time in an environment. Furthermore, these results align with other research that shows emotional perceptions can impact user behavior (Mehrabian & Russell, 1974).

6. THE EFFECT ON COGNITIVE RESPONSES

When asked to state the time on the clock and complete the tic-tak tasks, participants showed very slight differences in task completion time, as shown in Figure 9. The mean task completion time for the clock task was 40.3 seconds in the non-biophilic environment and 40.2 seconds in the biophilic environment. The mean task completion time for each of the tic-tak tasks was 4.5 seconds in the non-biophilic environment and 4.9 seconds in the biophilic environment. While the task completion times were slightly different for the two tasks in each environment, the differences were not statistically significant (p=0.48, p=0.19).

Figure 9

Differences in Task Completion Time for the Two Environments

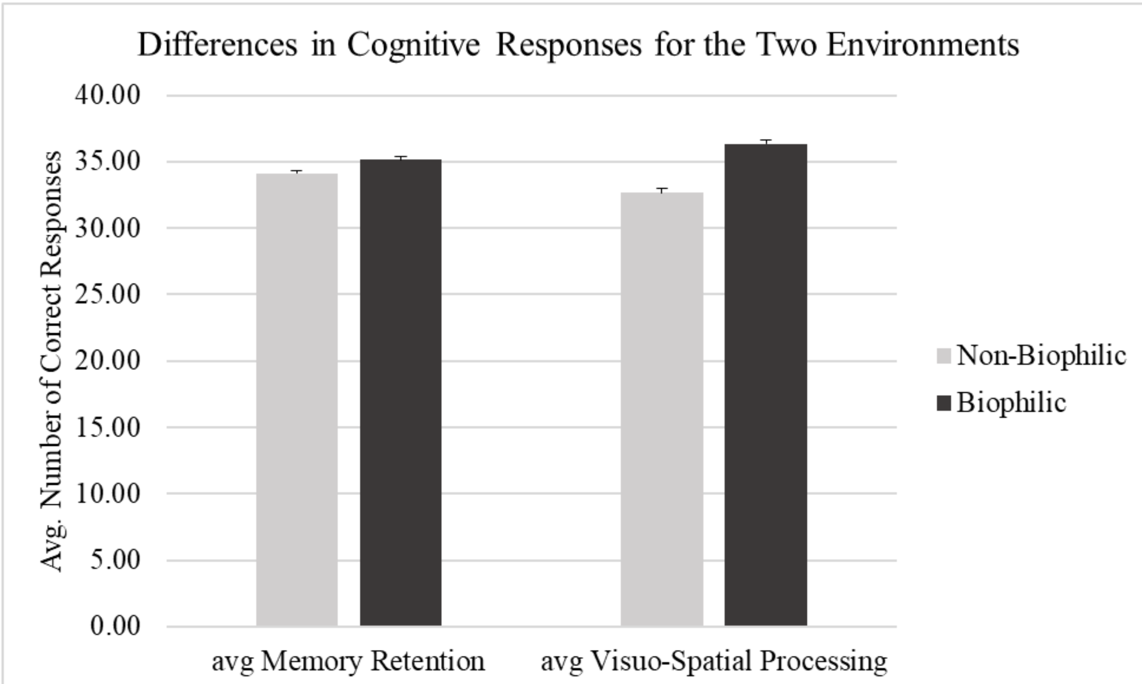


Based on these results, it can be concluded that the type of environment does not affect task completion time. This could be for a variety of reasons. First, the tasks might not have been mentally demanding enough in order for the environment to have an impact on task completion time. Identifying the time on a clock is likely to be simpler than many tasks astronauts might conduct during spaceflight. It would be beneficial to study the effect of environment on task completion time for more complex, long duration tasks such as operating parts of the spacecraft, conducting research in space, or overseeing space walks. Furthermore, the tasks completed here (clock task, tic-tac tak) were completed after exposure to each environment, meaning that participants completed these tasks outside of the virtual environment. This could be why there was no significant difference as every participant completed these tasks in the same computer lab on a university campus. If participants were able to complete these tasks on a computer while inside the virtual reality model, there might have been a difference in the two environments.

Two more cognitive responses, memory retention and visuo-spatial processing, were also assessed, as shown in Figure 10. The number of correct responses were recorded, and the study found that slightly more participants answered the memory questions correctly in the biophilic environment than in the non-biophilic environment, but the results were not statistically significant ($p=0.25$). For the visuo-spatial processing questions, the study found that slightly more participants answered correctly after exposure to the biophilic environment, but the results were not statistically significant ($p=0.13$).

Figure 10

Differences in Cognitive Responses for the Two Environments



Analysis of the data showed that there was no statistically significant difference in memory retention and visuo-spatial processing for the two environments. The study aimed to determine if there was a correlation between pupil dilation and cognitive responses of task completion time, memory retention, and visuo-spatial processing. The study found that there was a very weak relationship between pupil dilation and cognitive responses, as shown in Table 7 (Akoglu, 2018). Based on this data, the null hypothesis (H_4) was not rejected as there was no correlation between pupil dilation and cognitive responses of task completion time, memory retention, and visuo-spatial processing. These findings are not in agreement with Van Der Wel & Van Steenbergen (2018), who found that increases in task demand typically leads to an increase in pupil dilation. However, this is not always the case. Another study found that increasing task difficulty can be linked to increased pupil dilation in the initial phases of an experiment, but in a later phase of the experiment, pupil dilation was found to be larger in response to easier tasks (Boersma et, al,1970). This could be one reason the present study found no difference in pupil dilation as different studies have shown different results for pupil dilation and its relationship to cognitive responses.

Table 7

Correlation Between Cognitive Responses and Pupil Dilation

Cognitive Responses	**Pupil Dilation**	
	r^2	p-value
Memory Retention	0.12	0.271
Visuo-Spatial Processing	0.01	0.900
Task Completion Time	-0.14	0.209

The results presented indicate clearly that the participants in this study demonstrated differences in responses for the two virtual environments. The study found that there were more positive perceptions of the biophilic environment and more negative perceptions of the non-biophilic environment. Researchers found that while biophilic environments reduce stress and anxiety, virtual simulations of biophilia also have similar effects (Yin, et. al, 2020). The current study also found that participant ratings for discomfort were lower in the biophilic condition. Another study found that if participants experience a space with no biophilic or natural elements, then it can have a negative effect on the well-being of participants (Grinde and Patil, 2009). The current study findings align with this as participant ratings for discomfort were higher in the non-biophilic environment. Biophilic environments have been shown to improve physiological measurements (Yin, et. al, 2019) In this study there was no difference in heart rate between the two environments. However, there was a significant difference in the cognitive measure of pupil dilation.

7. LIMITATIONS

One of the limitations of the study was the nature of virtual reality simulations. As the experiment was not a fully realistic environment, there could be differences in physiological, cognitive, and emotional measures if participants were interacting with a physical space. Additionally, participants completed questionnaires after experiencing each environment. As virtual reality technology further develops, it would be beneficial to have participants complete these questionnaires and measurements while in the virtual model to see if there are greater differences in perceptions and measures between the two spaces. Furthermore, the study was not tested in a partial gravity environment such as in a spaceflight or the ISS.

As for participants, they should also be required to spend more time in each environment. In the current study, participants spent less than 15 minutes in each environment. In reality, a person using this space would spend hours in it every day so the study should test participants experience with each environment after spending a greater amount of time in it. Lastly, future studies might find it beneficial to recruit a larger sample of participants with varying backgrounds and experiences. As not every participant was familiar with virtual reality, that alone may have affected their perceptions of the spaces. Furthermore, there could be differences in perceptions among male and female participants, as well as participants from different generations, nationalities, and cultures. It is important to understand the role these differences play in perceptions, especially for commercialized space travel. Additionally, the current study used a within-subjects study design, which could have led to fatigue or post-test learning for participants. It could be beneficial for future studies to use a between-subjects design to minimize a carryover effect.

Lastly, the study did not find any significant differences in cognitive responses (task completion time, memory retention, and visuo-spatial processing) for the two environments. This could be due to limitations with how the cognitive responses were tested and measured. Due to technology limitations, it was not possible to have participants complete cognitive response tests while wearing the virtual reality headset. Therefore, participants were only able to take these tests after exposure to each environment and removal of the virtual reality headset. As participants were not directly immersed in the environment for these tests, it follows that the results from each exposure would be similar. As each participant took these tests in the same computer lab after exposure to each environment, this could be one of the reasons why there was so difference in cognitive responses. Therefore, future research should aim to have participants complete cognitive response tests while immersed in the virtual simulation.

8. FUTURE DIRECTIONS

The nature of the environment holds limitations as it was assessed in a virtual environment but not in a partial gravity environment. As the experience of earth’s gravity

(1g) is different than the microgravity experienced on the ISS, the model should be evaluated in a microgravity environment in future studies. This could be done through an underwater habitat mockup model or a harness system such as the suspension partial-gravity simulator that reduces participants weight to what would be expected on spacecraft (Akin, McBryan, Limparis, D'Amore and Carlsen, 2014; Dong, Hsiang, and Smith, 2008). In addition to the experiment not being conducted in a partial gravity environment, the test was also done using a virtual simulation. The nature of a virtual simulation leads to an environment that is not fully representative of a physical real-world environment.

In future studies, researchers should consider modeling a physical space for participants to interact with. Along with a physical environment, other senses could also be incorporated. This can be achieved through a speaker that plays biophilic soundscapes or an air diffuser (Browning & Ryan, 2020). Nature inside: a biophilic design guide. Routledge. that allows users to experience natural smells while interacting with the model. Researchers should also consider co-designing spaces while seeking input from stakeholders including astronauts, designers, space travelers etc. before evaluating the spaces. Researchers might find it beneficial to approach space industry experts and incorporate a user-centered design process in designing the crew quarters, along with designing with patterns of biophilia.

Currently, most of the existing designs for transit habitats are created by architects, engineers, or industrial designers. Interior designers offer a unique perspective to the design of these habitats as interior designers focus specifically on how individuals interact within the space. Designing with interior designers provides a unique human-centered approach to design that creates spaces using empathic design and evidence-based design (Leonard & Rayport, 1997; Hamilton & Watkins, 2008). While previous short-term space habitats have been designed purely for functional and utilitarian purposes, a long-term space flight poses unique design challenges which if done as part of a collaborative co-design effort with engineers, interior designers and astronauts could positively impact the health and well-being of astronauts.

CHAPTER V

CONLCUSIONS

This study was conducted to explore the relationship between virtual non-biophilic spaces and virtual biophilic spaces and its effect on the participants. In this study, four main research questions were investigated. These questions related to how a virtual environment could affect feelings experienced, cognitive load, intention to spend more time in and environment, satisfaction, and cognitive responses.

The problem statement for the study is that while the current design for the ISS crew quarters meet the needs of its occupants, a redesign while integrating biophilic elements could be more beneficial for occupants who use the crew quarters for long term or commercialized space travel. As ideas for a mission to Mars are becoming more prevalent, it is necessary to understand the impact that the built environment can have on occupants and if it is possible to design the crew quarters as a countermeasure to improve human health and wellbeing.

In this study, participants observed and interacted with two different virtual reality environments. The virtual reality environments were designed to measure participants' emotional, physiological, and cognitive responses on simulated non-biophilic and proposed crew quarters. Both crew quarters applied design techniques similar to those used within the aerospace industry, but one environment featured elements of biophilic design.

In the non-biophilic condition, the crew quarter environment was based on the existing crew quarters currently used on the ISS and remained as realistic as possible using appropriate materials, colors, lighting, and dimensions. Participants virtually entered each space using a virtual reality headset. In the treatment condition, the crew quarters had the same dimensions as the control, but incorporated design elements based off various biophilic patterns. Quantitative data of heart rate, task load, pupil dilation, and emotions and perceptions were collected.

The study found that the environment can impact the feelings experienced by participants. In the non-biophilic model, participants experienced greater feelings of nervousness and indecisiveness and lower feelings of calmness and content. In the biophilic environment, there were higher feelings of calmness and content and decreased feelings of nervousness and indecisiveness. The research also found that there was a significant difference in pupil dilation for each environment. The study found a moderate to strong correlation between feelings experienced and satisfaction and intention to spend more time in the environment. In addition, there was a weak correlation between cognitive load and cognitive responses; pupil dilation and task completion time, memory retention, and visuo-spatial processing.

Overall, there was a difference in emotional and cognitive responses for the non-biophilic and the biophilic environment. This study provides unique research for the design of crew quarters on spacecrafts as previous short-term space habitats have been designed primarily for efficiency and safety, and less focused on the occupant's quality of life. A long-term space flight, such as a mission to Mars, poses unique design challenges as astronauts will have limited resources and are likely to be psychologically and physiologically impacted by the built environment. As there are limited studies and data supporting interior design and biophilic design in transit habitats, studies in this area are vital to the development of the space architecture field. Designs such as the one in this study could be beneficial for creating spaces that act as a human health countermeasure and help ensure the happiness, satisfaction, and quality of life for astronauts and space travelers.

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Appendix A

Classroom Presentation Script for Recruiting Participants

Hi everyone! I would like to invite you to participate in a research study for my thesis titled "Biophilic Interventions in Crew Quarters for Deep Space Transit Habitats to Improve Cognitive and Physiological Health Measures". The purpose of this study is to evaluate how biophilic design affects an individual's physiological and cognitive responses while in a virtual model of a spacecraft. The findings from this study will be used to recommend design choices to space industry professionals that are looking to improve the mental and physical health of their astronauts and those traveling to space. As a participant you could learn about different strategies that you could use to enhance your own spaces to help reduce stress, improve physiological measures, and improve mood. The information gathered from this study will help researchers, interior designers and architects, and space industry professionals better understand the role that biophilic design plays in the cognitive and physiological measures of astronauts and those traveling in spacecraft.

Keep in mind that participating in this research study is completely voluntary and whether you decided to participate or not participate, that is completely up to you and in will not impact your grade in any way.

If you are between the ages of 18-55 & you would like to participate in a 45 min study to share insights on how design of spacecraft with and without biophilic patterns could impact space travelers' well-being and health, please let me know after class today.

Appendix B

Email Script for Recruiting Participants

E-mail Script

Hello,

You are being invited to participate in a study titled "Biophilic Interventions in Crew Quarters for Deep Space Transit Habitats to Improve Cognitive and Physiological Health Measures". The purpose of this study is to evaluate how biophilic design affects an individuals physiological and cognitive responses while in a virtual model of a spacecraft. The findings from this study will be used to recommend design choices to space industry professionals that are looking to improve the mental and physical health of their astronauts and those traveling to space. As a participant you could learn about different strategies that you could use to enhance your own spaces to help reduce stress, improve physiological measures, and improve mood. The information gathered from this study will help researchers, interior designers and architects, and space industry professionals better understand the role that biophilic design plays in the cognitive and physiological measures of astronauts and those traveling in spacecraft.

If you are between the ages of 18-55 & you would like to participate in a 45 min study to share insights on how design of spacecraft with and without biophilic patterns could impact space travelers well-being and health, please contact

Aditya Jayadas at aditya.jayadas@okstate.edu or at 405-269-8971

Audrey Firth at audrey.firth@okstate.edu 580-799-0256

Sincerely,

Dr. Jayadas

Appendix C

Flyer for Recruiting Participants

Biophilic Interventions in Crew Quarters for Deep Space Transit Habitats to Improve Cognitive and Physiological Health Measures

If you are between the ages of 18-55 & you would like to participate in a 45 min study to share insights on how design of spacecraft with and without biophilic patterns could impact space travelers well-being and health, please contact

Aditya Jayadas at aditya.jayadas@okstate.edu or at 405-269-8971

Audrey Firth at audrey.firth@okstate.edu or at 580-799-0256

Appendix D

COVID-19 Screening Questionnaire

Due to the ongoing COVID-2019 Pandemic, all participants are required to complete this form prior to participating in the study.

Have you or anyone in your household traveled outside the US in the past 2 weeks (14 days)?
YES / NO
IF YES, WHERE ______________________

Have you or anyone in your household have travelled outside
of Oklahoma in the past 2 weeks (14 days)? **YES / NO**
IF YES, WHERE ______________________

In the past 2 weeks (14 days) have you or anyone in your household had contact with any person suspected to have contracted
coronavirus (COVID-19)? **YES / NO**

Including being tested for COVID-19, & being in self-isolation for COVID-19 In the past 2 weeks (14 days) have you or anyone in your household had contact with any person confirmed to have contracted
coronavirus (COVID-19)? **YES / NO**

Have you been exposed to someone with flu-like symptoms (cough, shortness of breath or fever)? **YES / NO**

Please select YES/NO for the symptoms you are currently being experiencing.

In the last 72 hours have you experienced

FEVER (of at least 100.4 degrees or higher) **YES / NO**

COUGHING **YES / NO**

SORETHROAT **YES / NO**

DIFFICULTY BREATHING, SHORTNESS OF BREATH OR WHEEZING **YES / NO**

MUSCLE ACHES **YES / NO**

STOMACH PAINS **YES / NO**

VOMITING OR DIARRHEA **YES / NO**

PINK EYE/ RED EYES **YES / NO**

RASH **YES / NO**

FATIGUE OR FEELING UNWELL **YES / NO**

Appendix E

Pre-test Questionnaire

Screening Questions

Due to the ongoing COVID-2019 Pandemic, all participants are required to complete this form prior to participating in the study. Have you or anyone in your household traveled outside the US in the past 2 weeks (14 days)?

◯ Yes

◯ No

If yes, where?

Have you or anyone in your household have travelled outside of Oklahoma in the past 2 weeks (14 days)?

◯ Yes

◯ No

If yes, where?

In the past 2 weeks (14 days) have you or anyone in your household had contact with any person suspected to have contracted coronavirus (COVID-19)?

◯ Yes

◯ No

In the past 2 weeks (14 days) have you or anyone in your household had contact with any person confirmed to have contracted coronavirus (COVID-19)?

◯ Yes

◯ No

Have you been exposed to someone with flu-like symptoms (cough, shortness of breath or fever)?

◯ Yes

◯ No

Please select YES/NO for the symptoms you are currently being experiencing. In the last 72 hours have you experienced:

	Yes	No
FEVER (of at least 100.4 degrees or higher)	◯	◯
COUGHING	◯	◯
SORETHROAT	◯	◯
MUSCLE ACHES	◯	◯
STOMACH PAINS	◯	◯
VOMITTING OR DIARRHEA	◯	◯
PINK EYE / RED EYES	◯	◯
RASH	◯	◯
FATIGUE OR FEELING UNWELL	◯	◯

	Yes	No
DIFFICULTY BREATHING, SHORTNESS OF BREATH, OR WHEEZING	◯	◯

Are you at least 18 years of age or older?

◯ Yes

◯ No

Have you ever used virtual reality before?

◯ Yes

◯ No

If yes, do you get dizzy while using virtual reality?

◯ Yes

◯ No

◯ N/A- Have not used virtual reality before

Do you have any vision issues that may prevent you from using virtual reality or looking at a computer screen while answering questions?

◯ Yes

◯ No

Do you have any hearing issues that may prevent you from following verbal instructions or answering questions?

◯ Yes

◯ No

Do you have any physiological issues that may prevent you from having a normal heart rate (Heart murmur, arrhythmia, etc.)?

◯ Yes

◯ No

Do you have any cognitive issues or disabilities that may prevent you from following basic verbal instructions?

◯ Yes

◯ No

Consent Form

Consent Form

You are being invited to participate in a research study titled, “Biophilic Interventions in Crew Quarters for Deep Space Transit Habitats to Improve Cognitive and Physiological Health Measures.” This study is being led by Audrey Firth, a graduate student in the Design, Housing, and Merchandising department at Oklahoma State University. The Faculty Mentor for this study is Dr. Aditya Jayadas, who is an Associate Professor in the Department of Design, Housing, and Merchandising at Oklahoma State University.

What the Study Is About

The purpose of this study is to evaluate how biophilic design affects an individuals physiological and cognitive responses while in a virtual model of a crew quarter on a spacecraft. The findings from this study will be used to recommend design choices to space industry professionals that are looking to improve the mental and physical health of their astronauts and those traveling to space.

What We Will Ask You to Do

The researcher will ask you to digitally explore two different spaces using virtual reality and carry out specific tasks. These tasks may include looking outside a window, finding and identifying a specific object, reading text on a computer screen, etc. While in these spaces, you are encouraged to "think aloud", meaning that you verbalize anything that comes into your mind as you are exploring the environments. You will be asked to wear a non-invasive device that monitors your heart rate and skin conductance. After experiencing each crew quarter virtually, you will be asked to complete a brief survey about your experience. The virtual experiences will be audio recorded if you consent. In total, the study is expected to take approximately 45 minutes.

Risks and Discomforts

There will not be any major health risks to you from participating in this research study. However, some participants may experience dizziness when using virtual reality headsets. If you do experience any discomfort when wearing the headset, please let me know immediately and we can stop the experiment.

What Steps Are Being Taken to Reduce Risk of Coronavirus Infection?

The researcher has been fully vaccinated and will wear a mask and follow all local, federal and state guidelines regarding COVID-19. The following steps are being taken to address the risk of coronavirus infection:

Screening: Researchers and participants who show potential symptoms of COVID-19 (fever of 100.4 degree or higher, cough, shortness of breath, etc.) will NOT participate in this study at this time.

Physical distancing: Whenever possible, we will maintain at least 6 feet of distance between persons while conducting the study.

Mask/Covering: Researcher will wear and participants will be advised to shield their mouth and nose with a cloth face cover or mask during the study, even when maintaining at least 6 feet of distance. Tissues will be available to cover coughs and sneezes.

Handwashing: Researchers and participants will wash hands before/during the IAQ activity or use a hand sanitizer containing at least 60% alcohol.

Disinfecting materials: When feasible, researchers will clean and disinfect surfaces between participants, using an EPA-registered disinfectant or a bleach solution (5 tablespoons of regular bleach per gallon of water) for hard materials and by laundering soft materials. Disinfected materials will be handled using gloves, paper towel, plastic wrap or storage bags to reduce the chance of re-contamination of materials.

Benefits As a Participant

You could learn about different strategies that you could use to enhance your own spaces to help reduce stress, improve physiological measures, and improve mood. The information gathered from this study will help researchers, interior designers and architects, and space industry professionals better understand the role that biophilic design plays in the cognitive and physiological measures of astronauts and those traveling in spacecraft.

Compensation for Participation

There is no monetary compensation for participation in this study.

Audio Recording

Audio recording is necessary for the think aloud protocol portion of this study so I can go back and re-listen to your responses. The recording will not be released to anyone and the research team (Dr. Aditya Jayadas and Audrey Firth) will be the only individuals with access to it. The recording will be deleted after approximately one (1) months (December 1st, 2021) after the data has been transcribed.

Privacy/Confidentiality/Data Security

To protect your identity, your name will not be used in any presentation or publications of this study. No identifiable information (e.g. your name, major, school) will be used in any presentations or publications of this study. Your age, gender, and ethnicity may be used. The research team will be the only individuals with access to any information you give to the researcher, and only non-identifiable information (e.g. your age, gender, heart rate) will be used in presentations or publications of this study.

Please note that the surveys are being conducted with the help of Qualtrics, a company not affiliated with Oklahoma State University and with its own privacy and security policies. The research team works to ensure confidentiality to the degree permitted by technology. It is possible, although unlikely, that unauthorized individuals could gain access to your responses because you are responding online. However, your participation in this online survey involves risks similar to a person's everyday use of the internet. If you have concerns, you should consult the survey provider privacy policy at https://www.qualtrics.com/privacy-statement/.

No identifiable information will be included in the surveys, participants will be given unique codes to act as an identifier. We anticipate that your participation in this survey presents no greater risk than everyday use of the internet. The information you give in the study will be stored anonymously. This means that your name will not be collected or linked to the data in any way. For the audio data, the transcribed audio data will prevent anyone from recognizing the voice of a participant.

Taking Part is Voluntary

Your participation in this study is completely voluntary. If at any time you do not want to complete an action, you will not be negatively affected. You have the right to skip any questions or procedures that make you feel uncomfortable. If you decide to conclude your participation in this study before it is completed, you will not be negatively affected in any way.

Contacts and Questions

The Institutional Review Board (IRB) for the protection of human research participants at Oklahoma State University has reviewed and approved this study. If you have questions about the research study itself, please contact the Principal Investigator at 580-799-0256 or audrey.firth@okstate.edu. If you have questions about your rights as a research volunteer or would simply like to speak with someone other than the research team about concerns regarding this study, please contact the IRB at (405) 744-3377 or irb@okstate.edu. All reports or correspondence will be kept confidential.

Statement of Consent

I have read the above information. I understand that my actions in this study will be audio recorded. I have had the opportunity to ask questions and have my questions answered. I consent to participate in the study.

If you agree to participate in this research, please complete the question below.

If you agree to participate in this research, please complete the question below:

◯ Yes, I agree to participate in this research

◯ No, I do not agree to participate in this reseach

Demographics Survey

What is your participant ID:

What is your age (in years)?

What is your gender?

- ◯ Male
- ◯ Female
- ◯ Non-binary / third gender
- ◯ Prefer not to say

What is your ethnicity?

- ◯ Caucasian
- ◯ African-American
- ◯ Latino or Hispanic
- ◯ Asian
- ◯ Native American
- ◯ Native Hawaiian or Pacific Islander
- ◯ Two or More
- ◯ Other
- ◯ Prefer not to say

What is your major (interior design, merchandising, etc.)?

How familiar are you with the term "biophilic design"?

- ◯ Not familiar at all
- ◯ Slightly familiar
- ◯ Moderately familiar
- ◯ Very familiar
- ◯ Extremely familiar

How familiar are you with the virtual reality experience?

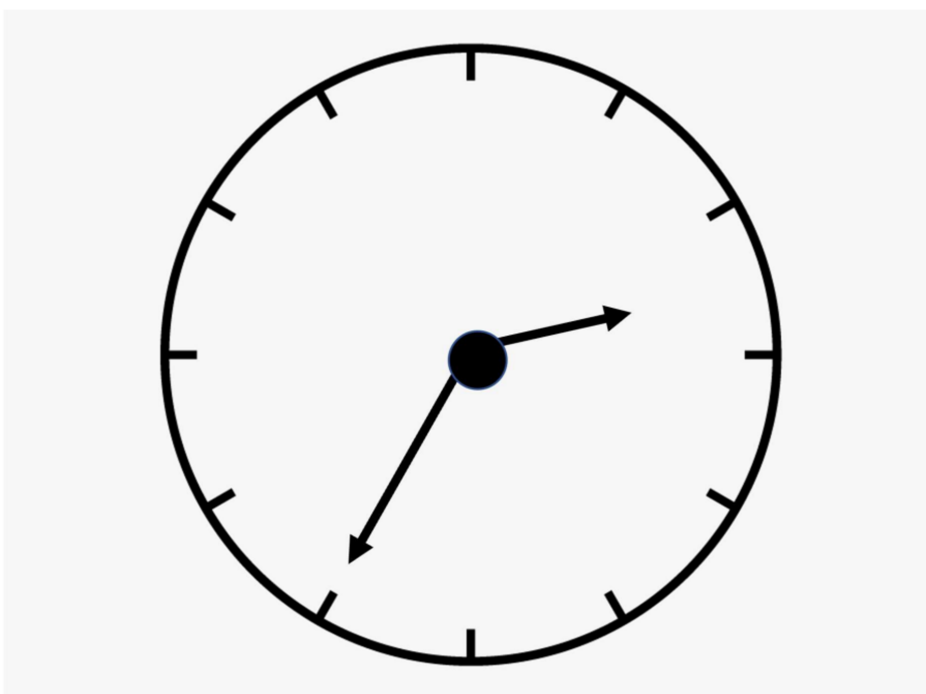
- ◯ Not familiar at all
- ◯ Slightly familiar
- ◯ Moderately familiar
- ◯ Very familiar
- ◯ Extremely familiar

Appendix F

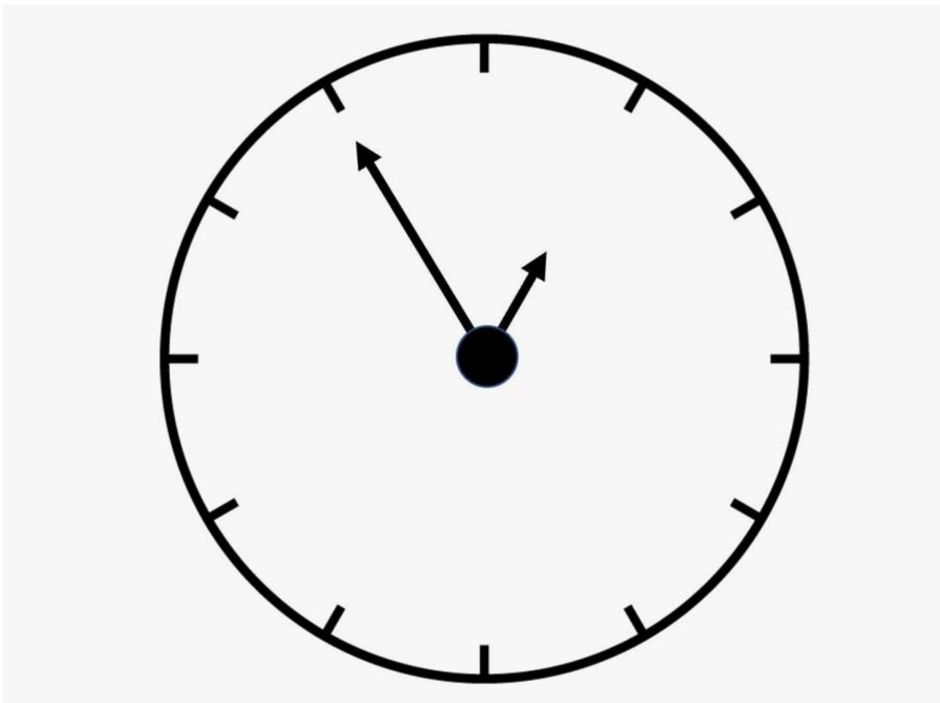
Post-Test Questionnaire for Non-Biophilic Environment

Default Question Block

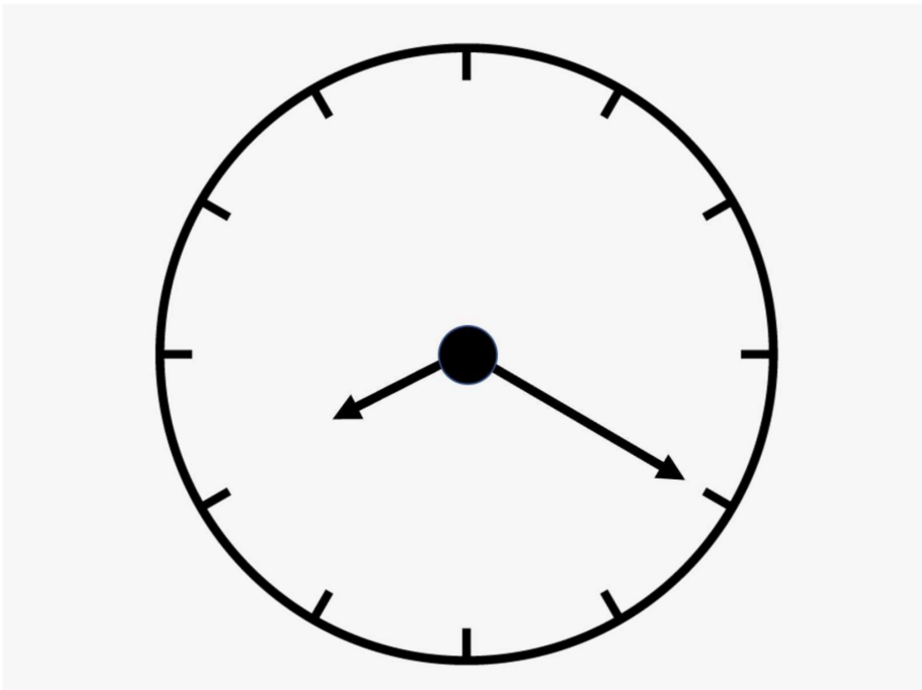
Enter your participant ID:



What is the time on the clock (ex. 00:00) ?

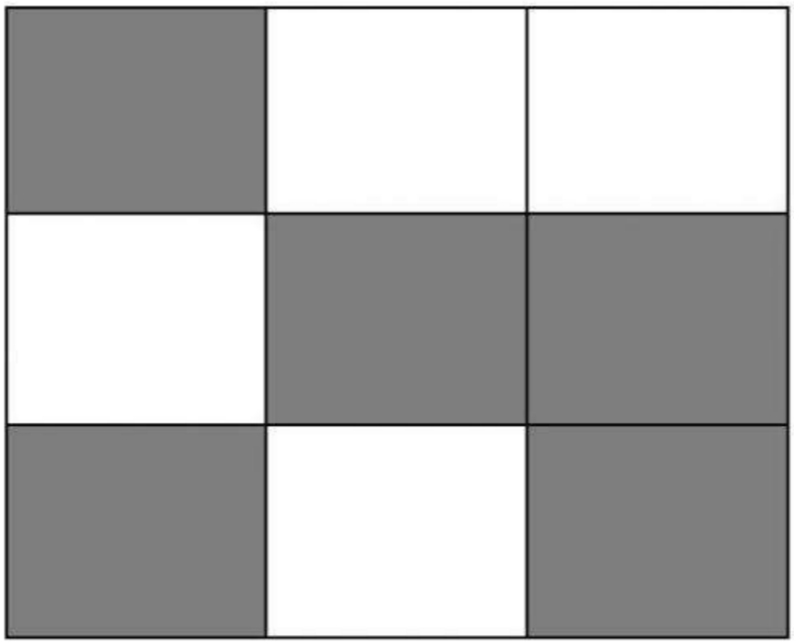


What is the time on the clock (ex. 00:00) ?



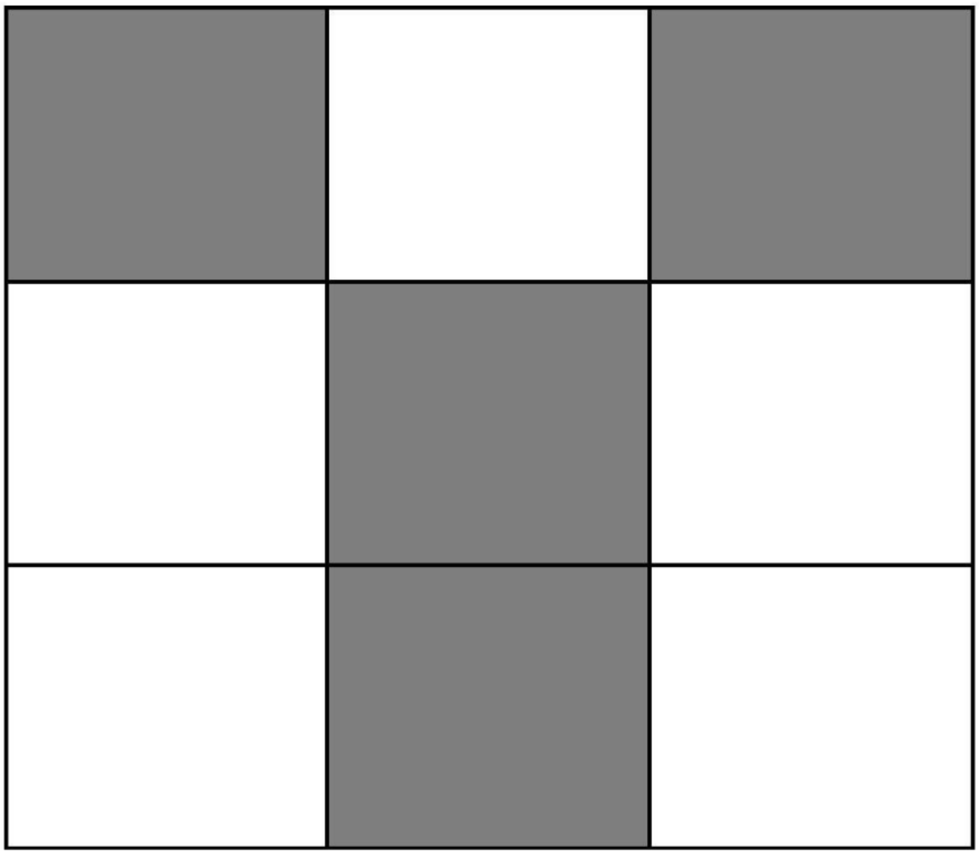
What is the time on the clock (ex. 00:00) ?

The next three questions will be timed. You will be briefly presented with a 3x3 block matrix where three to five squares will be shaded in. On the next page, you will indicate which blocks contained the illuminated squares by selecting the corresponding numbers. The images below are an example of the format of the questions. In the example below, the corresponding sections are 1, 5, 6, 7, and 9.



1	2	3
4	5	6
7	8	9

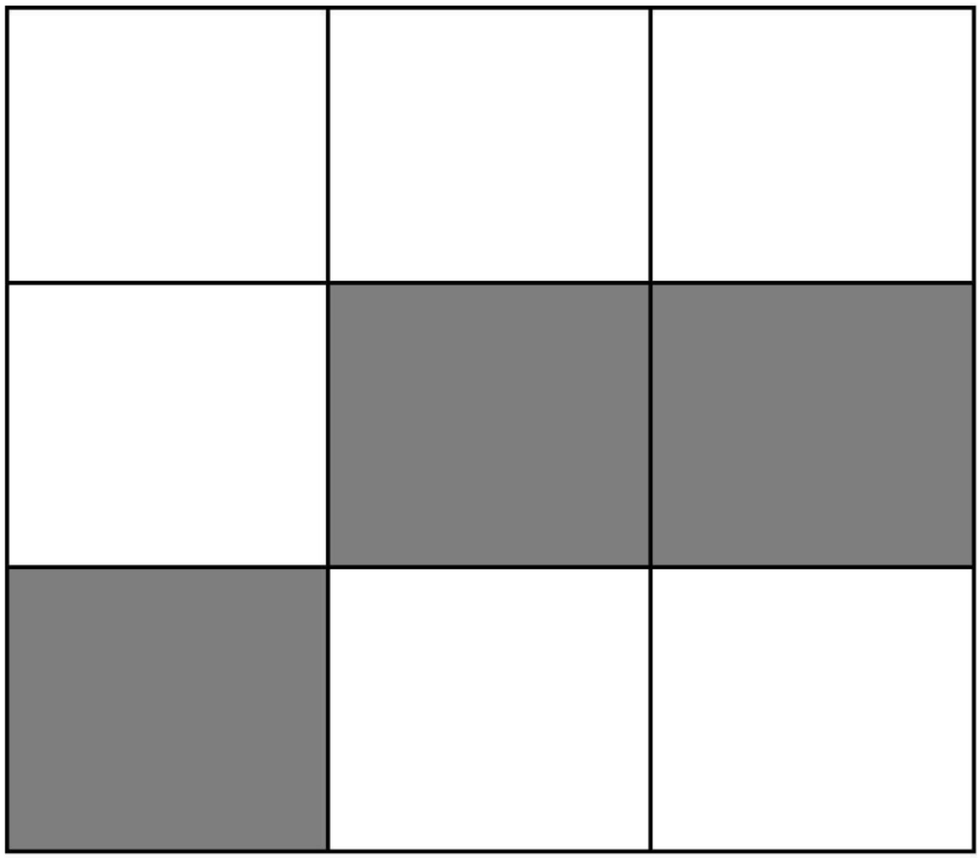
When you are ready to begin, please click the next button.



1	2	3
4	5	6
7	8	9

Please select the corresponding squares that were shaded in on the previous screen (Select all that apply)

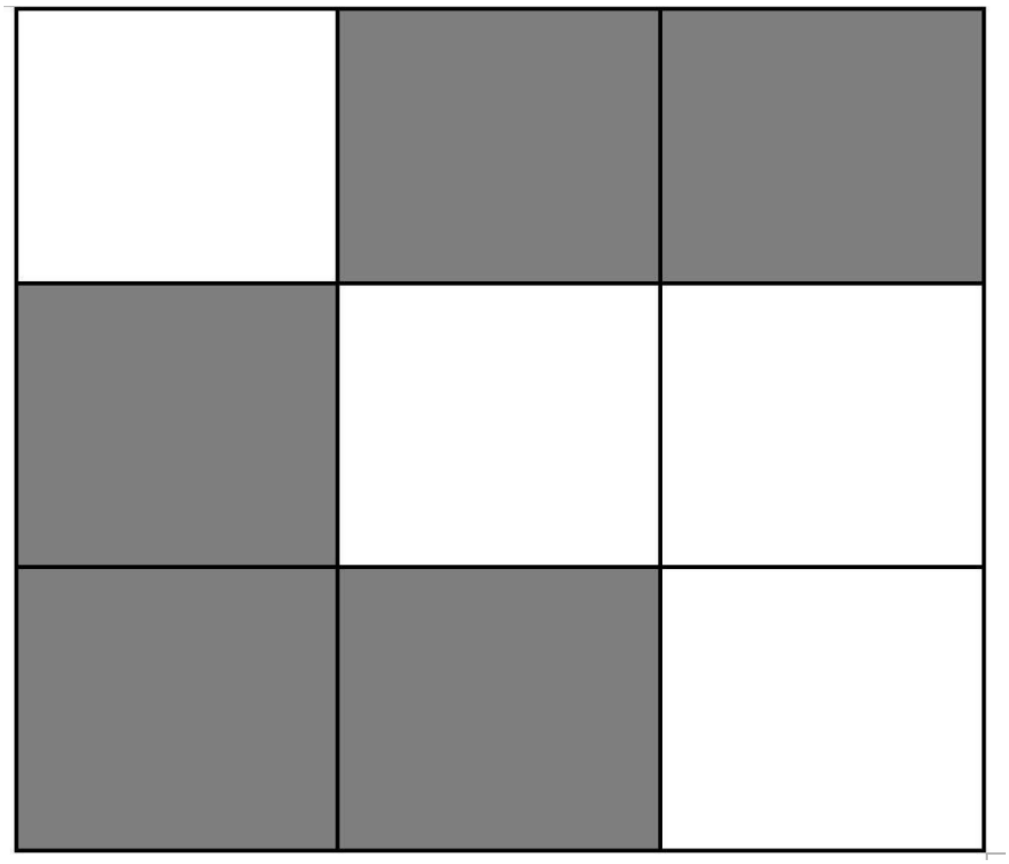
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9



1	2	3
4	5	6
7	8	9

Please select the corresponding squares that were shaded in on the previous screen (Select all that apply)

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9



1	2	3
4	5	6
7	8	9

Please select the corresponding squares that were shaded in on the previous screen (Select all that apply)

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9

What color was the sleeping bag?

◯ White
◯ Green
◯ Brown
◯ Blue
◯ Other

What was the name of the street on the return address of the envelope?

What material were the walls?

◯ Fabric
◯ Plastic
◯ Wood
◯ Paint

What did the text on the computer say that the researcher asked you to read?

Where was the children's drawing of a rocket located?

◯ On the wall near the doors
◯ Above the computer on the right
◯ Above the computer on the left
◯ On the wall to the right of the computers

Where was the iPad located?

- ◯ On the wall near the doors
- ◯ Above the computer on the right
- ◯ Above the computer on the left
- ◯ On the other wall to the right of the computers

Where were the three round patches located?

- ◯ On the wall near the doors
- ◯ Below the computer on the right
- ◯ Below the computer on the left
- ◯ On the other wall to the right of the computers

What was the color of the notebook that had a pen on top of it?

- ◯ Green
- ◯ Yellow
- ◯ Red
- ◯ Purple

Read each statement and select the appropriate response to indicate how you feel right now, that is, at this very moment. There are no right or wrong answers. Do not spend to much time on any one statement but give the answer which seems to describe your present feelings best.

1	2	3	4
Not at all	A little	Somewhat	Very much

	1	2	3	4
1. I felt calm in the space	◯	◯	◯	◯
1. I felt secure in the space	◯	◯	◯	◯
2. I felt tense in the space	◯	◯	◯	◯
3. I felt strained in the space	◯	◯	◯	◯
4. I felt at ease in the space	◯	◯	◯	◯
5. I felt upset in the space	◯	◯	◯	◯
6. I was presently worried about possible misfortunes in the space	◯	◯	◯	◯
7. I felt satisfied in the space	◯	◯	◯	◯
8. I felt frightened in the space	◯	◯	◯	◯
9. I felt uncomfortable in the space	◯	◯	◯	◯
10. I felt self-confident in the space	◯	◯	◯	◯
11. I felt nervous in the space	◯	◯	◯	◯
12. I felt jittery in the space	◯	◯	◯	◯
13. I felt indecisive in the space	◯	◯	◯	◯
14. I felt relaxed in the space	◯	◯	◯	◯
15. I felt content in the space	◯	◯	◯	◯
16. I felt worried in the space	◯	◯	◯	◯
17. I felt confused in the space	◯	◯	◯	◯
18. I felt steady in the space	◯	◯	◯	◯
19. I felt pleasant in the space	◯	◯	◯	◯
20. I would not like to spend more time in the space in the future	◯	◯	◯	◯
21. I would like to spend more time in the space in the future	◯	◯	◯	◯
22. I was satisfied with the space	◯	◯	◯	◯
23. I was dissatisfied with the space	◯	◯	◯	◯

Please answer the questions below relating to your experiences in the virtual reality environment, with 0 being very low and 100 being very high

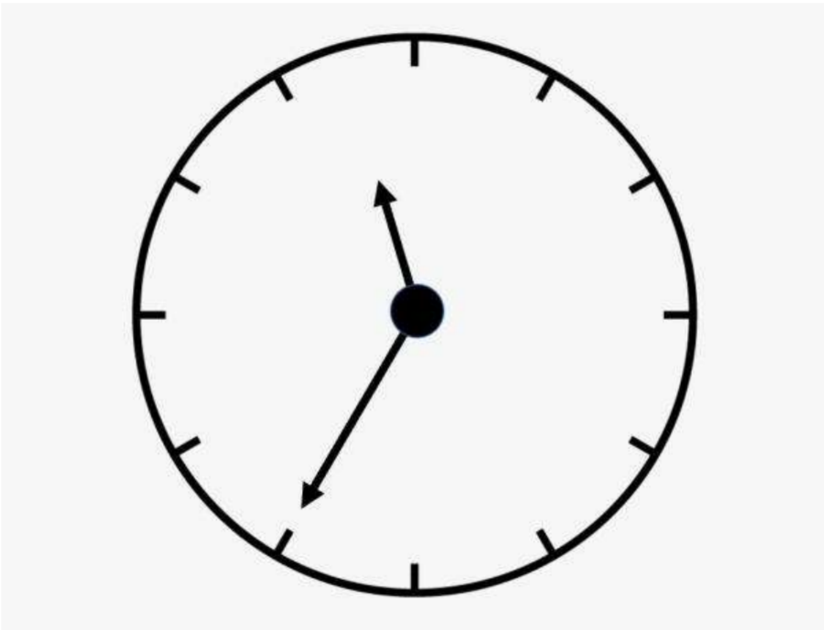
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. How mentally demanding were the tasks?																					
2. How successful were you in accomplishing what you were asked to do?																					
3. How hard did you have to work to accomplish your level of performance?																					

Appendix G

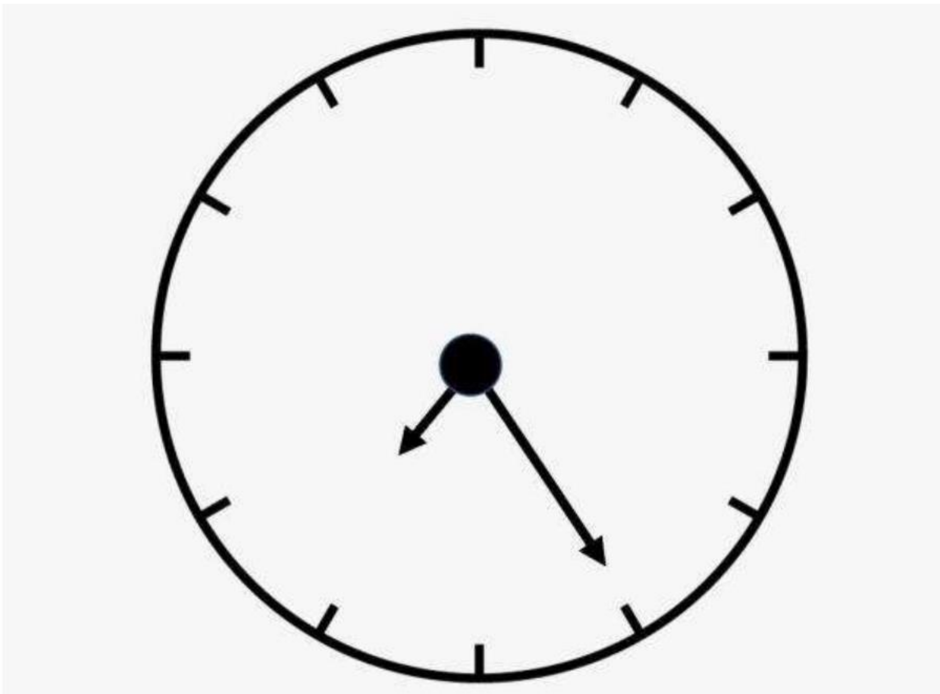
Post-Test Questionnaire for Biophilic Environment

Default Question Block

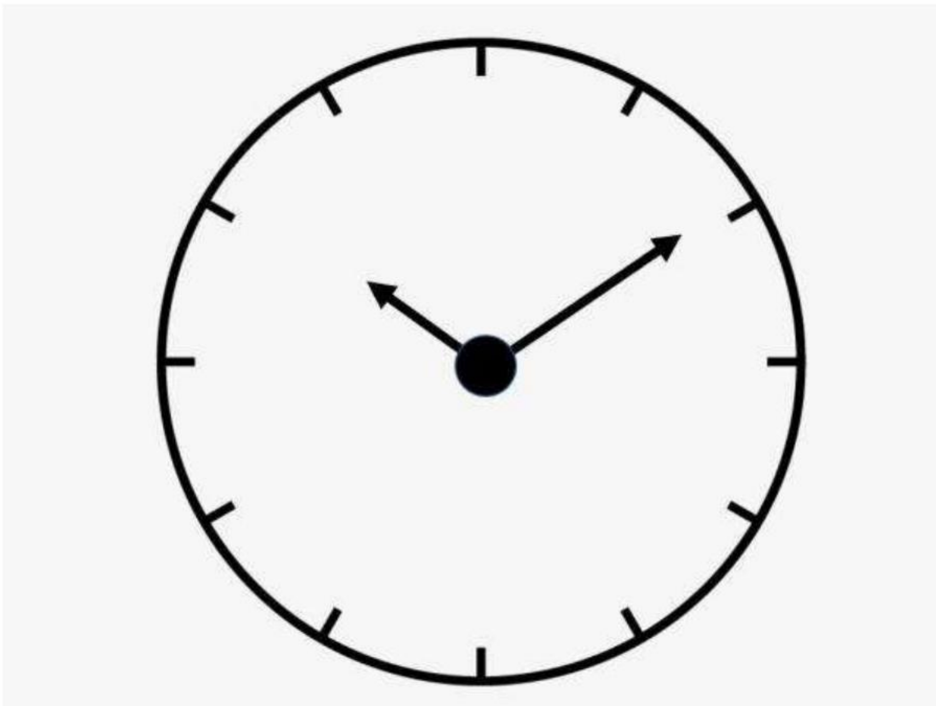
Enter your participant ID:



What is the time on the clock (ex. 00:00) ?

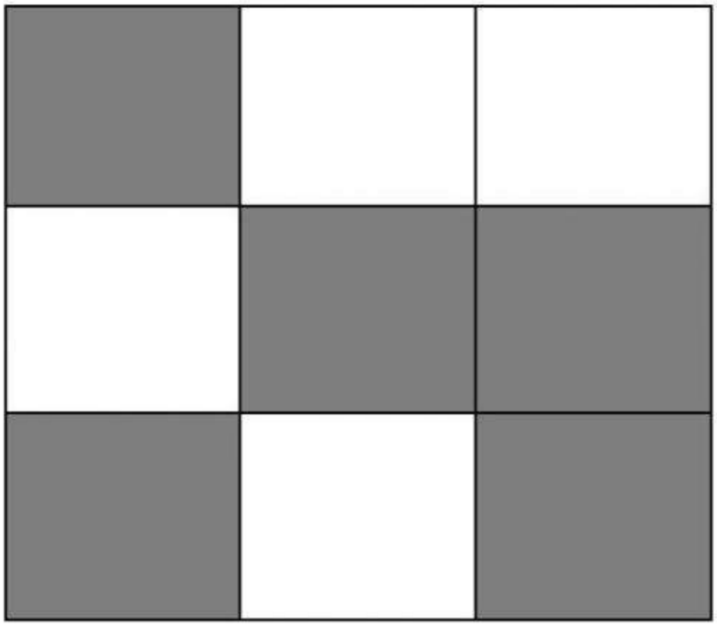


What is the time on the clock (ex. 00:00) ?



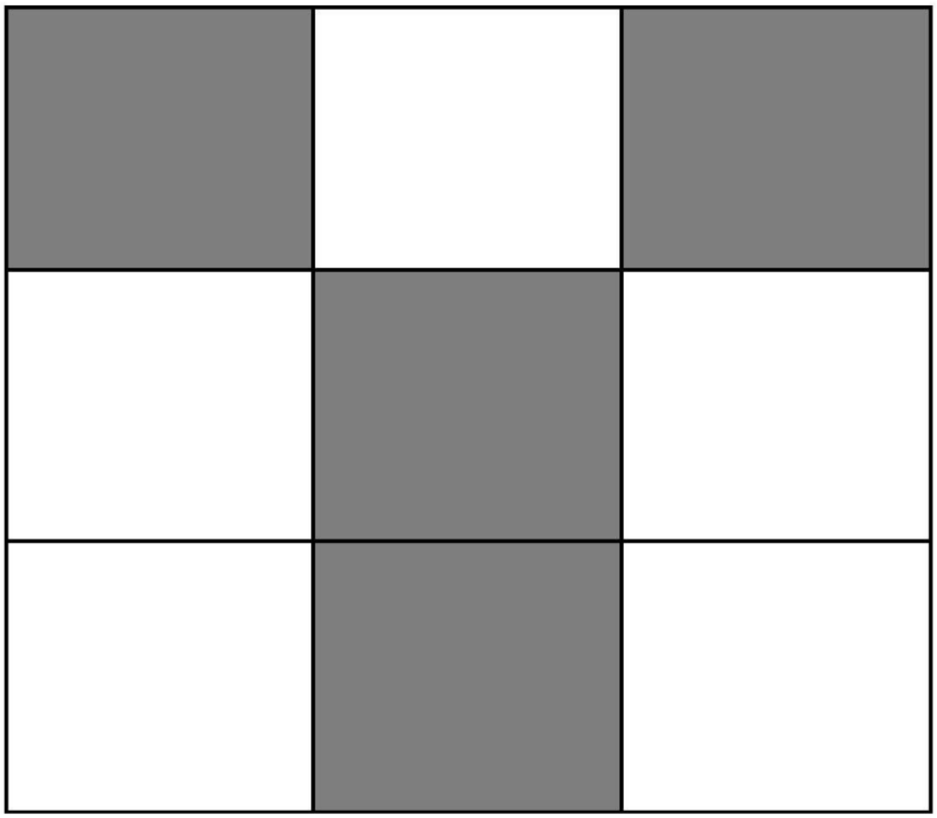
What is the time on the clock (ex. 00:00) ?

The next three questions will be timed. You will be briefly presented with a 3x3 block matrix where three to five squares will be shaded in. On the next page, you will indicate which blocks contained the illuminated squares by selecting the corresponding numbers. The images below are an example of the format of the questions. In the example below, the corresponding sections are 1, 5, 6, 7, and 9.



1	2	3
4	5	6
7	8	9

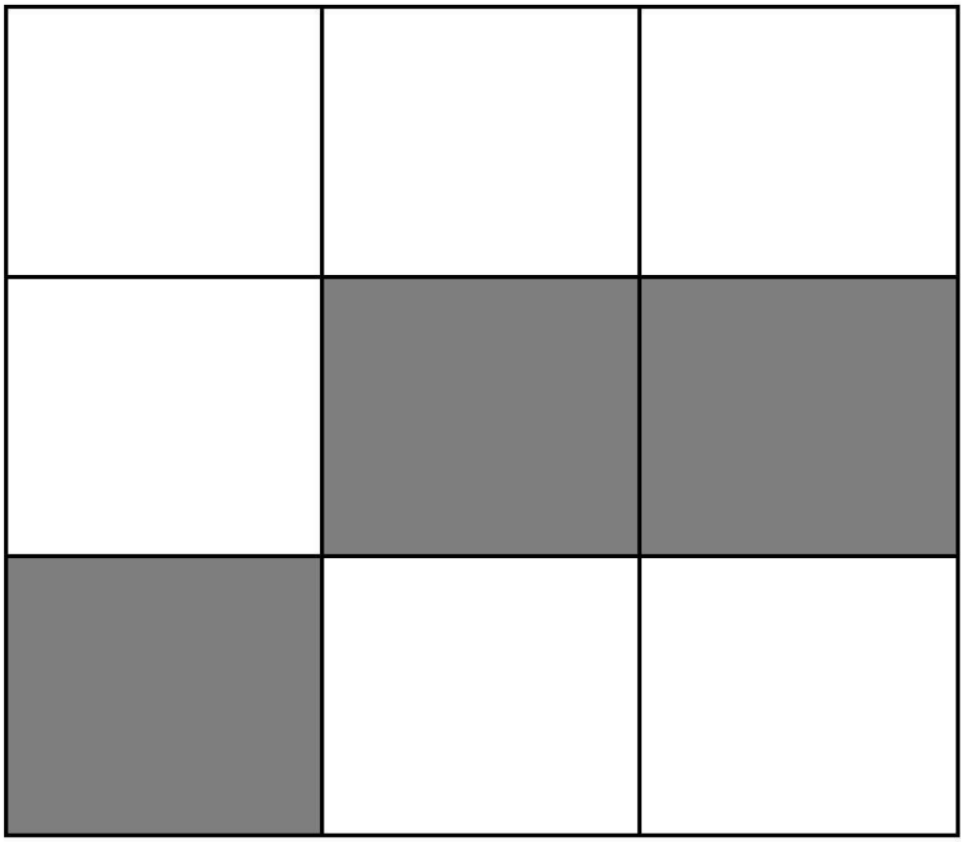
When you are ready to begin, please click the next button.



1	2	3
4	5	6
7	8	9

Please select the corresponding squares that were shaded in on the previous screen (Select all that apply)

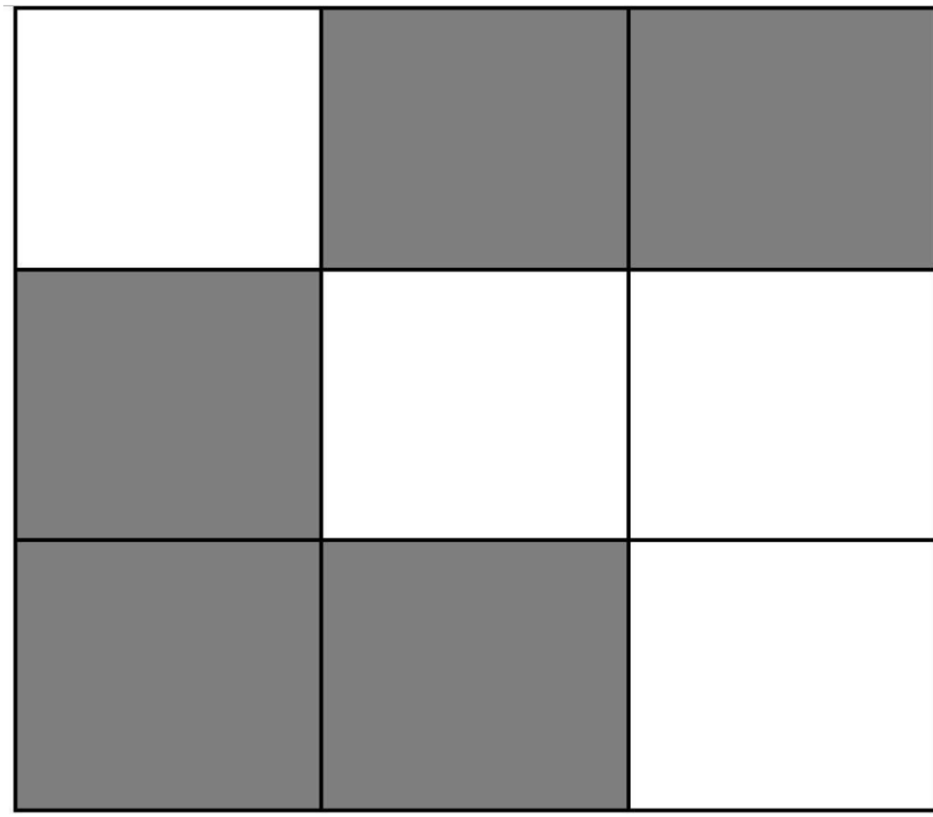
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9



1	2	3
4	5	6
7	8	9

Please select the corresponding squares that were shaded in on the previous screen (Select all that apply)

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9



1	2	3
4	5	6
7	8	9

Please select the corresponding squares that were shaded in on the previous screen (Select all that apply)

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9

What color was the sleeping bag?

◯ White
◯ Green
◯ Brown
◯ Blue
◯ Other

What was the name of the receiver on the envelope?

What material were the walls?

◯ Fabric
◯ Plastic
◯ Wood
◯ Paint

What did the text on the computer say that the researcher asked you to read?

Where was the children's drawing of a house located?

◯ On the wall near the doors
◯ Above the computer on the right
◯ Above the computer on the left
◯ On the wall to the right of the computers

Where was the iPad located?

- ◯ On the wall near the doors
- ◯ Above the computer on the right
- ◯ Below the computer on the left
- ◯ On the other wall to the right of the computers

Where were the three round patches located?

- ◯ On the wall near the doors
- ◯ Below the computer on the right
- ◯ Below the computer on the left
- ◯ On the other wall to the right of the computers

What was the background color of the paper that the researcher had you read a quote from?

- ◯ Green
- ◯ Yellow
- ◯ Red
- ◯ Purple

Read each statement and select the appropriate response to indicate how you feel right now, that is, at this very moment. There are no right or wrong answers. Do not spend to much time on any one statement but give the answer which seems to describe your present feelings best.

1	2	3	4
Not at all	A little	Somewhat	Very much

so

	1	2	3	4
1. I felt calm in the space	◯	◯	◯	◯
1. I felt secure in the space	◯	◯	◯	◯
2. I felt tense in the space	◯	◯	◯	◯
3. I felt strained in the space	◯	◯	◯	◯
4. I felt at ease in the space	◯	◯	◯	◯
5. I felt upset in the space	◯	◯	◯	◯
6. I was presently worried about possible misfortunes in the space	◯	◯	◯	◯
7. I felt satisfied in the space	◯	◯	◯	◯
8. I felt frightened in the space	◯	◯	◯	◯
9. I felt uncomfortable in the space	◯	◯	◯	◯
10. I felt self-confident in the space	◯	◯	◯	◯
11. I felt nervous in the space	◯	◯	◯	◯
12. I felt jittery in the space	◯	◯	◯	◯
13. I felt indecisive in the space	◯	◯	◯	◯
14. I felt relaxed in the space	◯	◯	◯	◯
15. I felt content in the space	◯	◯	◯	◯
16. I felt worried in the space	◯	◯	◯	◯
17. I felt confused in the space	◯	◯	◯	◯
18. I felt steady in the space	◯	◯	◯	◯
19. I felt pleasant in the space	◯	◯	◯	◯
20. I would not like to spend more time in the space in the future	◯	◯	◯	◯
21. I would like to spend more time in the space in the future	◯	◯	◯	◯
22. I was satisfied with the space	◯	◯	◯	◯
23. I was dissatisfied with the space	◯	◯	◯	◯

Please answer the questions below relating to your experiences in the virtual reality environment, with 0 being very low and 100 being very high

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. How mentally demanding were the tasks?																					
2. How successful were you in accomplishing what you were asked to do?																					
3. How hard did you have to work to accomplish your level of performance?																					

Appendix H

Proof of IRB Approval

Firth, Audrey

From:	IRB Office <irb@okstate.edu>
Sent:	Thursday, September 16, 2021 9:13 AM
To:	Firth, Audrey; Firth, Audrey; Jayadas, Aditya
Subject:	Approval of Expedited IRB Application IRB-21-379

Dear Audrey Firth,

The Oklahoma State University Institutional Review Board (IRB) has approved the following application:

Application Number: IRB-21-379
PI: Audrey Firth
Title: Biophilic Interventions in Crew Quarters for Deep Space Transit Habitats to Improve Cognitive and Physiological Health Measures.
Review Level: Expedited

You will find a copy of your Approval Letter in IRBManager. Click IRB - Initial Submission to go directly to the event page. Please click attachments in the upper left of the screen. The approval letter is under "Generated Docs." Stamped recruitment and consent documents can also be found in this location under "Attachments". Only the approved versions of these documents may be used during the conduct of your research.

As Principal Investigator, it is your responsibility to do the following:

- Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted for IRB approval before implementation.
- Submit a request for continuation if the study extends beyond the approval period.
- Report any adverse events to the IRB within 5 days. Adverse events are those which are unanticipated and impact the subjects during the course of the research; and
- Notify the IRB office when your research project is complete by submitting a closure form via IRBManager.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact the IRB office at 405-744-3377 or irb@okstate.edu.

Best of luck with your research,

Sincerely,

Dawnett Watkins, CIP
Beth Weichold, MS

Oklahoma State University
Institutional Review Board
Office of University Research Compliance
223 Scott Hall, Stillwater, OK 74078
Website: https://irb.okstate.edu/
Ph: 405-744-3377 | Fax: 405-744-4335| irb@okstate.edu

VITA

Audrey Firth

Candidate for the Degree of

Master of Science

Thesis: INTERVENTIONS IN CREW QUARTERS FOR DEEP SPACE TRANSIT HABITATS TO IMPROVE COGNITIVE AND PHYSIOLOGICAL HEALTH MEASURES

Major Field: Design, Housing & Merchandising

Biographical:

Education:

Completed the requirements for the Master of Science in Design, Housing & Merchandising at Oklahoma State University, Stillwater, Oklahoma in May 2022.

Completed the requirements for the Bachelor of Science in Design, Housing & Merchandising at Oklahoma State University, Stillwater, Oklahoma in May 2020.

Experience: Interior Design Intern in Aviation Studio at Corgan Associates in Dallas, Texas for June 2020- July 2020, and June 2019-July 2019. Interior Design Intern at Rees Associates in Oklahoma City, Oklahoma for November 2019-January 2020. Graduate Teaching and Research Assistant in Department of Design, Housing & Merchandising for Oklahoma State University in Stillwater, Oklahoma for August 2020-May 2022.