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Biophilia in Healthcare Design

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Abstract

This study explores the impact of biophilic design on patient stress levels within healthcare environments using virtual reality (VR). Despite the popularity of biophilic design, its effects on cognitive load and stress in healthcare settings remain under-researched. A between-group experiment with 60 participants was conducted where participants were exposed to three different VR healthcare environments: one without biophilic elements, one with a single biophilic element, and one with combined biophilic elements. Physiological responses, including heart rate and skin conductance were measured using the BIOPAC system, while cognitive load and stress were assessed through questionnaires and eye-tracking data.

The results indicate no significant effect of biophilic elements on cognitive load, stress levels, or physiological responses. However, a significant difference in valence was observed, with condition two differing from condition three. These findings suggest that while biophilic design may not significantly reduce stress or cognitive load in healthcare environments, it can influence emotional responses. Further research is needed to understand the mechanisms through which biophilic elements affect patient experiences in healthcare settings Expanding the sample size and conducting studies in actual environments could further validate these findings.

Keywords: *Biophilic Design, Healthcare Environments, Virtual Reality, Cognitive Load, Stress, Emotional Responses*

Introduction

Americans are separated from the natural environment now more than ever 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 meagre extant findings on its impact on cognitive load pertaining to 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 aim of this study is to investigate the impact biophilic design has on patient stress levels within healthcare environments. There is a critical need for inclusion of biophilic elements within healthcare environments, so that patients' well-being – both physical and mental – can positively benefit. Additional research on this subject could influence the way healthcare spaces are designed in order to improve patient satisfaction. Not only can the inclusion of biophilic elements increase patient experience, but it has also been proven to increase satisfaction levels amongst 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. However, there is a way to incorporate aesthetics while ensuring functionality (Totaforti, 2018). The problem is that while only focusing on functionality of a given healthcare space, it unintentionally can cause negative impacts on mental and physical health of those who are associated with it. 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. The Research Questions and Hypotheses are as follows. RQ1: How do biophilic elements effect cognitive load?, RQ2: How do biophilic elements effect satisfaction in virtual healthcare environments?, RQ3: How do biophilic elements effect stress in virtual healthcare environments?, RQ4: How do biophilic elements effect pleasure in virtual healthcare environments?, RQ5: How do biophilic elements effect arousal in virtual healthcare environments?; H1: Biophilic environments decrease cognitive load of that environment., H2: Decreased cognitive load decreases stress levels of that environment., H3: Decreased cognitive load increases satisfaction of that environment., H4: Decreased cognitive load increases pleasure and arousal of that environment.

Theoretical Background

Biophilia and Design

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). People naturally prefer biomorphic forms and natural elements. This is because they offer 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 an overall experience. Botanical motifs, simulation of natural features and biomimicry are all means designers can incorporate such forms and patterns of nature 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.

Use of 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 execute 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. This can be a very costly process. Visual simulations such as VR conversely, allows designers to implement multiple modifications that omit such costs. Users can interact with a virtual environment (VE), and move objects around, or perform actions within virtual space. Using VR can not only provide participants an immersive experience, but can also use to detect effects of specific environments on stress reduction and cognitive functioning (Yin et al., 2019). A study assessing 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). Biophilic design has been shown to reduce stress and promote positive emotions across diverse fields, from office spaces to educational settings. For example, studies in environmental psychology demonstrate that exposure to natural elements can improve mood, reduce mental fatigue, and enhance satisfaction. This research underscores the potential value of biophilic principles in healthcare, where patients and staff alike may benefit from stress-reducing and restorative environments. However, little empirical work has examined these effects within healthcare settings specifically, and even less within virtual simulations, which offer controlled environments for preliminary testing.

Methodology

A between-group experiment was conducted to explore the effect of biophilia on stress, pleasure and arousal, satisfaction, and cognitive load. The data collection took place on the 10th of January 2021, in a Mid-Western university in the US. 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.

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 Acknowledge 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.

60 participants were recruited to participate in this study by reaching out to them during their classes, posted flyers, and email invitations. A convenience sampling method was applied to recruit subjects. Before asking participants to sign the informed consent form, they were 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.

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 them. Heart rate and skin conductance levels were measured to assess 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 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 (Figure 1). The virtual environments were designed using Sketchup software, and then rendered in Enscape to wield a 360-degree spherical image.

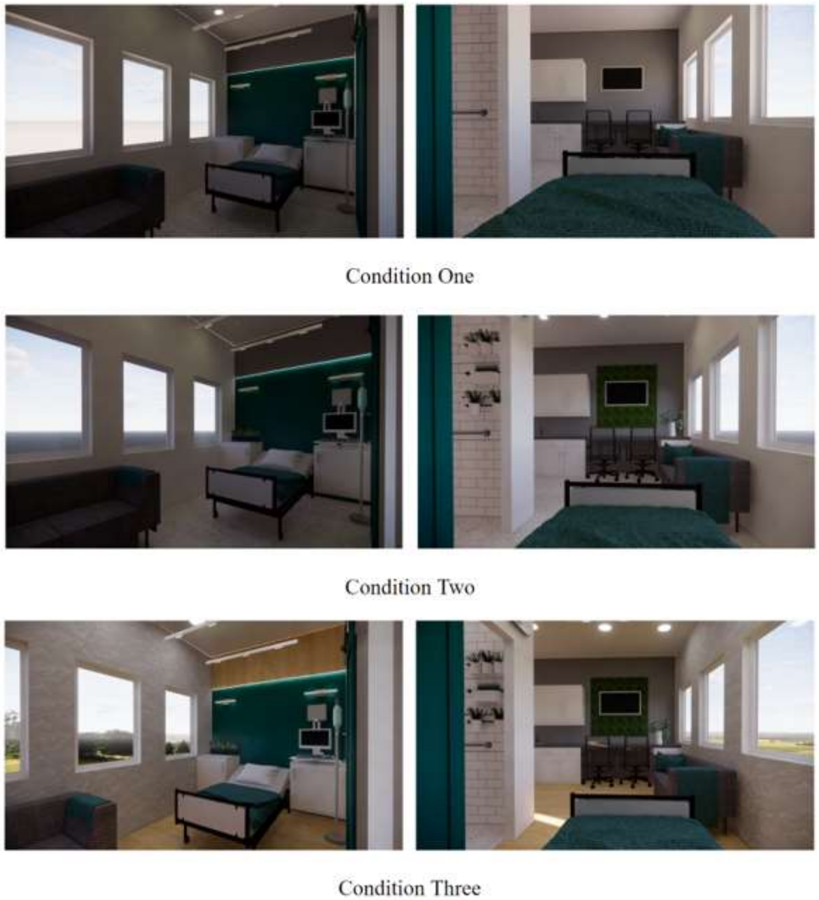

Fig.1 Three conditions of the healthcare environments
(Condition 1, Condition 2, Condition 3)
Source: Authors (2025)

Results and Discussion

Cognitive Load

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 Table 01. 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. An analysis was run to determine if there was a difference in cognitive load between the three different conditions. However, there was not a significant effect caused by the inclusion of biophilia on cognitive load for the three conditions. In addition, a small effect size was found (Cohen's d = .201).

	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			

Table 1: One Way Analysis of Variance – Mental Demand
Source: Authors (2025)

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

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

Table 2: One Way Analysis of Variance – Pupil Dilation
Source: Authors (2025)

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 were 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. Stress: 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 data gathered from the Acknowledge 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 was not included in the discussion of results.

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. 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].

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.

Fixation

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).

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]. 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. 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].

	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 3: One Way Analysis of Variance – Valence
Source: Authors (2025)

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

Table 4: Post Hoc – Valence
Source: Authors (2025)

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

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. 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].

	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 5: One Way Analysis of Variance – Satisfaction
Source: Authors (2025)

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

Table 6: Post Hoc – Satisfaction
Source: Authors (2025)

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.

Conclusions

The current study pertaining to biophilia is of great significance, owing to its potential positive implications for healthcare environments. In the contemporary times, with most of people's time being spent indoors, many have or will have an experience in a healthcare setting – either as a patient or a visitor. The inclusion of biophilic design within interior environments has been thoroughly studied, and extant research indicate that it has physiological and cognitive benefits. However, when it comes to biophilia in healthcare, a knowledge gap exists with relation to the need for more research on how it could impact patients cognitively. Consequently, a between-group experiment to explore the effect of biophilia on stress, pleasure and arousal, satisfaction as well as cognitive load was carried out. 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 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. Yet, 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.

Participants' familiarity with VR technology may have influenced their responses, as VR experience can impact cognitive and emotional reactions. Controlling for VR familiarity could provide clearer insights into biophilic design effects. Finally, while VR simulations allowed for controlled testing of biophilic elements, real-world studies in physical healthcare settings could further validate these findings and reveal more nuanced effects of biophilia on stress, cognitive load and satisfaction.

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