UNDERSTANDING THE EFFECTS OF BIOPHILIC DESIGN IN HEALTHCARE ENVIRONMENTS THROUGH THE USE OF VIRTUAL REALITY

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UNDERSTANDING THE EFFECTS OF BIOPHILIC

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THROUGH THE USE OF VIRTUAL REALITY

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Title of Study: UNDERSTANDING THE EFFECTS OF BIOPHILIC DESIGN IN HEALTHCARE ENVIRONMENTS THROUGH THE USE OF VIRTUAL REALITY

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Abstract: Biophilic Design encourages the use of natural systems and processes within the design of a built environment. The biophilic hypothesis stems from the belief that humans have an innate connection with the natural world and having exposure to the natural world is essential for human wellbeing. It helps explain why a view to nature can enhance our ability to deal with stress and why plants can reduce our fatigue. Research has shown that biophilic design can impact an individual's health and well-being in a variety of ways. Studies have identified that the majority of patients exposed to direct nature and natural patterns reported experiencing less stress and increased coping ability. Despite the emergence in popularity of Biophilic Design research, there is still little research on its overall impact on cognitive load in healthcare environments. In this study we explored how Biophilic Design effected participants' stress levels after being exposed to an immersive image of a virtual healthcare environment. Eye-tracking together with physiological monitors that measured heart rate and skin conductance levels were used to analyze participants stress responses after randomly being selected to experience one of three virtual environments (VE). We hypothesized that exposure to the VEs with biophilic design would result in lower stress levels in patients. In order to test this, we recruited 60 participants to participate in a between-group study using VR. Participants were randomly assigned to experience one of three virtual healthcare settings and had their physiological indicators measured as they experience the space. Finally, participants were asked to fill out questionnaires regarding their stress, pleasure and arousal, and satisfaction levels. Eye-tracking paired with physiological indicators will allow researchers to measure cognitive load and fixation in participants. Researchers did not find significant differences among participants cognitive load ($p = .745$), but they did however find significant differences in participants moods between the three conditions. Going forward, this study could have implications for not only patients but healthcare professionals in their place of work.

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CHAPTER I

INTRODUCTION

According to McGee and Marshall-Baker, Americans are separated from the natural environment now more than any time throughout history with an average of 93% of life being spent inside (McGee & Marshall-Baker, 2015). Despite the emergence in popularity of biophilic design research, there is still little research on its impact on cognitive load in healthcare environments. Biophilia has been increasingly gaining more attention in research, but there are mixed feelings regarding the inclusion of biophilic design within healthcare environments and whether people find it comforting. Additional research on this subject could influence the way healthcare environments are designed in new ways that improves patient satisfaction. The purpose of this study is to investigate the impact Biophilic Design has on patient stress levels within healthcare environments.

1. CRITICAL NEED

There is a critical need for the inclusion of Biophilic elements within healthcare environments so that patients' well-being both physically and mentally can positively increase. Additional research on this subject could influence the way that healthcare spaces are designed in new ways that improves patient satisfaction. Not only can the inclusion of biophilic elements increase the patient experience, but it has also been proven to increase the satisfaction among healthcare employees and visitors (Totaforti, 2018).

Research on biophilic design in healthcare will have a further impact on the design of these spaces and make people more aware of the positive impacts biophilia can have on individuals. Functionality is and will always be valued over aesthetics within healthcare design, but there is a way to incorporate aesthetics while ensuring functionality (Totaforti, 2018). The problem is that while only focusing on functionality for those who are working in the space, it unintentionally has caused negative impacts on mental and physical health of patients. The objective of this study is to further research the impacts of biophilic design within healthcare environments through the use of virtual reality and determine its impacts on stress levels in patients.

Virtual Reality (VR) allows for researchers to alter environments that would be costly to do so in the real world. Utilizing VR provides participants an immersive experience and has been used to detect the effects of virtual environments on stress reduction and cognitive functioning (Yin et al., 2019). A study looking at the difference between VR and a physical environment found that participants have the same physiological and cognitive responses in a virtual indoor environment as if they were within the real physical environment (Yin et al., 2018). Virtual reality environments allow designers to explore design ideas and assist them with the development of concepts (Yu & Gero, 2017).

2. SPECIFIC AIMS

This study focused on four specific aims by looking at participants stress responses such as heart rate, skin conductance, fixation, etc. These aims were:

- **Specific aim 1**: Determine if the virtual biophilic healthcare environments will result in increased satisfaction among participants compared to the virtual healthcare environment with no biophilia.
- **Specific aim 2**: Determine if the virtual biophilic healthcare environments will result in reduced stress among participants compared to the virtual healthcare environment with no biophilia.
- **Specific aim 3**: Determine if the virtual biophilic healthcare environments will result in reduced cognitive load among participants compared to the virtual healthcare environment with no biophilia.
- **Specific aim 4**: Determine if the virtual biophilic healthcare environments will result in an increased feeling of pleasure and arousal among participants compared to the virtual healthcare environment with no biophilia.

3. SIGNIFICANCE OF STUDY

With the majority of our time being spent indoors, there is no question that the inclusion of biophilia is important (Ulrich et al., 1991 & Kaplan, 1995). How and where we incorporate it is still being studied. Overall, the inclusion of biophilic elements within interior environments has been thoroughly studied, but when it comes to biophilia in healthcare, more research is needed on its impacts on cognitive load in patients. Many of us have and will experience a time where we are in a hospital, whether we are the patient or visiting one. Experiences associated with hospitals can be stressful and sometimes traumatic. The combination of interior design strategies such as the inclusion of biophilia and evidence-based design can enhance the health, safety, and welfare of patients during their stay. More research on biophilic interventions within healthcare could impact how these spaces are designed in the future to further enhance experiences of everyone interacting with the space.

4. PROBLEM STATEMENT

The problem statement of this study is that despite the emergence in popularity of Biophilic design research, more research is needed on its impact on patient's cognitive load in healthcare environments.

5. METHODOLOGY

A between-group experiment was conducted to explore the effect of biophilia on stress, pleasure and arousal, satisfaction, and cognitive load. Participants were randomly assigned to one of three virtual healthcare environments: no biophilia, a single biophilic element, and a combination of biophilic elements. During participants exposure to the virtual healthcare environment, a VIVE Pro Eye eye-tracking headset recorded their pupil dilation and fixation. Along with the eye-tracking data, their skin conductance levels, and heart rate were also being recorded. Following their exposure, participants completed the NASA TLX, stress level questionnaire, self-assessment manikin questionnaire, and a satisfaction questionnaire.

6. SCOPE

Research regarding biophilic design in healthcare could have implications for any type of person that interacts with healthcare environments but for this project, the impacts of biophilic design was investigated from the patient perspective.

7. DEFINITION OF TERMS

Biophilia: the inherent human inclination to affiliate with nature that even in the modern world continues to be a critical to our physical and mental wellbeing (Kellert & Calabrese, 2015).

Biophilic Design: seeks to create good habitat for individuals as a biological organism in the modern build environment that enhances individuals health and wellbeing (Kellert & Calabrese, 2015).

Evidence Based Design: the process of building/designing a built environment based on research/evidence.

Eye Tracking: recording and studying the eye movements on visual stimuli

Cognitive Load (CL): the amount of mental effort involved when an individual is using their working memory.

Fixation: when the eyes stop scanning the stimuli and hold the vision in a certain place

Attention Restoration Theory (ART): argues that people can concentrate better after viewing nature or physically spending time in nature

Stress Recovery Theory (SRT): a theory that proposes natural environments help with stress recovery

CHAPTER II

REVIEW OF LITERATURE

1. INTRODUCTION TO BIOPHILIC DESIGN

Biophilia is a concept coined by American ecologist Edward O. Wilson in the 1980s (Krčmářová, 2009). The biophilic hypothesis stems from the belief that humans have an innate connection with the natural world and having exposure to the natural world is essential for human wellbeing (Gillis & Gatersleben, 2015). Therefore, the incorporation of natural features and systems within the built environment provides humans with their much-needed exposure to nature. Wilson set up a framework to support his hypothesis which included intercultural comparisons, phylogenic comparisons, and psychological methods. Studies observing biophilia, including the current study, have fallen into part of this framework that Wilson provided (Krčmářová, 2009).

Biophilic design encourages the use of natural systems and processes within the design of a built environment. There is a plethora of research from over decades that shows the impact of nature on human health and wellbeing which justifies the fact that biophilic design is indeed beneficial (Gillis & Gatersleben, 2015). Gillis and Gatersleben have proposed three biophilic design experiences: direct experience of nature, indirect experience of nature, and experience of space and place (Gillis & Gatersleben, 2015). Each of the three experiences have their own unique attributes which have their own benefits.

Healthcare design has gone through extreme changes in the last 20-30 years due to technological discoveries and new treatment protocols. Within that time frame, there have been an emergence of new hospital designs which have a relationship with nature. In return, this highlighted how there needed to be a change in the relationship between people and nature (Totaforti, 2018). However, the design of most modern hospitals to this day are still geared towards only one goal which is ensuring proper operation of all procedures such as surgical or clinical procedures, reflecting design from the past (Totaforti, 2018). Humanizing hospital spaces through nature offers positive impacts in patients psychologically while also keeping functionality in mind to ensure proper operations. When investigating the application of biophilic design in healthcare, it is important to consider that some of the attributes that fall under the different experiences may not be appropriate for the interior hospital environment. Rooms with natural ventilation, natural light, plants, natural patterns, and natural materials have been shown to have a variety of positive benefits such as the reduction of stress not only for patients, but their families and the staff working at the hospital (Totaforti, 2018). On the other hand, presence of water is a biophilic pattern that elicits a strong response in individuals as it is a basic human need, but it would not be appropriate for a hospital setting due to sanitation issues (Kellert et al., 2011). The selection of biophilic patterns for this research will be later discussed in this paper.

Biophilia can impact an individual in many different ways. A study has shown that the majority of patients and their families exposed to direct nature and natural patterns reported experiencing less stress and increased coping ability (Totaforti, 2018). It has also been found that including plants in patient rooms reduced their level of pain, anxiety, and their tiredness (Totaforti, 2018). An additional study showed that by viewing a tree, patients were positively impacted even though direct contact with nature did not occur (McGee & Marshall-Baker, 2015). Not only can biophilic design have these positive impacts on patients and their families, but employees reported higher satisfaction and experienced less negative stress revolving around their job. This could benefit hospitals economically, and the people within the interior environment physically and psychologically (McGee & Marshall-Baker, 2015).

2. BIOPHILIA

For decades, theorists have been researching which parts of biophilia impact our satisfaction the most within the built environment (Ryan et al., 2014). There are 14 different biophilic design patterns that can be split into 3 categories.

Nature in the space patterns:

1. Visual-connection with nature
2. Non-visual connection with nature
3. Non-rhythmic sensory stimuli
4. Thermal and airflow variability
5. Presence of water
6. Dynamic and diffuse light
7. Connection with natural systems (Ryan et al., 2014)

Nature in space looks at the direct and physical presence of nature within a built environment. This could be plant life, water, animals, sounds, scents, and even breezes. Strong nature in space experiences is created through direct and meaningful connections with natural elements (Ryan et al., 2014). Kellert and Calabrese found evidence that plants can translate the experience of nature indoors (Kellert & Calabrese, 2015). Responses to views of nature have been shown to reduce stress and improve recovery rates and even if people are within a windowless environment, people still seem to have these positive responses to simulated nature (Ryan et al., 2014). Non-visual sensory interactions with nature that is non-threatening has also been found to improve mental health and cognitive performance (Ryan et al., 2014).

Figure 1

Vodogray Offices – Chernivtsi

Note: Examples of nature in the space patterns: presence of water, visual connection to nature (Andrey, 2020)

Natural analogues patterns:

8. Biomorphic forms and patterns
9. Material connection with nature
10. Complexity and order (Ryan et al., 2014)

Natural analogues look at the non-living and organic depictions of nature. This could include colors, materials, objects, patterns found in nature, furniture, and décor within a built environment. Furniture that has an organic shape, mimicry of leaves, and natural materials that have been processed all provide an indirect connection to nature (Ryan et al., 2014). Natural analogues patterns such as complexity and order are characterized by rich sensory information that is organized with a spatial hierarchy which is similar to the design in nature and can reduce stress (Ryan et al., 2014).

Figure 2

The Nature Conservancy – San Francisco Offices

Note: Example of natural analogues patterns: natural materials (Rubio, 2014)

Nature of the space patterns:

11. Prospect
12. Refuge
13. Mystery
14. Risk/peril (Ryan et al., 2014)

Nature of the space looks at the spatial configuration within nature which includes our innate and learned desire to be able to see beyond our surroundings (Ryan et al., 2014). Nature of the space patterns such as prospect is a spatial condition which has a view over a distance for surveillance. Prospect combines the view of objects, habitats, horizons, and movement to create a satisfying environment (Kellert et al., 2011). Prospect can reduce stress, irritation, and fatigue (Ryan et al., 2014). Refuge showcases a structure or the natural environment's ability to provide an individual a safe and secure space (Kellert et al., 2011). Refuge and prospect are commonly used together.

Figure 3

PSLab Offices – London

Note: Example of nature of the space patterns: refuge (Gardiner, 2020)

2.1 *Justification for Selected Patterns*

In this research paper, only three specific biophilic patterns will be utilized. Those three are visual connection with nature, biomorphic forms and patterns, and material connection with nature. When selecting patterns for this project, it is important to keep in mind that certain patterns such as water, could pose sanitation risks. The patterns selected, and how they are implemented need to be easily cleanable or easily replaced. Such as plants or bleach cleanable surfaces. For this study, plants and views of nature were patterns selected because plants can be easily replaced, or artificial plants can be cleaned easily. Glass windows can also be cleaned with harsh cleaning agents without diminishing. In addition to plants, wooden flooring was selected as a natural material because there are hygienic floor covering solutions and different flooring types which can mimic wood but handle heavy traffic, fluids, and cleaning agents. Lastly, a wall covering was selected to showcase a biomorphic pattern. This was selected because it is possible to utilize a high-performance commercial wall covering which can be bleach cleanable. In addition to sanitation measures being considered, research has shown these patterns have positive impacts on individuals (Gillis & Gatersleben, 2015). These reasons will be covered in the three sections below.

2.2 *Visual Connection with Nature*

The overall experience of visual connection with nature is interacting with a space that makes you feel calm and conveys living things. Views to nature either through images or in real life have been shown to reduce stress, improve concentration, and improve emotional functioning (Ryan et al., 2014). Research has found that the preferred view of nature is looking out at a scene with shade trees, plants, non-threatening animals, and bodies of clean water. This can be difficult to achieve based on building location, and in general is hard to have all these elements within a single built environment. It has been found that simply looking at a forest scene for 20 minutes following a mental stressor can return an individual's cerebral blood flow and brain activity back to its relaxed state (Ryan et al., 2014).

Plants are sources of food, resources, and protection that can be important to human survival. Plants in the built environment can increase comfort, satisfaction, performance, and wellbeing. In addition to this, buildings that have vegetative facades or green walls are likely to provoke interest and satisfaction (Kellert et al., 2011). Plants can directly bring living nature and greenness into indoor environments. There has been little research on what qualities or plant types are most preferred, but a study showed that small green plants and ones that are lightly scented were best for health and well-being (Gillis & Gatersleben, 2015). The presence of plants can positively impact mood and reduce stress levels among building occupants. The presence of plants can also improve comfort and physical health (Kellert & Calabrese, 2015). In addition to these impacts, indoor plants can also reduce air pollution within the built environment which can be caused by numerous things such as furnishings and equipment. Clean air has been found to have a positive relationship with better mental sharpness (Gray & Birrell, 2014).

2.3 *Biomorphic Forms and Patterns*

Spaces with biomorphic forms and patterns feel comfortable to viewers and can reduce stress due to causing a shift in focus (Ryan et al., 2014). We naturally have a preference for biomorphic forms and natural elements. This is because they offer us opportunities for relaxation and restoration from stress (Joye & van den Berg, 2011). The idea of utilizing biomorphic forms and patterns is to provide design elements that allows viewers to make their own connections to nature. There are two approaches to incorporating this pattern, either through decorative components or as structural/functional design (Ryan et al., 2014). Both approaches can be used at the same time to enhance the overall experience. Botanical motifs, simulation of natural features, and biomimicry are all ways designers can include these forms and patterns into the built environment. Trees have played an important role for human life as a way of providing materials for shelter, firewood, and more (Kellert et al., 2011). When tree motifs are shown as a group, it can suggest the feeling of a forest. As mentioned previously, this has helped with mental stressor recovery.

2.4 *Material Connection to Nature*

Material connection to nature helps a space feel warm and rich. Material connection with nature helps us explore the characteristics of natural materials that influence positive physiological and cognitive responses (Ryan et al., 2014). There has recently been research to showcase the impact of natural materials on an individual's health. Wood on the walls of interior spaces has been found to enhance our physiological responses such as a reduction in blood pressure and lowered brain activity (Ryan et al., 2014). Natural materials can be either functional or decorative. An example of décor would be utilizing a natural color palette, woodwork, or through interior surfaces.

There is limited research on natural materials and how the type or number of materials can impact an individual. A study that focused on patient rooms using different amounts and layouts of wood found that an intermediate amount of wood was preferred (Gillis & Gatersleben, 2015). According to this study, an intermediate amount of wood would include the floor, one wall, and one piece of furniture with wood. In addition to this, another study positively associated wood in the built environment with reduced stress and reduced strain (Burnard & Kutnar, 2015).

3. VIRTUAL REALITY

Within various studies regarding the impacts of biophilic design, researchers have found numerous ways to effectively look at biophilia using digital media. Virtual Reality (VR) allows for researchers to manipulate environments that would be costly to do in the real world. Retrofitting is when a built environment is changed to get rid of both functional and operative problems that were discovered following the occupancy of a space (Palmon et al., 2006). This can be a very costly process but visual simulations such as VR allows designers to implement multiple modifications before spending. Users can interact with the virtual environment (VE) and move objects around and perform actions within the space (Palmon et al., 2006). Using VR can not only provide participants an immersive experience but can also used to detect the effects of specific environments on stress reduction and cognitive functioning (Yin et al., 2019). A study looking at the difference between VR and a physical environment found that participants could have the same physiological and cognitive responses in a virtual indoor environment as the actual physical environment (Yin et al., 2018). VR technology today is fully capable of simulating very realistic and complex environments. In addition to the realistic environments, head mounted displays allow realistic and real time rotation head and body movements. This visual realism provides the immersive experience that individuals need to provide realistic use responses (Kuliga et al., 2015).

3.1 *Eye-Tracking as a VR Tool*

Eye-tracking has been used in consumer behavior, design analysis, and cognitive science which allows researchers to assess users gaze and eye movements (Kim & Lee, 2020). Eye-tracking can also be used to measure the fixation in participants by looking at how long they focused on one specific element within a VE. VR has been used continuously as a learning tool and due to technological innovations, we now have cost effective, portable, and accurate head mounted displays with eye tracking integrated into them (Soler et al., 2017). Many studies have done research looking at photographs or videotapes but the use of VR mimics real world scenes more accurately by letting users manipulate their environment (Dinis et al., 2013). VR is able to simulate realistic environments which can impact participants moods. Dinis et al. (2013) found while utilizing VR to test the emotional responses of rooms with natural objects, they were able to get positive test results by using VR which will be discussed later in this paper (Dinis et al., 2013).

4. COGNITIVE LOAD

Cognitive load is the amount of mental effort involved when an individual is using their working memory. Research has shown that pupillary response is correlated with cognitive load (Palinko et al., 2010). Pupils are known to dilate when reading more complex sentences and when one is solving mathematics problem (Yu & Gero, 2017). From this, researchers can infer that the higher the cognitive load, the more dilated the pupil gets. When one is relaxed, it is possible they are not participating in an activity that requires much mental effort and that their cognitive load is low. In the current study, the researchers will test different representations of interior spaces and investigate their effects on cognitive load. Based on the findings mentioned above, it is reasonable to predict that when one enters a high stress environment, such as a crowded airport terminal, the individuals stress levels will increase due to having to exert more mental effort in navigating their way to their endpoint.

4.1 *Eye-Tracking as a Tool to Measure Cognitive Load*

Eye tracking devices help researchers assess users' visual attention and also provide physiological measurements of cognitive load (Palinko et al., 2010). On an eye tracking device, an individual's pupil dilation can be recorded, and pupil dilation could indicate a higher cognitive load. This would occur when an individual is facing a challenging cognitive task. In addition to pupil dilation, other physiological responses that have been shown to correlate with cognitive load are heart rate and skin conductance responses (Palinko et al., 2010). An eye tracking study has shown that percent change of pupil size correlated well with the mental difficulty of the task (Palinko et al., 2010). In addition to measuring pupil dilation, eye tracking devices can also measure gaze position, fixation number, fixation duration, repeat fixations, and search patterns (Ikehara & Crosby, 2005). There are three characteristics of fixation that are important: number of fixations, fixation duration, and fixation/saccade ratio (Soler et al., 2017). The higher the cognitive load, the lower the number of fixations. If the fixation time is longer, this could mean there is a high cognitive load because the user is spending more of their time processing. Lastly, higher fixation/saccade ratios mean that cognitive load within the VR is higher (Soler et al., 2017). A long fixation is considered to be >500msec and indicates that there is a possibility of deeper cognitive processing (Buettner, 2013).

4.2 *NASA TLX Questionnaire as a Tool to Measure Cognitive Load*

There are two measurements of cognitive load: objectivity and causal relation. Objectivity refers to objective versus subjective measurements. Objective measures can be observations of one's behavior or subject performance (Pachunka, 2018). However, these can be impacted by factors such as stress. Subjective measures of cognitive load reflect the assumption that participants are able to report their own processes. These could include rating scales immediately after a task is completed. A tool frequently used to measure cognitive load subjectively is the NASA Task Load Index (NASA TLX) (Hart & Staveland, 1988). The NASA TLX looks at mental demand, physical demand, temporal demand, performance, effort, and frustration and generates a workload score based on the participants ratings across the six scales (Pachunka, 2018). The NASA TLX assesses cognitive load by asking questions such as "how much mental demand and perceptual activity was required to complete the task?" and "how insecure, discouraged, irritated, stressed, and annoyed did you feel during the task?"

4.3 *Physiological Indicators as a Tool to Measure Cognitive Load*

Physiological measurements are methods that have been used to measure cognitive load and can be unobtrusive. They also allow for real time measurements to be taken without impacting the user's performance (Ikehara & Crosby, 2005). Skin conductivity (galvanic skin response) and heart rate are commonly used physiological measurements utilized when assessing cognitive load. Skin conductance has been utilized to study mental status, emotions, stress, and cognitive load. A study looking at stress and cognitive load found correlations between readings of the two physiological measurements (Nourbakhsh et al., 2012). In addition to skin conductance, heart rate measurements have also been used to measure cognitive load. When individuals perceive a situation or task as a challenge or threat, this can increase heart rate (Minkley et al., 2021). Changes in heart rate indicate responses to changes such as a mental stressor (Solhjoo et al., 2019). Because of the connections made between physiological measurements in stress and cognitive load in the literature above, it is reasonable for researchers to infer that stress and cognitive load are correlated.

Combining physiological measurements with the NASA TLX was done in this study to avoid any possible limitations of an individual's ability to assess their own cognitive load. Some may not be able to identify if they have exceeded their mental capacity (Solhjoo et al., 2019). Physiological measurements are not likely to be influenced by these limitations and are well established.

5. THEORETICAL BACKGROUND

5.1 *Stress Recovery Theory*

Stress is when an individual experiences a situation that threatens their well-being and they respond physiologically, psychologically, and often with actions (Ulrich et al., 1991). This can result in emotions such as fear and anger, responses in bodily systems such as our cardiovascular system, and decline in cognitive performance. Stress Recovery or restoration includes numerous positive changes to an individual such as reduced feelings of anger or fear and increased positive-toned affects such as arousal (Ulrich et al., 1991).

In the Stress Recovery Theory (SRT), it is claimed that individuals experience immediate positive responses which are induced by experiencing unthreatening natural settings (Joye & van den Berg, 2011). In this case, threatening natural scenes would include a dangerous animal or individual, or something that would make an individual worried about their well-being. The SRT also assumes that natural environments provide a link between restorative responses and positive effects on individuals (Joye & van den Berg, 2011). The idea proposed by this theory essentially says that we can quickly recover from stress, also known as restoration, when we are near or exposed to natural environments. The positive emotional impacts provided by viewing nature has also been applied in healthcare research focusing on patient anxiety. It was found that patients who viewed murals depicting natural scenes experienced lower heart rate and reported feeling less stress compared to days when they did not have the mural to view (Ulrich et al., 1991).

An example of the SRT could be how environments impact us physiologically and emotionally when viewing a scene that represents a challenge or threat (Hartig et al., 2003). It is proposed that certain qualities within natural scenes can support stress recovery such as natural contents that include vegetation and water. These natural scenes have been found to evoke positive emotions, aid a return of arousal, and restrict negative thoughts. Studies have shown that natural surroundings have physical and psychological restoration effects such as decline in blood pressure and an increase in overall happiness (Hartig et al., 2003).

5.2 *Attention Restoration Theory*

The Attention Restoration Theory (ART) claims that people can recover from mental fatigue by spending time in environments the provide a sense of being away, compatibility, and fascination (Rosenbaum & Camino, 2018). Natural environments such as forests contain those four properties that can promote recovery from mental fatigue. In this case mental fatigue would indicate when an individual exceeds their mental capacity, indicating a high cognitive load (Solhjoo et al., 2019). ART also posits that when individuals direct their attention to challenging/unpleasant stimuli, they can experience mental fatigue which can lead to negative experiences such as stress and depression (Rosenbaum & Camino, 2018).

Natural phenomena that give strong attention holding properties can play an important role in stress recovery and restoration. It has been argued that natural settings have restorative effects on individuals because they hold our attention without using mental effort, are pleasurable, and also block out other demands such as stress (Ulrich et al., 1991). In a research study on cancer patients, it was found that the patients experienced less fatigue after spending time in centers that had restorative properties such as greenery (Rosenbaum & Camino, 2018). In addition to this, another study showed that recovering cancer patients who recently had surgery suffered attention deficits following their procedure but those who participated in outdoor nature-based activities following their procedure showed significant improvements to their attentional performance compared to those who did not participate in the nature-based activities (Kaplan, 1995).

An example of the ART could be how when we are needing to focus our attention on something demanding, the factors of the environment that interrupt us can cause mental fatigue (Sanchez et al., 2018). Corporate offices that have incorporated nature have successfully provided calmer environments that make it easier to restore our cognitive load (Sanchez et al., 2018). How this is applied in the workplace can just as easily be applied in healthcare environments. Patients are spending most of their time in their hospital bed, focusing their attention to their healing but can be distracted by the demanding healthcare environment. If healthcare implemented interior design solutions such as biophilia, the interior environment patients experience could help them heal by restoring their mental capacity and allowing them to focus more on their healing. In other words, instead of having a high cognitive load caused by the demanding healthcare environment full of distractions, biophilic design can help patients by restoring their mental capacity, decreasing their cognitive load, and allowing them to focus on what is important, their healing.

6. APPLYING BIOPHILIA IN HEALTHCARE

6.1 *Impact on Stress*

As mentioned previously, the SRT states that natural phenomena have strong attention holding properties that play an important role in stress recovery and restoration. It has been argued that natural settings or biophilic design have restorative effects on individuals because they hold our attention without using mental effort, are pleasurable to look at, and also block out other demands such as stress (Ulrich et al., 1991). According to Park and Mattson (2008), patients in hospital rooms with plants and flowers had more positive physiological responses such as lower blood pressure and heart rate. They also experienced less pain, less anxiety, higher satisfaction and increased mood. Patients had stated that the plants had made them feel more relaxed. The inclusion of plants increased satisfaction and decreased anxiety among patients (Park & Mattson, 2008). Patients who have exposure to natural lighting experience improvements in their physiological and psychological states such as reduced stress and anxiety (Alzoubi, 2015).

6.2 *Impact on Cognitive Load*

The ART and the SRT provide explanations for the cognitive effects of biophilia as well. A study has shown that exposure to images of urban environments compared to natural environments required a higher number of cognitive resources (Burtan et al., 2021). Using a higher number of cognitive resources could indicate a higher cognitive load because more mental effort is being used. A different study looking at the effects of biophilic regeneration pods within a workplace were able to find that employees who took breaks in the biophilic regeneration pods experienced lower perceived workload which in return lowered their perceived stress (Roskams & Haynes, 2020). In both of these studies, researchers were able to find the restorative effects biophilia has on an individual's cognitive load and how exposure to a natural environment can have positive impacts on stress and perceived workload. Sanchez et al., (2018) assessed subjective workload among three different spaces and found that workload sensation was significantly lower when both daylight and greenery was present compared to the other two spaces: no daylight and no greenery, no daylight and greenery (Sanchez et al., 2018). This shows the direct impact biophilia can have on our cognitive load when conducting tasks within our built environment.

6.3 *Impact on Mood*

Both the patient experience and patient satisfaction have become increasingly crucial in healthcare as perceptions of care have become important in the outcomes of patients (Wichrowski et al., 2021). A study that added greenery to a workspace and later assessed the satisfaction among its workers found that 73% of the people who took the survey claimed to be satisfied or extremely satisfied (Sanchez et al., 2018). Rehab patients experienced an increase in satisfaction when there were plants added to the rehabilitation center's common space and views of nature have also increased patient satisfaction (Wichrowski et al., 2021). Wichrowski et al., (2021) conducted a study in which they explored the effects of biophilic imagery in hospital rooms and assessed patient satisfaction. They found that the presence of biophilic nature scenes within the physical rehabilitation rooms positively impacted the patients' ratings of the space and satisfaction (Wichrowski et al., 2021). Lee (2019) conducted a study in which they assessed pleasure and arousal of a biophilic hotel lobby. They found that the presence of plants resulted in higher levels of pleasure and arousal. In addition to this, having natural lighting in the lobby also increased pleasure and arousal (Lee, 2019).

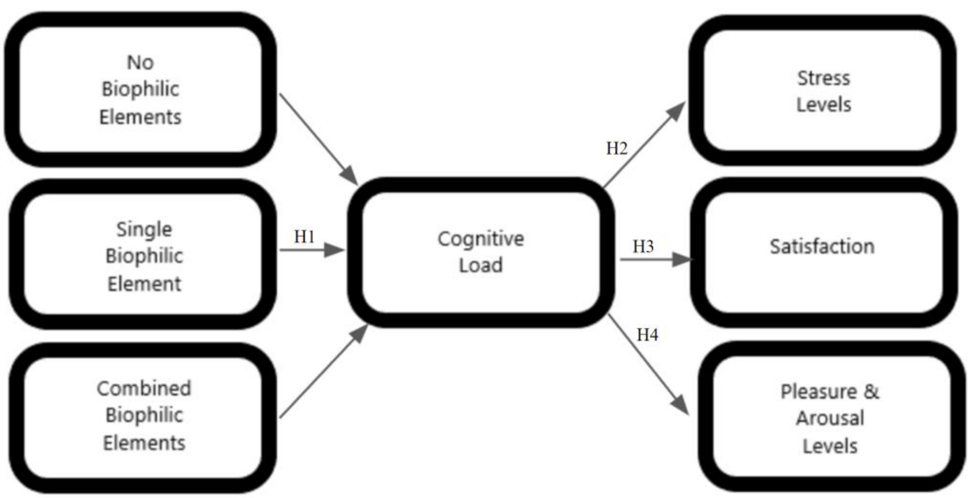
CHAPTER III

METHODOLOGY

A between-group experiment was conducted to explore the effect of biophilia on stress, pleasure and arousal, satisfaction, and cognitive load. The independent variable had three levels: no biophilia, a single biophilic element, and combined biophilic elements. The dependent variables were stress levels, satisfaction, and pleasure and arousal levels.

Figure 4

Theoretical framework guiding research question.



1. RESEARCH QUESTIONS AND HYPOTHESES

1.1 Research Questions

1 How do biophilic elements effect cognitive load?

2. How do biophilic elements effect satisfaction in virtual healthcare environments?

3. How do biophilic elements effect stress in virtual healthcare environments?

4. How do biophilic elements effect pleasure in virtual healthcare environments?

5. How do biophilic elements effect arousal in virtual healthcare environments?

1.2 Hypotheses

1. H_1: Biophilic environments decrease cognitive load of that environment.
2. H_2: Decreased cognitive load decreases stress levels of that environment.
3. H_3: Decreased cognitive load increases satisfaction of that environment.
4. H_4: Decreased cognitive load increases pleasure and arousal of that environment.

The research procedure included use of the following assessment tools: participants filled out a brief demographic questionnaire prior to their exposure to the virtual healthcare environment, then following their exposure they filled out a satisfaction questionnaire, a self-assessment manikin questionnaire (Bradley & Lang, 1994), the NASA TLX (Hart & Staveland, 1988), and a stress level questionnaire which is a modified version based on the State-Trait Anxiety Inventory (STAI) (Spielberger et al., 1983). During their exposure, the Biopac system was utilized with the Acqknowledge software to measure physiological responses: skin conductance levels and heart rate. The BIOPAC was used with the VIVE Pro Eye eye-tracking headset and the iMotions software to measure participants pupil dilation and fixation during their exposure to the virtual healthcare environment.

During the Spring of 2021, a pilot study was conducted. The recruitment invitation email for participating in the study was sent to 12 subjects. Announcement about the study was also made in several classes to invite students to participate voluntarily. The primary investigator also invited persons in their network to participate in the study. The recruitment invitation included a brief purpose of the study, where the study will take place, and the time commitment. The recruitment invitation, informed consent, and modified research design were approved by the Institutional Review Board (IRB). The data collection was done throughout a two-week time span. Findings from the pilot study showed that the 12 participants reported higher satisfaction levels, less stress, and having an easier time relaxing within condition three compared to the other two conditions. However, participants skin conductance levels (SCL) lowered in condition two, but we did not identify participants heart rate (HR) lower when viewing the biophilic spaces. This could mean that participants seemed to overall experience less stress when viewing plants, which were included in condition two. Overall, patients who experienced condition three felt less stress and were more satisfied than condition two and three. However, participants did not report feeling less pleasure or arousal in condition one compared to condition three. This could mean that even though participants were more comfortable in condition three, participants were still pleased with condition one. Finally, researchers found that pupil dilation was the highest in condition three. This was the opposite of what we expected to occur, but this could also mean that their pupils dilated because they enjoyed condition three that they experienced more than the others.

60 participants were recruited to participate in this study in the Spring of 2022 by direct recruitment, posted flyers, and email invitations. A convenience sampling method was applied to recruit subjects. The subject population consisted of students, faculty, and staff of Oklahoma

State University. Convenience sample was chosen because it is cost effective, easily reachable to the subjects, an easy process of recruitment, and because the willingness of the participants to participate in the study (Etikan et al., 2016). Convenience sampling has disadvantages such as the lack of generalizability and the potential for producing biased results (Jager et al., 2017). Participants were OSU students, staff, and faculty. Participation was completely voluntary and there will be no compensation. Before asking participants to sign the informed consent form, they will be made aware of study exclusion criteria such as taking medication for stress, heavy tobacco or alcohol use within the past 24 hours leading up to their participation, and any sort of intense exercise within 5 hours of the experiment. Prior to conducting the study, researchers received approval from the Institutional Review Board (IRB) from Oklahoma State University (OSU).

Three different conditions were simulated as 360-degree spherical images and participants were provided with VR head mounted displays to view the environment. The environments were developed in SketchUp Pro 2021 and rendered in Enscape version 3.0. The three spaces are identical besides the difference in biophilic elements within the three different conditions. Heart rate and skin conductance levels were measured to look at the participants stress reactions. Additionally, participants pupillary responses and fixation were measured using the VIVE pro eye VR tracking device and iMotions software.

Participants were scheduled for 30-minute time slots and were invited to the Mixed Reality Lab in the Nancy Randolph Davis building located on OSU’s Stillwater Campus. Participants were then randomly selected to experience one of three virtual environments, condition one: non-biophilic hospital room, condition two: a hospital room with plants, and condition three: a hospital room with natural materials, plants, and views of nature. The virtual environments were designed in the Sketchup software then rendered in the Enscape as a 360-degree spherical image.

Figure 5

Methodology Diagram

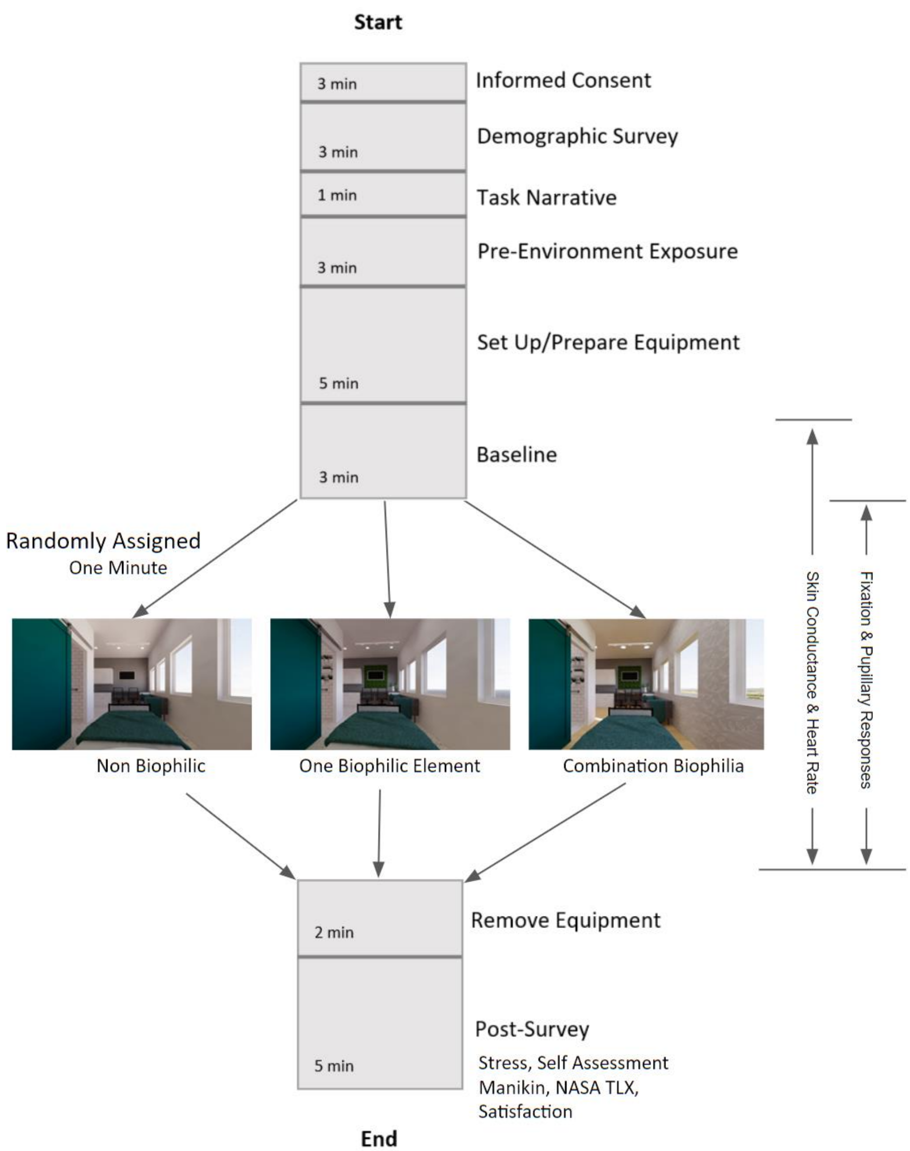
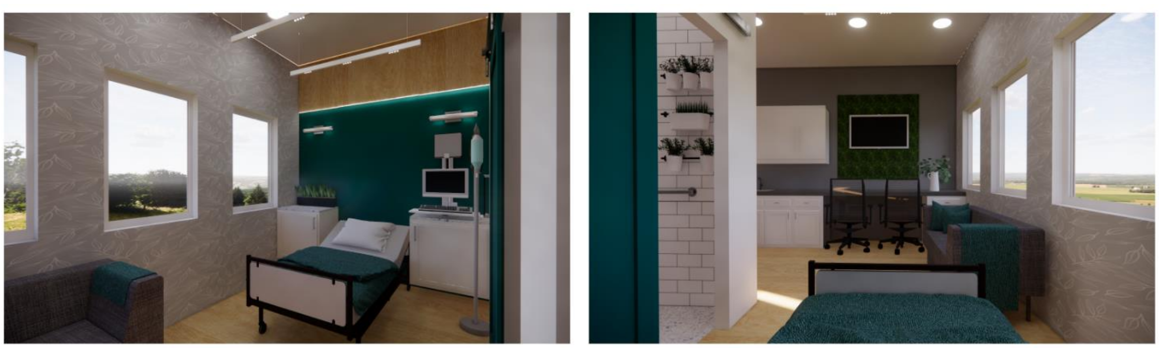


Figure 6

Three conditions of the healthcare environments

Condition One

Condition Two



Condition Three

Note. This figure demonstrates the three conditions that participants randomly experienced for our research study.

For researchers to investigate the effects biophilic design on patients' cognitive load during their exposure to the 360-degree spherical image, the VIVE Pro eye-tracking device paired with the iMotions software recorded both the dilation of the participants' pupils, as well as their fixation. Additionally, researchers utilized heart rate (HR) and skin conductance level (SCL) monitors to measure stress among participants. The Biopac device was used to gather this data through the Acqknowldge software to measure and record the participants SCL and HR. In order to use the Biopac to get these measurements, participants had to wear two electrodes on the tips of their pointer and middle finger, one electrode on their collar bone, and another electrode on their rib cage. These electrodes allowed the Biopac to measure their physiological responses and record them in the Acqknowledge software.

Upon participants arrival, they were asked to sign an informed consent form and to fill out a demographic questionnaire. The demographic questionnaire asked questions regarding their stress levels that day and if they had gotten a good night's rest. After participants signed the informed consent form and completed the demographic questionnaire, they were given a task narrative to prime them prior to their exposure to the virtual environments. The narrative told participants they were going into the hospital for a routine checkup. Following the narrative, participants experienced a pre-environment. This allowed them to get familiar with being in VR. Once participants felt comfortable in VR, researchers set up the heart rate and skin conductance monitors and then asked participants to rest with their eyes closed for 3 minutes. This allowed researchers to identify participants baseline physiological conditions. Once their rest time was over, they were able to view the selected healthcare 360-degree spherical image with the VIVE Pro headset for 1 minute while staying seated. As participants viewed the image, their heart rate and skin conductance levels were continued to be measured in addition to the data being recorded on the eye tracking headset. Lastly, participants were asked to complete a stress level questionnaire, a satisfaction level questionnaire, and the self-assessment manikin questionnaire that measured pleasure, arousal, and dominance. In addition to these questionnaires, participants were also asked to complete a NASA TLX questionnaire to assess their cognitive load. Once participants completed their final task, they were able to leave the lab. The process took approximately about 20 minutes for each participant.

A one-way analysis of variance (ANOVA) was conducted followed by a post-hoc analysis using Tukey's honestly significant different (HSD) test to determine the effects the three healthcare environment conditions had on cognitive load in participants. In addition to this, effect sizes were calculated, and correlation analyses were conducted with the dependent variables (stress, pleasure & arousal, satisfaction). The significance level was set at = 0.05. MS excel and SPSS were used for the data analysis.

CHAPTER IV

RESULTS

1. DEMOGRAPHICS

The 60 participants in this study were all Oklahoma State University students, staff, and faculty. Out of the 60 participants, 85% of them were female, 13.3% male, and 1.7% other. Participants ranged from being 18 to 57 years of age with the average age being 24.17. Over half of the participants were raised in a suburban area, with the other half being raised in either urban or rural areas. In addition to this, half of the participants claimed they liked natural spaces very much and only 4 participants said they felt neutral about natural spaces. Finally, researchers asked participants if they had ever stayed in a hospital before, and 41.7% said yes, and 58.3% said no. A correlation analysis was conducted between stress and previous hospital stays and there was a weak negative relationship. So, participants previous hospital experiences should not have had an impact on the results.

2. COGNITIVE LOAD

2.1 NASA TLX

To assess cognitive load, participants pupil responses were recorded during their one-minute exposure to the random environment and then participants completed the NASA TLX questionnaire following their exposure period. The impacts biophilia had on self-reported mental demand are depicted in Tables 1 & Figure 7 below. Biophilia seemed to have little effect on participants self-reported cognitive load according to the NASA TLX responses. For condition one, the average self-reported mental demand was 1.45 with a standard deviation of 0.945. For condition two, the average self-reported mental demand was 1.65 with a standard deviation of 0.745. Finally, for condition three, the average self-reported mental demand was 1.55 with a standard deviation of 0.759. We ran an analysis to determine if there was a difference in cognitive load between the three different conditions. However, there was not a significant effect of the inclusion of biophilia on cognitive load for the three conditions. In addition to this, a small effect size was found (Cohen's d = .201).

Table 1

One Way Analysis of Variance – Mental Demand

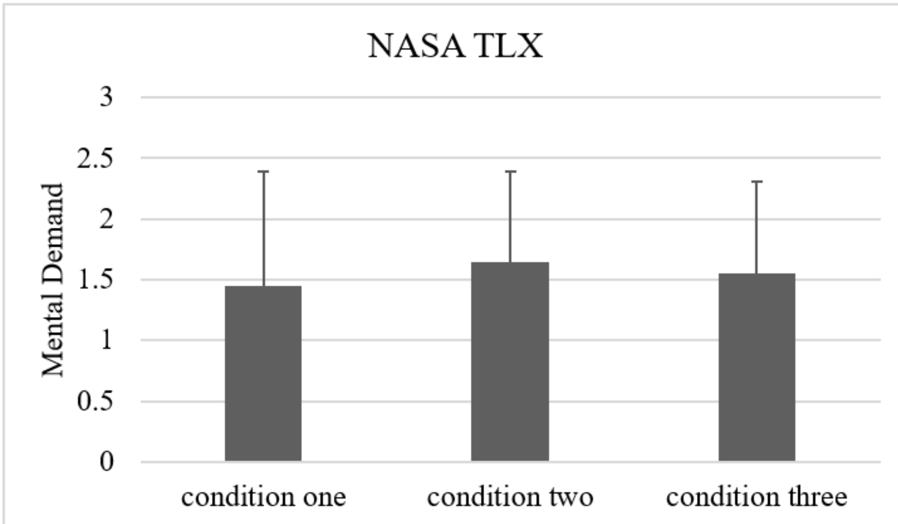
ANOVA

Mental Demand

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	.400	2	.200	.296	.745
Within Groups	38.450	57	.675		
Total	38.850	59			

Figure 7

NASA TLX - Mental Demand Chart



2.2 Pupil Dilation

In addition to the NASA TLX results, pupil dilation data recorded from the VIVE Pro Eye Eye-Tracking headset showed that the average and maximum pupil dilation were slightly lower in condition three compared to condition one. A one way analysis of variance was carried out to determine if there was a difference in pupil dilation between the three different conditions. There was not a significant effect of the inclusion of biophilia on pupil dilation for the three conditions (p = 0.617). A large effect size was found (Cohen's d = 2.538). The impacts biophilia had on the average pupil dilation between conditions one, two, and three are shown in Table 2 & Figure 8 below.

A Pearson's correlation coefficient was calculated to assess the linear relationship between the NASA TLX responses and pupil dilation. There was weak positive relationship between the two variables [r (58) = -0.2, p = .246].

Table 2

One Way Analysis of Variance – Pupil Dilation

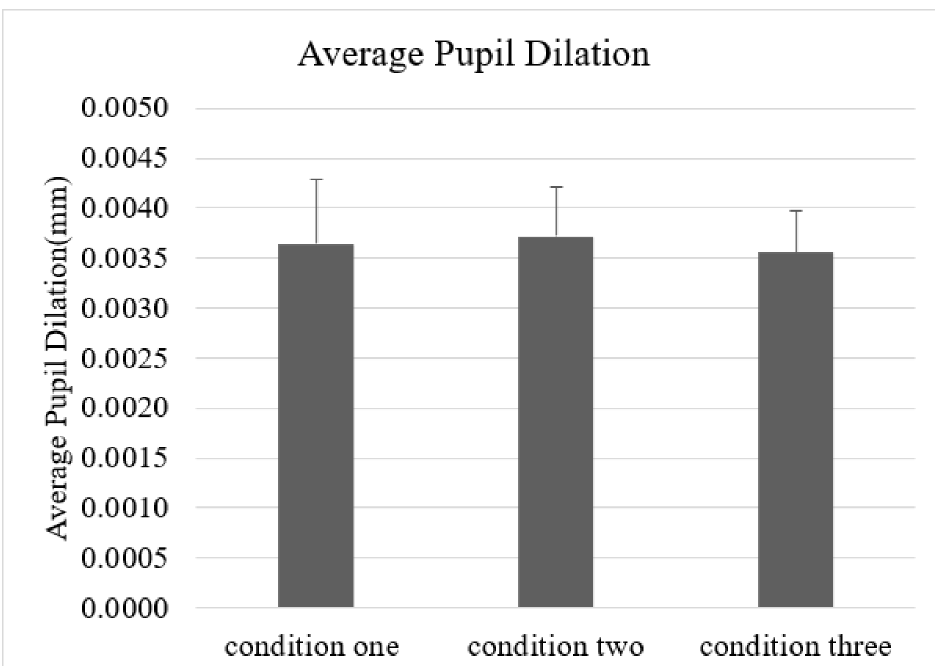
ANOVA

Pupil Dilation

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	.000	2	.000	.488	.617
Within Groups	.000	56	.000		
Total	.000	58			

Figure 8

Average Pupil Dilation Across Three Conditions



Based on the results outlined above, it can be seen that condition two had higher cognitive load than the other two conditions. Cognitive load was reported to be lower in condition three than condition one. In addition to this, pupil dilation was larger in condition two and at its lowest in condition three. However, after running the analysis, none of these observations showed to be statistically significant. It can be concluded that the amount of biophilia overall did not impact how participants reported their cognitive load and it also did not impact their pupil dilation while viewing their virtual healthcare environments enough to be statistically significant. Cognitive load and pupil dilation was expected to be at its lowest in condition three due to the combination on biophilic elements. Possible reasons why this occurred will be discussed in the next chapter. Therefore, the findings of the current study did not fully support H1 which predicted the cognitive load will decrease within conditions one, two, and three.

3. STRESS

3.1 *Physiological Measurements*

To assess stress, physiological indicators were recorded which included heart rate and skin conductance. Once the heart rate and skin conductance of participants was taken, the normalized heart rate was calculated by using the baseline measurements and exposure measurements. The impacts biophilia had on participants physiologically are shown in Figures 9 & 10. The data gathered from the Acqknowldge software showed that participants in condition three had a slightly lower normalized heart rate compared to those who experienced condition one. The average normalized heart rate in condition one was 1.06, in condition two it was 1.08, and for condition three it was 1.02. A one-way analysis of variance was carried out to determine if there was a difference in normalized heart rate between the three different conditions. However, there was not a significant effect of the inclusion of biophilia on normalized heart rate for the three conditions (p = .120). In addition to this, we found that normalized skin conductance was slightly higher in condition three than condition one and two, but there was not a significant effect of the inclusion of biophilia on normalized skin conductance for the three conditions (p = .332). The average normalized skin conductance for condition one was 1.8, for condition two it was 1.7, and for condition three it was 2.1. A large to medium effect size for heart rate was found (Cohen's d = .739) and a small to medium effect size for skin conductance was found (Cohen's d = .397).

A Pearson's correlation coefficient was calculated to assess the linear relationship between normalized heart rate and cognitive load. There was a weak positive relationship between the two variables [r (58) = .08, p = .430]. In addition to this a Pearson's correlation coefficient was calculated to assess the linear relationship between normalized skin conductance and cognitive load. There was a weak negative relationship between the two variables [r (58) = -.25, p = .869]. It seems very unlikely that a negative relationship is correct considering that there is plenty of research that supports the positive relationship between skin conductance and cognitive load. This could be a result of faulty equipment and because of this, the discussion of the skin conductance data will not be included in the discussion of results.

Figure 9

Average Normalized Heart Rate Across Three Conditions

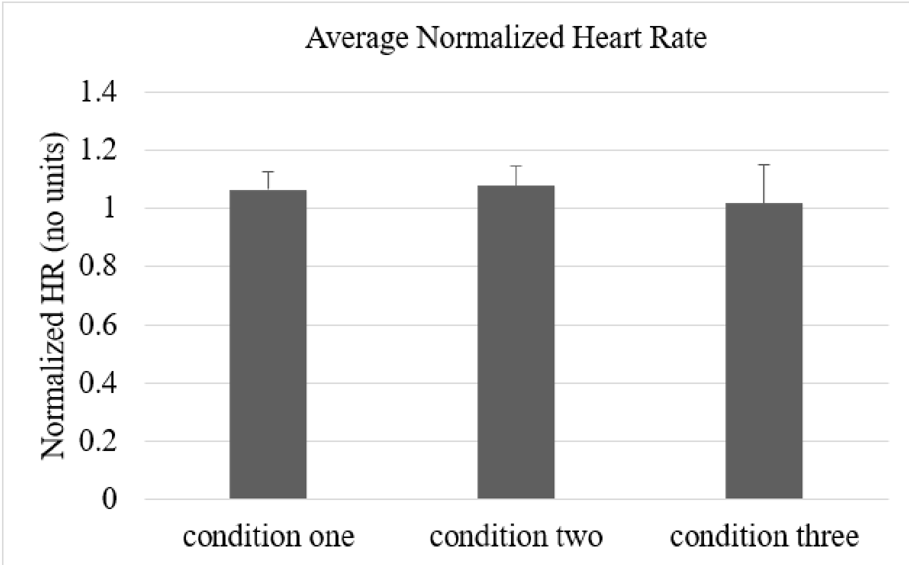
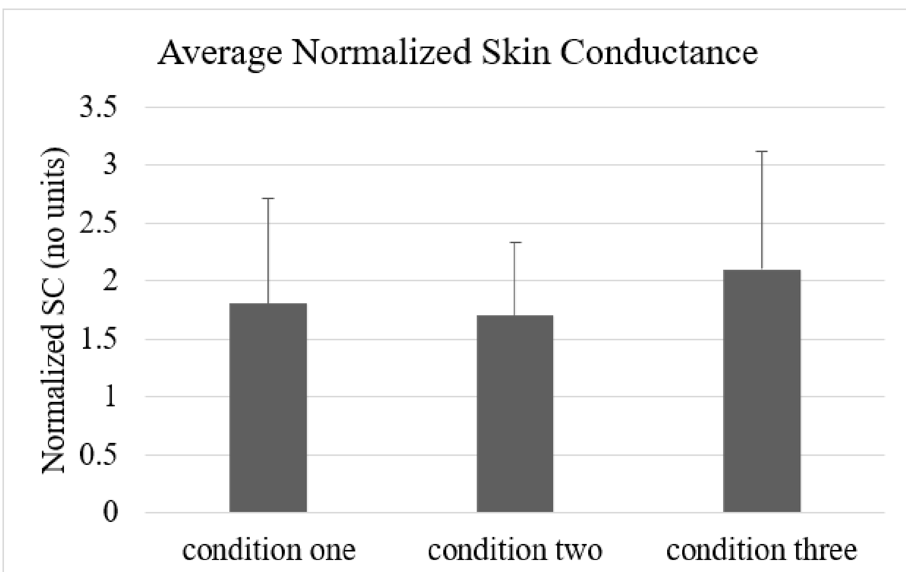


Figure 10

Average Normalized Skin Conductance Across Three Conditions



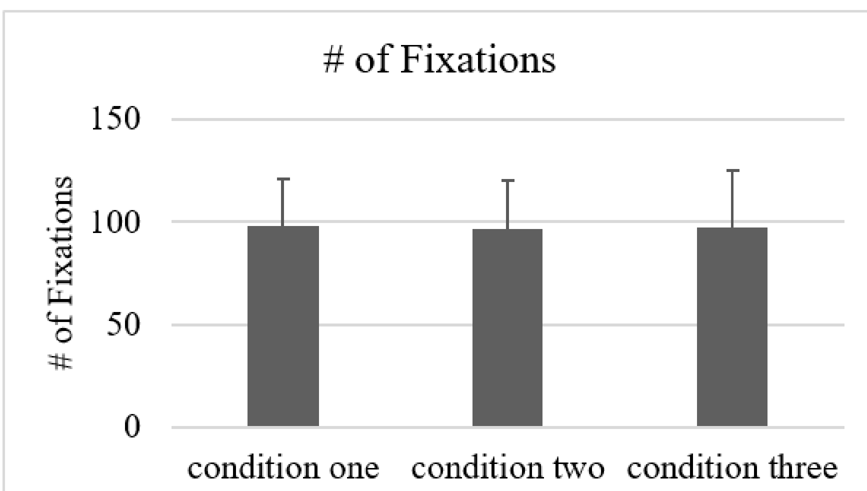
3.2 *Fixations*

The eye-tracking headsets gathered the number of fixations among participants between the three groups as a way to measure stress. The number of fixations did not seem to differ between the three groups with the average number of fixations in condition one being 98.5, condition two was 96.95, and in condition three it was 97.2. A one-way analysis of variance was carried out to determine if there was a difference in the number of fixations between the three different conditions. There was not a significant effect of the inclusion of biophilia on fixations for the three conditions (p = .978). A small effect size for number of fixations was found (Cohen's d = .063). The impacts biophilia had on number of fixations are illustrated in Figure11 below.

A Pearson's correlation coefficient was calculated to assess the linear relationship between number of fixations and cognitive load. There was a weak positive relationship between the two variables [r (58) = .03, p = .542].

Figure 11

Number of Fixations Across Three Conditions



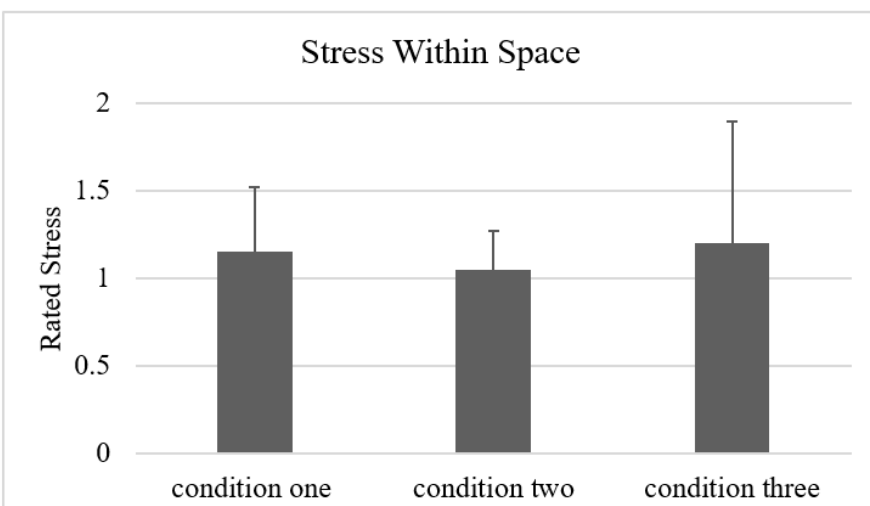
3.3 *Stress Questionnaire*

In addition to this, participants completed a stress level questionnaire following their exposure period which asked participants to rate their level of stress while being within the virtual healthcare environment. The impacts biophilia had on participants self-reported stress within the space are shown in Figure 12. A one-way analysis of variance was carried out to determine if there was a difference in stress between the three different conditions. There was not a significant effect of the inclusion of biophilia on stress for the three conditions ($p = .595$). A small effect size for stress was found (Cohen's $d = .271$).

A Pearson's correlation coefficient was calculated to assess the linear relationship between stress and cognitive load. There was a strong positive relationship between the two variables [$r(58) = .65$, $p = .001$].

Figure 12

Stress Within Space Across Three Conditions



Based on the results outlined above, researchers found that normalized heart rate was lower in condition three compared to conditions one and two. It was expected the heart rate in condition two would be lower than condition one but that is not the case. Normalized skin conductance was lower in condition two compared to the other two conditions and was at its highest in condition three which was the opposite of what researchers expected. In addition to this, self-reported stress was higher in condition three compared to the other two conditions which is also the opposite of what was expected. However, it was be concluded that the amount of biophilia did not impact participants physiological and self-reported stress responses enough to be statistically significant. Therefore, the finding in the current study did not support H2 because the amount of biophilia did not result in a decrease in stress levels among participants.

4. PLEASURE & AROUSAL

To assess pleasure and arousal, participants completed a self-assessment manikin questionnaire following their exposure period. The questionnaire assessed participants self-reported valence, arousal, and dominance by choosing avatars they most identified with while within the virtual healthcare environment. Participants between the three conditions felt differences in their pleasure and arousal when completing the questionnaire regarding their experience with their random condition. A one-way analysis of variance was carried out to determine if there was a difference in pleasure between the three different conditions There was a significant difference of the inclusion of biophilia on valence for the three conditions [F (2, 57) = 3.015, p = 0.057]. The results of this are shown in Tables 3 & Figure 13 below. Tukey's HSD test indicated that condition two had significant differences in valence with condition three (p = .068) but condition one did not have significant differences with condition two (p = .944) or condition three (p = .135). Tukey's HSD Test for multiple comparison findings can be found in Table 4. On the other hand, arousal was shown to be slightly higher in condition one than the other two, but there was not a significant effect of the inclusion of biophilia on arousal for the three conditions (p = .785). A small effect size for arousal was found (Cohen's d = .180).

A Pearson's correlation coefficient was calculated to assess the linear relationship between valence and cognitive load. There was a strong positive relationship between the two variables [r (58) = .64, p = .935]. In addition to this, a Pearson's correlation coefficient was calculated to assess the linear relationship between arousal and cognitive load. There was a strong positive relationship between the two variables [r (58) = .67, p = .012].

Table 3

One Way Analysis of Variance – Valence

ANOVA

Valence

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.433	2	.717	3.015	.057
Within Groups	13.550	57	.238		
Total	14.983	59			

Table 4

Post Hoc – Valence

Condition	One	Two	Three
One	x	0.944	0.135
Two		x	0.068
Three			x

Figure 13

Valence Across Three Conditions

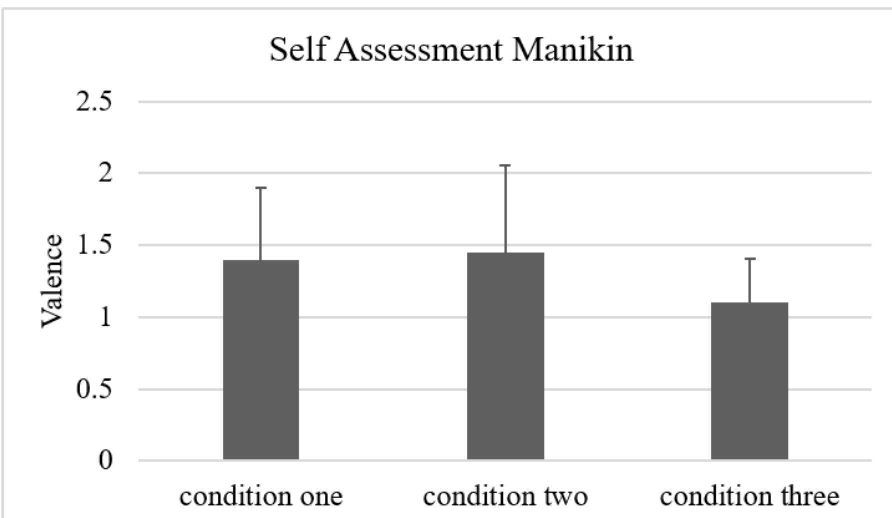
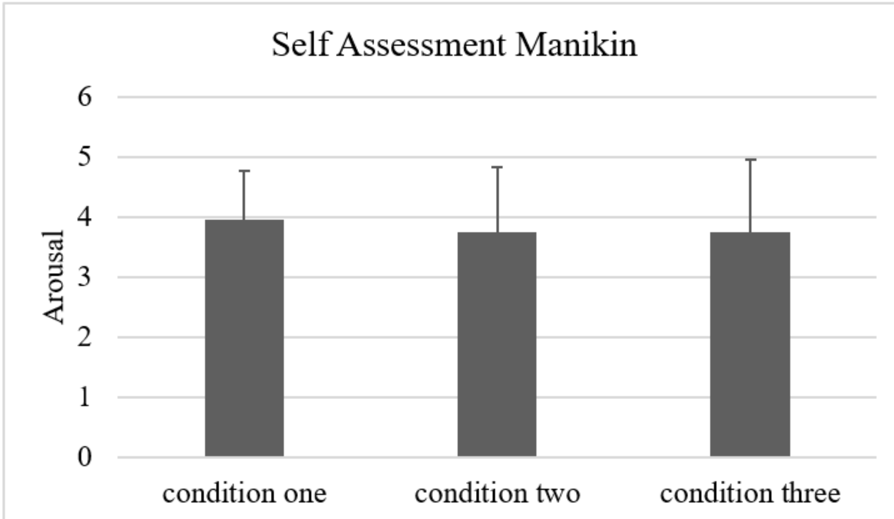


Figure 14

Arousal Across Three Conditions



Based on the results depicted above, it can be concluded that the amount of biophilia did have a significant effect on valence but not on participants arousal. Therefore, the findings from the current study only partially support H4.

5. SATISFACTION

Participants satisfaction was documented by having them complete a questionnaire following their exposure period. Overall, participants self-reported satisfaction within condition three was greater than conditions one and two. The average self-reported satisfaction for condition one was 4.35 with a standard deviation of 0.75, for condition two it was 4.8 with a standard deviation of 0.41, and for condition three it was 4.95 with a standard deviation of 0.22. A one-way analysis of variance was carried out to determine if there was a difference in satisfaction between the three different conditions. There was a significant difference of the inclusion of biophilia on satisfaction for the three conditions [$F(2, 57) = 180.355$, $p = .001$]. The results are shown in Tables 5 & Figure 15 below. Tukey's HSD test indicated that condition one had significant differences in satisfaction with condition two ($p = .019$) and condition three (p =

.001), but no differences were found between condition two and three (p = .621). Tukey's HSD Test for multiple comparison findings can be found in Table 6.

A Pearson's correlation coefficient was calculated to assess the linear relationship between satisfaction and cognitive load. There was a moderate positive relationship between the two variables [r (58) = .37, p = .001].

Table 5

One Way Analysis of Variance – Satisfaction

ANOVA

Satisfaction

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	3.900	2	1.950	7.561	.001
Within Groups	14.700	57	.258		
Total	18.600	59			

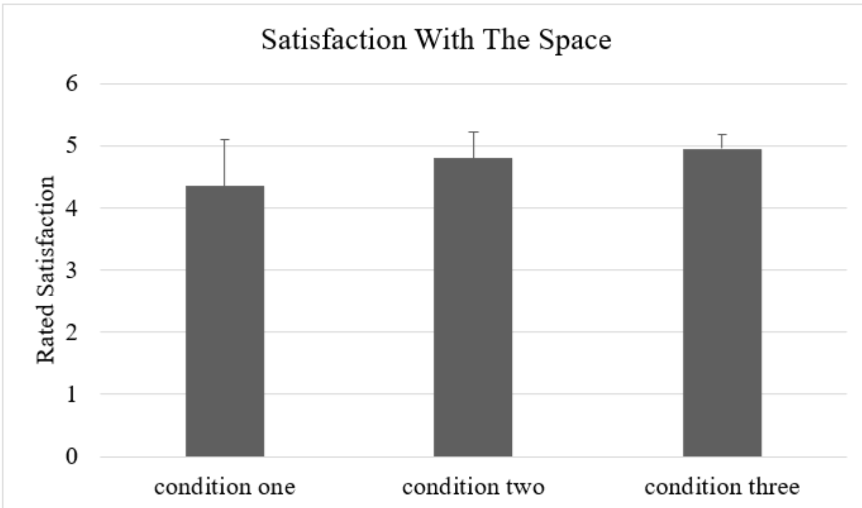
Table 6

Post Hoc – Satisfaction

Condition	One	Two	Three
One	x	0.019	0.001
Two		x	0.621
Three			x

Figure 15

Satisfaction Across Three Conditions



Based on the results depicted above, it can be concluded that the amount of biophilia positively impacted satisfaction among participants. It was expected that satisfaction would be highest in condition three which is what the current study confirmed. Therefore, the findings of this study support H3.

The results of this study have indicated that there are differences between emotions and moods towards the three different virtual healthcare conditions: condition one (no biophilia), condition two (single biophilic element), and condition three (combination of biophilic elements). Participants had more positive feelings such as pleasure and satisfaction towards condition three than condition one. However, in some cases we found that biophilia did not impact cognitive load significantly. Chapter V will go into more details about the results presented above.

CHAPTER V

DISCUSSION & CONCLUSION

This study explored the effects biophilic design has on participants cognitive load within virtual healthcare environments through the use of virtual reality. An aim of this study was to answer five research questions and investigate four hypotheses. All four hypotheses were tested, and this final chapter will be a review of the previous four chapters then discuss limitations and future directions.

The virtual 360-degree spherical images were designed in the Sketchup software and rendered in Enscape. Participants began by completing a demographic questionnaire which asked questions regarding their age, stress levels, and how they felt about natural spaces. Following the completion of the demographic survey, participants viewed a pre-environment for up to three minutes to give them the opportunity to get used to wearing/using the virtual reality headset. When they felt comfortable to move forward, we gathered their baseline heart rate and skin conductance through the Biopac by having them sit with their eyes closed for three minutes. Before participants viewed their random environment, they were given a task narrative that they were going in for a routine check-up. They then viewed one of three virtual healthcare environments (no biophilia, single biophilic element, and a combination of biophilic elements) for a minute and then filled out a Satisfaction, NASA TLX, Self-Assessment Manikin, and Stress Questionnaire.

1. RESULTS

1.1 *Hypotheses*

H_0: μ non-biophilic = μ single-biophilic = μ combination-biophilic
H_A: μ non-biophilic ≠ μ single-biophilic ≠ μ combination-biophilic

H_1: Biophilic environments decrease cognitive load of that environment.

For hypothesis one through three, we conducted a one-way analysis of variance to assess whether cognitive load was impacted by the inclusion of biophilic elements. To do this we took our two measurements of cognitive load (NASA TLX & Pupil Dilation) and used SPSS to run a one-way ANOVA. However, we found that there was not a significant difference in cognitive load between the three virtual healthcare conditions. Therefore, we retained the null hypothesis. Overall, our hypotheses one did not show to be statistically significant in this study.

H_2: Decreased cognitive load decreases stress levels of that environment.

For hypothesis four, we ran a correlation analysis between cognitive load measurements (NASA TLX and pupil dilation) and with our measurements for stress (heart rate, skin conductance, stress questionnaires, and number of fixations). Out of the five variables, only the responses from the stress questionnaire had a strong linear relationship with cognitive load. Overall, hypothesis two is partially supported by our findings.

H_3: Decreased cognitive load increases satisfaction of that environment.

For our fifth hypothesis, we ran a correlation analysis between cognitive load and our satisfaction questionnaire response. The results showed that cognitive load had a moderate linear relationship with satisfaction. However, we also used SPSS to run a one-way ANOVA on the satisfaction responses and found there was a significant difference in satisfaction among the three healthcare environments. Therefore, we reject the null hypothesis. Hypothesis three was partially supported.

H_4: Decreased cognitive load increases pleasure and arousal of that environment.

Finally, we ran a correlation analysis between pleasure & arousal and cognitive load. The results showed that cognitive load and valence had a strong correlation and cognitive load, and arousal had a strong correlation as well. In addition to this, we ran a one-way ANOVA for pleasure and arousal and found there was a significant difference in valence among the three healthcare environments. Therefore, we reject the null hypothesis. Hypothesis four was shown to be true.

2. DISCUSSION OF RESULTS

Recent research has shown that rehab patients who had access to plants in their common space or had views of nature experienced an increase in satisfaction (Wichrowski et al., 2021). Another study that occupied a workspace with greenery found that 73% of the workers within the space claimed to be satisfied or extremely satisfied (Sanchez et al., 2018). The findings from the current study aligned with the findings from the two studies previously mentioned. The current study found that participants experienced an increase in satisfaction when biophilia such as plants and views of nature was present. Another study found that the presence of plants resulted in higher levels of pleasure and arousal in addition to having natural lighting (Lee, 2019). The current study's findings aligned with this and identified that participants who experienced biophilia reported feeling higher levels of pleasure. According to Park and Mattson (2008), patients in hospital rooms with plants or flowers had more positive physiological responses such as lower blood pressure and heart rate (Park & Mattson, 2008). However, there were differences in normalized heart rate between the three environments, the differences were not statistically significant. This could be because of participants only viewed their condition for one minute. Participants viewed their virtual healthcare condition for one minute because the initial reactions in participants was being measured. Finally, Sanchez et al., (2018) assessed subjective workload among three different spaces and found that workload sensation was significantly lower when both daylight and greenery was present (Sanchez et al., 2018). The current study did not align with these findings. There were slight differences recorded, but the differences found in cognitive load among the three virtual healthcare conditions was not statistically significant. This could be because pupil dilation can also be caused by behavioral states such as emotional excitement or a change luminance. Pupil dilation among participants could have been triggered differently between the three groups (Pan et al., 2022). So, it is possible participants in condition one could have had higher pupil dilation due to stress, but pupil dilation could have been higher in condition three because of pleasure or being satisfied. Another reason for these results could also be because participants looked at a 360-degree spherical image which could have caused different cognitive responses than physically navigating the space with the virtual reality headset. This was due to a limitation in the software that was used in the study.

3. IMPLICATIONS

The current study found that while biophilia may not have statistical differences on cognitive load and physiological measurements of stress, there was still a slight difference. In addition to this, biophilia had positive impacts on moods such as pleasure and satisfaction. Some theoretical implications of this could be that when designers include biophilia in healthcare environments they design, this can positively impact on patients' satisfaction, stress, and cognitive load. The methodological implication of this study is also to shine some light on physiological equipment and virtual reality. In the future, designers who are carrying out an evidence-based design project, the current study shows that this equipment is beneficial and helps find positive findings. Second, virtual reality is a great tool for designers, researcher, and architecture and design firms to implement into their practice for evidence-based design. Virtual reality is a beneficial tool that helps control variables and reduces cost. Finally, the practical implications of this study include helping healthcare professionals by creating guidelines for healthcare designers to create spaces that keep the mental health of patients and healthcare professionals in mind.

4. LIMITATIONS

The first portion of limitations in the current study are regarding the fact that it is a virtual reality study using a 360-degree spherical image. Even though virtual reality is known for being immersive, it is reasonable to assume since it was a virtual space that could not be navigated, it could have affected participants cognitively and emotionally. In addition to virtual reality component, the use of the BIOPAC could have hindered participants comfort and ability to relax while experiencing their condition. While being hooked up with four separate wires, participants would get tangled in addition to having the headset on. This could have caused some discomfort. For the one-minute exposure period, participants should have had a task or assignment to hold their attention for the full minute. It was observed that once participants saw the entirety of the room, they would tend to sit still and just look straight forward.

The second portion of limitations in the current study are regarding the participants. When assigning participants to a random group, there is a possibility that the select number of participants who were experiencing higher stress that day, could have been randomly assigned to the biophilic conditions and that could have impacted results. In addition to this, the same scenario could be applied to those who said they only felt neutral about natural elements. It is also possible those who grew up in a more urban environment, could have a different view on nature as those who grew up in rural areas. There is no way of knowing what kind of experiences participants could have previously had with healthcare and how that could possibly negatively impact their responses. A little over 40% of the participants reported having stayed in a hospital prior to the completion of the study, but we do not know if that experience was good or bad and how that could have impacted them cognitively and emotionally while viewing the virtual healthcare environment. Finally, recruiting a larger sample size in the future that does not only consist of Oklahoma State University students, staff, and faculty may help get a wider variety of ages and genders.

5. FUTURE DIRECTIONS

In the future, limitations within the current study should be addressed including the fact that it is a 360-degree spherical image. It would allow participants to be further immersed in the environment if they could walk through or navigate the healthcare environment. In addition to this, I think having to navigate the space provides them a task that could impact their cognitive responses. Ideally, it would be great to make three physical mockup rooms participants could visit. If funds allow, that would be a great option. If not, it would also be useful to have a single plain mockup room with furniture set up just like the virtual healthcare environment for participants to physically navigate but pair it with a virtual reality headset. This would allow researchers to alter the amount biophilia or whatever condition the participant is randomly selected to view without having to pay for three separate spaces. Participants would be able to physically touch the objects as they view them in virtual reality. Soundscapes could be an addition as well. Additionally, in the future this research needs to be expanded to more types of individuals who are having experiences within the healthcare environment. This study could also look at biophilia's impact on nurses and doctors not just within the patient room, but in the ER, in surgery, and in nurse's stations/offices as well.

6. CONCLUSIONS

The current study about biophilia was important because it can have implications for the healthcare environment in the future. With most of our time being spent indoors, many of us have or will have an experience in a healthcare setting whether that be as a patient or a visitor. The inclusion of Biophilic design within interior environments has been thoroughly studied and research has shown that biophilia has physiological and cognitive benefits. However, when it comes to biophilia in healthcare, we felt more research was needed on how it could impact patients cognitively. For this reason, a between-group experiment was conducted to explore the effect of biophilia on stress, pleasure and arousal, satisfaction, and cognitive load. The independent variable had three levels: no biophilia, a single biophilic element, and combined biophilic elements. The dependent variables were stress levels, satisfaction, and pleasure and arousal levels. Five research questions were answered in the current study.

The findings of this study showed that participants did not experience any statistically significant differences in their cognitive load between the three virtual healthcare environments according to the pupil dilation data gathered from iMotions and their NASA TLX responses. This is the opposite of what was expected. In addition to this, it was expected to find a significant decrease in stress when biophilia was present but that was not the case. To assess stress between participants, the number of fixations during their exposure period, normalized heart rate, and normalized skin conductance were measured and a stress questionnaire was completed. None of these dependent variables were significantly impacted by the inclusion of biophilia. However, the Self-Assessment Manikin showed that biophilia significantly impacted valence between participants which is what was expected. Finally, participants who experienced biophilia reported being more satisfied with their space compared to those who did not experience biophilia. The findings from this study showed that biophilia had a significant impact on participants moods.

Using interior design strategies such as the inclusion of biophilia with evidence-based design can enhance the health, safety, and welfare of patients during their stay. The current study about biophilic interventions within healthcare could further impact how healthcare spaces are designed whether this be in an in-patient or out-patient setting. This research has the possibility to further enhance experiences of not just patients, but healthcare workers and families in the future. This research also serves as an example for other researchers or designers who are also wanting to implement biophilia into their practice.

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APPENDICES

APPENDIX A

Informed Consent Form

Informed Consent Form for Social Science Research
Title of Project: Understanding the Effects of Biophilic Design in Healthcare Environments Through the Use of Virtual Reality

Principal Investigator: Tilanka Chandrasekera,PhD
429D, Human Sciences
405-744-9524
tilanka@okstate.edu

1. Purpose of the Study: The purpose of this study is to identify if Biophilic Design effects patients' stress in healthcare environments.

2. Procedures to be followed: The study will consist of three parts: a demographic survey, an activity in VR, and four surveys afterwards.

3. Discomforts and Risks: There are no risks in participating in this study.

4. Duration/Time: The duration of this study is 30 minutes.

5. Benefits: There are no benefits to you.

6. Statement of Confidentiality: No personal information will be collected and only the researchers will have access to the information collected. Your participation in this research is therefore confidential. The data will be stored online on a password protected account. The research team works to ensure confidentiality to the degree permitted by technology. It is possible, but unlikely, that unauthorized individuals could gain access to your responses because you are responding online. However, your participation in this online survey involved risks similar to a person's everyday use of the internet. If you have concerns, you can consult the survey provider privacy policy at https://go.okstate.edu/tos/privacy.html

7. Right to Ask Questions: Please contact Dr. Tilanka Chandrasekera 405-744-9524 with questions about this research. If you have any questions, concerns, problems about your rights as a research participant, please contact the Oklahoma State University's Review Board at irb@okstate.edu.

8. Voluntary Participation: Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty. You must be 18 years of age or older to consent to take part in this research study.

APPENDIX B

Recruitment Letter

Subject: Looking For Participants

Good afternoon _____,

We are currently looking for participants to partake in a design study. For our research, we will be looking at the effects of biophilic design in patients. It will involve some questionnaires and a quick VR activity. The study will take place in the mixed reality lab in the Nancy Randolph Davis building on the OSU Stillwater campus. The whole thing should take about 30 minutes. If you would like to participate or want any further information please feel to email me at allison.b.howard@okstate.edu.

Thank you,

Allison Howard

APPENDIX C

Demographic Questionnaire

1. Please select your group number provided by researcher.

   Mark only one oval.

   - ⬭ 1
   - ⬭ 2
   - ⬭ 3

2. How old are you? (please type age in years ex. 24)

   ____

3. What is your gender?

   Mark only one oval.

   - ⬭ Male
   - ⬭ Female
   - ⬭ Other
   - ⬭ Prefer not to say

4. What is your occupation?

   Mark only one oval.

   - ⬭ Student
   - ⬭ Staff
   - ⬭ Faculty

5. Please specify your ethnicity

Mark only one oval.

- White/Caucasian
- Black or African American
- Asian
- Native Hawaiian or other Pacific Islander
- American Indian or Alaska Native
- Latino
- Multiracial
- Prefer not to say

6. Where were you raised?

Mark only one oval.

- Urban area
- Suburban area
- Rural area

7. In general, do you like to go to natural spaces (examples include parks/riversides/forests)

Mark only one oval.

- Not at all
- Not very
- Neutral
- Somewhat
- Very much

8. In general, would you say your health is

Mark only one oval.

- Excellent
- Very good
- Good
- Fair
- Poor

9. Did you take stress medicine or receive stress treatment during the past 24 hours?

Mark only one oval.

- Yes
- No

10. Did you smoke during the past 24 hours?

Mark only one oval.

- Yes
- No

11. Did you have alcohol during the past 24 hours?

Mark only one oval.

- Yes
- No

12. Did you have a good sleep last night?

Mark only one oval.

- Yes
- No

13. Did you participate in intensive exercise during the past 6 hours?

Mark only one oval.

- Yes
- No

14. Did you have any caffeinated beverages during the past 6 hours?

Mark only one oval.

- Yes
- No

15. How would you rate your stress level TODAY?

Mark only one oval.

- 1 (Very Little)
- 2
- 3
- 4
- 5 (extreme)

16. Have you ever stayed in a hospital?

Mark only one oval.

- Yes
- No

APPENDIX D

Satisfaction Questionnaire

1. Please select your group number provided by researcher.

   Mark only one oval.

   ◯ 1
   ◯ 2
   ◯ 3

2. I liked the design of the space

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

3. I enjoyed being in the space

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

4. Spending time in the space was annoying

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

5. I liked my experience in the space

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

6. I felt inspired in the space

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

7. I was happy with the existing elements in the space

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

8. I felt a connection to nature and the environment in this space

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

9. This space could positively impact my satisfaction when receiving care

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

10. This space could negatively impact my satisfaction when receiving care

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

11. I felt safe and in control in the space

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

12. My feelings about nature in this space positively affected how I felt in the space

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

13. My feelings about nature in this space negatively affected how I felt in the space

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

14. I believe natural elements (landscape, light, plants) are very important to be implemented in healthcare settings

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

15. Please rate the level of satisfaction with this space

Mark only one oval.

	1	2	3	4	5	
Not satisfied	⬭	⬭	⬭	⬭	⬭	Extremely satisfied

APPENDIX E

NASA TLX

16. How much mental demand and perceptual activity was required to complete the task?

Mark only one oval.

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

17. How much time pressure did you feel due to rate or pace at which the task occurred?

Mark only one oval.

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

18. How successful do you think you were in accomplishing the goals of the task?

Mark only one oval.

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Good

19. How hard did you have to work to accomplish the task?

Mark only one oval.

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

20. How insecure, discouraged, irritated, stressed, and annoyed did you feel during the task?

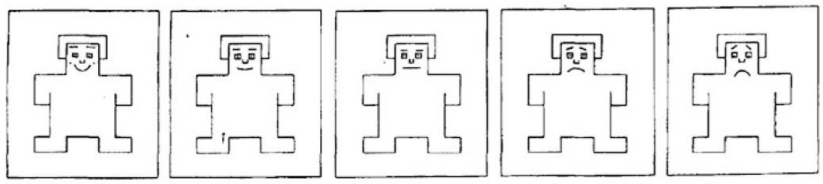
Mark only one oval.

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

APPENDIX F

Self-Assessment Manikin

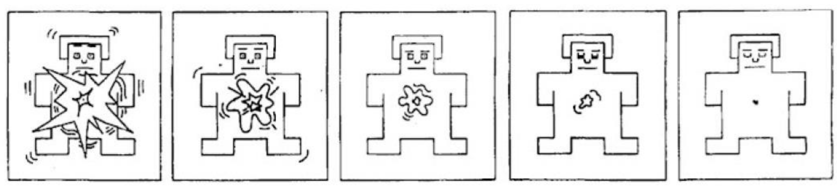
21. Please select the avatar that best describes how you feel (valence)



Mark only one oval.

	1	2	3	4	5	
Left Avatar	◯	◯	◯	◯	◯	Right Avatar

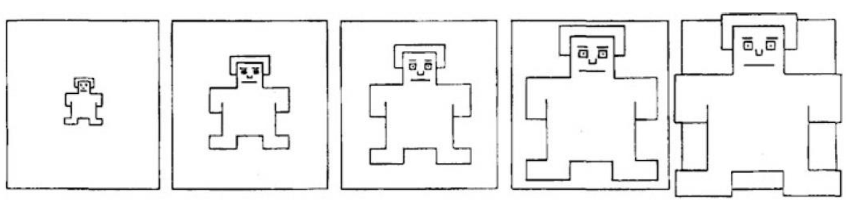
22. Please select the avatar that best describes how you feel (arousal)



Mark only one oval.

	1	2	3	4	5	
Left Avatar	◯	◯	◯	◯	◯	Right Avatar

23. Please select the avatar that best describes how you feel (dominance)



Mark only one oval.

	1	2	3	4	5	
Left avatar	◯	◯	◯	◯	◯	Right Avatar

APPENDIX G

Stress Level Questionnaire

24. I felt stressed in the space

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	strongly agree

25. I found it hard to be relaxed within the space

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

26. How would you rate your level of stress within the space?

Mark only one oval.

	1	2	3	4	5	
very little	◯	◯	◯	◯	◯	extreme

27. Can you list some positive aspects of the space?

____

28. Can you list some negative aspects of the space?

____

29. How likely are you to recommend someone else to walk through this space?

Mark only one oval.

	1	2	3	4	5	
Never	◯	◯	◯	◯	◯	Extremely likely

APPENDIX H

IRB Approval Letter

Oklahoma State University Institutional Review Board

Application Number:	IRB-21-182
Proposal Title:	Understanding the Effects of Biophilic Design in Healthcare Environments Through the Use of Virtual Reality
Principal Investigator:	Tilanka Chandrasekera
Co-Investigator(s):	Allison Howard
Faculty Adviser:	
Project Coordinator:	
Research Assistant(s):	

Status Recommended by Reviewer(s): Approved

Study Review Level:	Exempt
Modification Approval Date:	10/12/2021

The modification of the IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46. The original expiration date of the protocol has not changed.

Modifications Approved:
Modifications Approved: Minor revision to survey

The final versions of any recruitment, consent and assent documents bearing the IRB approval stamp are available for download from IRBManager. These are the versions that must be used during the study.

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

1. Conduct this study exactly as it has been approved.
2. Submit a status report to the IRB when requested
3. Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB policy.
4. Maintain accurate and complete study records for evaluation by the OSU IRB and, if applicable, inspection by regulatory agencies and/or the study sponsor.
5. Notify the IRB office when your research project is complete or when you are no longer affiliated with Oklahoma State University.

Sincerely,

Oklahoma State University IRB
223 Scott Hall, Stillwater, OK 74078
Website: https://irb.okstate.edu/
Ph: 405-744-3377 | Fax: 405-744-4335| irb@okstate.edu

VITA

Allison Howard

Candidate for the Degree of

Master of Science

Thesis: UNDERSTANDING THE EFFECTS OF BIOPHILIC DESIGN IN HEALTHCARE ENVIRONMENTS THROUGH THE USE OF VIRTUAL REALITY

Major Field: Design Housing & Merchandising

Biographical:

Education:

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