The Restorative Influence of Virtual Reality Environment Design

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Figure 1: In order from left to right, a screenshot of the moving virtual forest environment, an image of the still real forest, and an image of the abstract art, respectively. All users not in the control condition were in a 3D cabin with one wall looking out onto either the 3D moving virtual forest, a 2D still forest image, or a 2D abstract art image.

ABSTRACT

Virtual reality (VR) could support the need for easily accessible therapeutic techniques, such as viewing art and immersing oneself in nature. Our study searches for the optimal virtual environment (VE) by exploring whether beauty in moving and still VEs contributes to stress reduction and perceived restorativeness. We hypothesized that the moving forest environment would result in the most stress reduction, while the abstract art would result in the least, with additional comparisons to a still forest environment and a control condition. The control condition took place outside the virtual headset to simulate what stress reduction would look like without a nature intervention. After working with 78 participants, we found an increase in statistical significance for stress reduction and perceived restorativeness in the moving forest condition compared to the control, as measured by the Zuckerman Inventory of Personal Reactions (ZIPERS) positive affect and the Perceived Restorativeness Scale (PRS). Additionally, the PRS and heart rate measures showed greater restorativeness in the moving forest condition than in the abstract art condition. Heart rate measures also showed statistical significance between the forest image condition and the control and moving forest conditions.

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CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **Accessibility design and evaluation methods**.

KEYWORDS

Virtual Reality, Forest Bathing, Nature, Abstract Art, Stress Reduction.

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1 INTRODUCTION

There are two main types of stress: eustress, which is positive and motivational, and distress, which is harmful and exhausts mental resources. Distress is an increasingly prevalent issue, so effective stress management is essential for maintaining overall health [Organization 2021]. Many stress management techniques exist, such as breathing, exercising, viewing art, and spending time outdoors [Korpela and Kinnunen 2010; Scott 2017; Sharma et al. 2006]. Forest bathing, or nature immersion for stress reduction, [Park et al. 2010] is particularly effective because people have an innate connection with nature [Ulrich and Parsons 1992]. However, many people in high-stress environments such as hospitals or nursing homes without reliable access to nature would benefit the most from it [Browning et al. 2020]. The items surrounding these people are essential, and prior research with hospitalized adults suggests that having artwork around can improve individuals' moods and assist the healing process [Eisen et al. 2008]. Nature art can distract hospital patients from pain [Vincent et al. 2010]. More realistic, immersive depictions of nature may offer additional benefits beyond artwork.

Disability, work schedules, safety, and location are just a few problems surrounding immersive nature and art accessibility. Researchers are showing new interest in increasing accessibility via virtual reality (VR), an audio-visually immersive platform [Masters et al. 2022; Zhou 2019]. VR can integrate familiar and novel stress-reducing experiences into everyday life. VR forest bathing has shown the potential to lower stress similarly to real forest bathing [Hejtmánek et al. 2022]. Furthermore, while research shows that VR allows individuals to immerse and interact with art, little work has studied VR art and stress reduction [Zhou 2019]. One study found that immersing museum visitors in a virtual exhibit could reduce stress while improving experience [Lee and Yoon 2019]. Current literature on forest bathing and virtual art raises new, exciting questions for future work on how escape experiences can be structured to promote overall mental health and rehabilitation.

This study aims to understand better: **Does the stress-reducing benefits of virtual forest bathing come from seeing something beautiful or the realistic movement within nature?** Realistic movements are visible in the 3D-rendered virtual nature environment (VNE) that are not captured in a static 2D forest image. The study explores how viewing moving and still forest imagery compares to abstract art in VR, measuring stress reduction and perceived restoration (see Figure 1). A 3D VNE with moving plant assets is compared against a still image of real nature in VR to investigate further the role of realistic movement versus natural beauty for a restorative effect. Then, a VR abstract art display was chosen to examine the role of seeing natural beauty versus something generally beautiful, as it is beautiful without natural qualities. To exclude visual and audio simulation of nature, we requested participants to sit with their eyes closed without using a virtual headset in our control condition. Our control condition would allow for a complete comparison of the effects of the virtual visual conditions. Understanding the nuances of beauty and movement in nature and art will give insight into providing the optimal VR stress reduction tools.

The **contributions** of our work include (1) comparing the realistic characteristics of VNEs with (a) the beauty of nature and (b) the beauty of non-nature, as well as (2) providing further evidence on both the potential stress-reduction qualities of VNEs and (3) the effectiveness of the Masters et al. [Masters et al. 2022] implementation of the Markus and Peters Arithmetic Test (MPATest).

2 RELATED WORK

2.1 Using Virtual Environments for Alleviating Stress

VR Head-Mounted Displays (HMDs) facilitate users' immersion in a new environment, completely separating their visual senses from the real world [Jerald 2016]. Thus, VR can be a powerful stress reduction tool through experiences that enhance user perception using combined visual and audio elements, especially for people without nature access, by restoring attention and reducing stress. VNEs have successfully reduced self-reported stress in high-stress adults [Kim et al. 2021], in VEs such as guided meditation [Tarrant et al. 2018]. Additionally, a mini-review concluded that VNEs have the potential to contribute to relaxation measurable by physiological and psychological measurements [Li et al. 2021]. A previous study concluded that participants performed cognitively better after exposure to the VNE [Mostajeran et al. 2023]. A similar study showed young adults and senior citizens experienced reduced negative emotions and enhanced positivity after walking through a virtual forest [Chan et al. 2021]. Although these environments may be favored and demonstrate similar results as physical forests, replacing physical walks with virtual ones is not encouraged unless mobility is limited [Reese et al. 2022]. The qualities of VNEs that facilitate stress reduction and attention restoration are actively being studied, and there are more mediums outside of nature that have stress reduction qualities.

Art is one of these mediums, yet there are few studies on immersive virtual art viewing and stress reduction. Immersion is the capability of producing the sensation of presence, whereas presence is the sensation of being there [Riva et al. 2003]. The relation between immersion and stress reduction is unclear, but VEs with fascinating qualities have been shown to increase presence while enhancing stress-reducing effects [Velana et al. 2022]. As art has interesting qualities, it is important to understand the relationship between VR art and immersion. A common location that utilizes VR to present art is a museum. These museums will address participants' presence to determine the usefulness of VR mediums, demonstrating immersive VEs enhance overall tour experience [Lee and Yoon 2019]. This research suggested that VR art can improve museum visitors' experience, but more work is needed on how VR art can be used for stress reduction.

Since VR is an advanced media that simulates highly realistic VEs, benefits are being explored in healthcare settings [Li et al. 2021]. A study exploring cognitive training for those with Parkinson's Disease found that VR could potentially improve cognitive outcomes through rehabilitation [Maggio et al. 2018]. Regarding stress reduction, Prabhu et al. reported decreased surgical pain for patients in the VR group where the environment was based on Kaplan's Attention Restoration Theory (ART) [Prabhu et al. 2020]. Kaplan's ART proposed that people's attention gets restored during exposure to nature [Hartig 1996]. ART is also the basis for the Perceived Restorativeness Scale (PRS), which defines restorativeness as how well the user perceives the environment to restore their mental resources.

In addition to ART, Ulrich's Stress Reduction Theory (SRT) is fundamental for forest bathing research. SRT states that immersion in natural environments promotes stress recovery [Park et al. 2010; Ulrich 1981]. Both theories relate to the Biophilia Hypothesis [Wilson 1986], which says that humans have inner attraction and development that relates them to nature. Hansen et al. aimed to illustrate the benefits of this relation to healthcare providers to encourage incorporating nature immersion into existing therapeutic methods [Hansen et al. 2017]. There is a push to investigate the applications of these theories in VR. Browning et al. reported that similar positive effects are induced from both virtual and real nature environments [Browning et al. 2020]. Chirico and Gaggiloi found no significant difference between virtual and real nature environments [Chirico and Gaggioli 2019]. Conflicting evidence is drawn from Calogiuri et al.'s study that demonstrated real environments performed better in positive and negative affect measurements than VNEs [Calogiuri et al. 2018]. Further research is required to gain deeper insight into similarities and differences in stress reduction potential between VNEs and real nature. Several studies support that environmental characteristics such as quality and structure could influence stress reduction [Gatersleben and Andrews 2013; López-Pousa et al. 2015; Pretty et al. 2005]. Considering nature and art settings, the characteristics of VEs will be further explored to understand different stress reduction alternatives.

2.2 Characteristics of Restorative Virtual Environments

To successfully provide stress-reducing benefits to users via VEs, certain characteristics of these environments need to be further analyzed, including biomass, colors, audio, realism, point of view, biodiversity, and the inclusion of water. Masters et al. did an initial exploration into stress reduction in VNEs with and without plant life, finding trends in favor of plant life but no significant results [Masters et al. 2022]. The Biophilia Hypothesis supports the characteristics oriented with biological survival resources such as water [Wilson 1986]. Rikard et al. explored the use of ocean VNEs with the elderly, finding that this type of environment provoked various emotional reactions that may improve well-being [Lundstedt et al. 2021].

Beyond the characteristics and overall design of the VEs, the quality of the HMDs may also influence stress reduction. Headset qualities that commonly influence the flow of an experiment include stability, user motion, presence/immersion, brightness, field-of-view, and lag in the display. Issues with any of these qualities could result in cybersickness. Cybersickness is similar to motion sickness, characterized by headaches and dizziness. We attempted to counter cybersickness by removing the user's ability to move translationally in the VE. However, users could still rotate their heads and the chair they were physically sitting in. Allowing movement could influence the loss of direction, thus increasing dizziness.

3 METHOD

This study focuses on specific VNE characteristics, aiming to investigate the influence of the movement and beauty of nature and art environments on lowering stress and restoring mental resources. We created three immersive VR environments to accomplish this aim. Each is in the same 3D cabin with one wall showing either (1) a 3D moving forest environment, (2) a 2D still-life forest image, and (3) a 2D abstract art image. Through the 3D forest, we can observe how beauty and movement may reduce stress. In our 2D VR images, we can observe different kinds of beauty but not realistic movements. The Institutional Review Board approved this experiment. We **hypothesize** the following:

H_1: The VE that utilizes moving biomass is hypothesized to be more effective at reducing stress and perceived as more restorative than the other two VEs and our control condition [Jo et al. 2021].

H_2: The VE that uses abstract art is hypothesized to be the least effective at reducing stress and perceived as the least restorative of the three VEs based on the prior literature comparing nature depictions to abstract art forms [Ulrich and Lundén 1993].

3.1 Participants

After exclusion, 82 participants were recruited from Colorado State University, with a goal of 20 participants for each condition. Exclusion criteria included self-reported vision below 20/60 and self-reported history of heart conditions or seizures. Four participants were removed due to incomplete physiological measurements. We utilized the remaining 78 participants for the entirety of the study analysis. Ages ranged from 18 to 35, with a mean of 21. 31 of the individuals were female, and 47 were male. None of them selected any other gender. Only 12 claimed not to have used VR before. All participants reported weekly hours using VR, which ranged from zero to 24, with an average of 1.68. 47.4% of the pool reported wearing corrective lenses.

3.2 Materials

The consent form and questionnaires were delivered via Google Forms [Google 2023] on an HP Pavilion laptop. The stressor test was conducted on an Alienware personal computer (PC) with an 11th Gen Intel(R) Core(TM) i9 processor at 2.50GHz, 128 GB RAM, 1.84 TB hard drive space, and NVIDIA GeForce RTX 3090 GPU. The VEs were administered on an HTC Vive Pro 2 HMD on the same PC. Heart rate (HR) was collected on a Fitbit Sense (Model # FB512) using the Fitbit phone application. Blood Pressure (BP) measurements were collected with an Alphamed monitor (Model # U85H).

3.3 Procedure

The experiment was a between-subjects experiment, where participants were randomly (using Latin squares) assigned a participant number that corresponded to one of four environments. One participant entered the lab at a time, and the experiment took one hour to complete. Figure 2 shows the experiment procedure. The participants filled out a consent form and were informed they could leave anytime. The demographics questionnaire next inquired about age, major, gender, if they have used VR before, hours a week using VR, hours a week spent on a computer, hours a week spent playing video games, and their most commonly played games. Then, the first physiological and psychological measurements were taken, detailed in Section 3.4.2. Measurements were administered in this order: HR, BP, the Positive and Negative Affect Schedule (PANAS), the Zuckerman Inventory of Personal Reactions (ZIPERS), and the PRS. Afterward, participants completed the stressor task described in Section 3.4.1. The second set of measures was then collected to determine if the participant's stress increased from the stressor. The participants then entered one of the four environments based on participant number. These four environments are either the VR immersive nature as in Figure 1.1, VR nature image as in Figure 1.2, VR abstract art image as in Figure 1.3, or control. HR was collected from the Fitbit mobile application for each minute in the condition. After ten minutes in the condition, participants removed the HMD to have the third set of measures collected. A nature aesthetic preference questionnaire was completed, ranking natural environments that were similar and different from the experimental conditions on the PRS. An open-exit questionnaire was used to understand user experience and if they got cybersick. Participants were then debriefed and dismissed.

3.4 Design

The following subsections detail experimental tasks and measures.

3.4.1 Stressor Task. The task provided to participants is the MPATest [Peters et al. 1998], consisting of 20 one-minute questions, each with three parts. The first part is 40 seconds for solving a two-digit multiplication question (like 48 x 92). The second part is ten seconds to add or subtract a one-digit number from the prior answer. The third part is the same as the second part. The participant could also press enter to progress instead of waiting the full time. Participants were asked to put headphones on and listen to audio of traffic, sirens, and cars honking [Pals 2016] for the test duration. The stressor task was designed to guarantee that all participants entered the experiment condition with increased stress so that any stress reduction in the experiment condition was observable. Participants were not asked about prior math background, as the additional noise was designed to augment distress regardless of how well the individual answered the questions [Linden 1991].

3.4.2 Physiological and Psychological Measurements. Physiological and psychological measurements were taken three times: once as a baseline when participants entered (pre-stress), once after the stressor task (post-stress), and once after the condition (post-environment). The stressor is successful if post-stress measures show increased stress compared to pre-stress measures. The stress decrease between post-stress and post-environment measures is hypothesized in H_1 and H_2 to differ between experiment conditions.

The physiological measurements collected are HR and BP. Participants wore the Fitbit watch, so their HRs were collected in real-time throughout the experiment. In addition to the pre-stress, post-stress, and post-experiment data collection, HR was recorded every minute of the ten minutes participants were in the condition to observe how HR changed. BP was recorded three times throughout the experiment: baseline, post-stress, and post-environment. BP measurements were separated into systolic and diastolic BP. Systolic reports the pressure within the arteries when the heart beats. Diastolic reports the pressure within the arteries when the heart rests between the beats.

The psychological measurements used in the questionnaire include PRS, PANAS, and ZIPERS, all of which are five-point Likert scales. The PRS is divided into four subsections: being away, fascination, coherence, and compatibility. General restorativeness is a combination of being away, fascination, and compatibility. Statistical significance with PRS indicates that the participant reported perceived restorativeness [Hartig et al. 1997]. The PANAS surveys' self-reported stress levels are separated into two dependent variables: positive and negative affect. The higher the added score, the higher the positive/negative affect levels [Watson et al. 1988]. ZIPERS also measures positive and negative affect but uses 12 statements like "I felt sad." measuring elements like sadness, attentiveness, and anger. A statistically significant difference in the ZIPERS survey would demonstrate a difference in positive or negative affect levels [Zuckerman 1977]. Note that all three scales were provided in the pre-stress, post-stress, and post-experiment questionnaires.

3.4.3 Three Virtual Environments. Three of the four conditions that participants can be randomly assigned are within VEs designed using Unreal Engine 4 [Games 2021]. These environments are identical in every way, with the same tables, lights, and forest audio, including wind and rustling [Pixabay 2021]. The only difference is the display on one wall. Each participant is stationary, sitting in a chair in the middle of a cabin. While participants were allowed to move their heads to look around in the environment, they could not translationally move to minimize cybersickness [Jerald 2015].

The virtual chair is positioned towards a window view the size of the wall and shows one of three views. One view available to the participants was the **3D moving forest**, designed to look similar to the forest image but with moving qualities of nature using virtual assets in 3D (i.e., as if you were looking at the forest from your cabin). Specifically, we used tree movement, but the amount of movement was not measured. This forest is a 3D collection of virtual tree assets with movement and depth, rolling mountains in the background, a forest sloping downhill, snowy rocks in the foreground, and the sun in the same location as the forest image. This environment is hypothesized in H_1 to be the most restorative.

Another view was the **2D forest image** taken by a research team member overlooking a mountain range in Bailey, Colorado. The image has rolling mountains in the distance, forest trees sloping downhill, and snow-covered rocks in the foreground. This image captures the natural forest environment's beauty, yet it is 2D and lacks movement. This environment is hypothesized in H_1 and H_2 to be more restorative than the abstract art environment and less than the 3D moving forest environment.

The last view was an **abstract art image** of Piet Mondrian's Composition II in Red, Blue, and Yellow, 1930 [Mondrian 1930]. This piece was used because it contains abstract shapes and colors not found in forest environments, capturing the non-natural beauty of abstract art. Being a 2D art image on the wall, it also lacks movement and is hypothesized in H_2 to be less restorative than both VEs.

3.4.4 Control Condition. The control condition is the fourth environment in which participants did not use VR and were asked to shut their eyes for ten minutes in silence. This control condition aimed to observe how participants would reasonably reduce stress in the absence of VR solution and a nature invention. There was no audio as the goal was to remove all stimuli, and the experimenter remained in the room to continue monitoring the participant's HR. Having this as the control condition allowed no outside influence on what the participants saw in the space around them. Using a self-care technique of the participant's choice or a neutral VE was considered, but this environment can be vague and has confounding variables with unintended psychological effects on the wearer.

3.4.5 Questionnaires. The aesthetic preference questionnaire was completed at the end of the experiment to understand personal preferences on a five-point Likert Scale using PRS. This questionnaire consisted of six images: three images of real forest environments, two forest VEs, and Piet Mondrian's abstract art used in the study. The open-exit questionnaire asked three questions: Did they experience cybersickness? What could be improved? What did they enjoy? Responses will support analyzing the effectiveness of only allowing head rotation and considerations for future experiments.

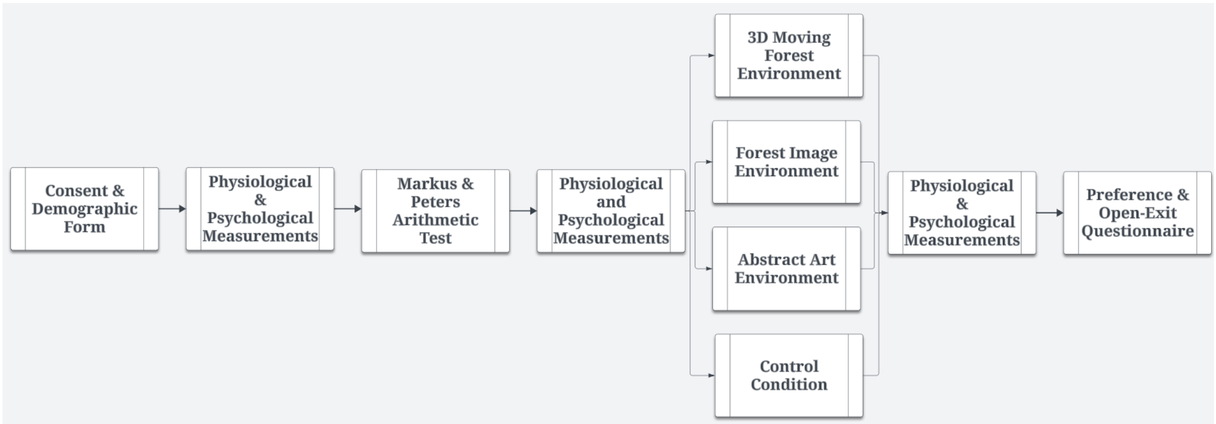

Figure 2: Order of the Study's Procedure

4 RESULTS

Three sets of measurements were taken throughout the study. Each time, the physiological measurements were collected before administering the psychological survey. As described in Section 3.4.2, we will continue to use the terms pre-stress, post-stress, and post-experiment. A preliminary Analysis of Variance (ANOVA) compared the differences (pre-stress to post-stress) between condition groups, followed by T-tests observing the efficacy of the stressor on all participants across conditions (pre-stress minus post-stress comparison). An ANOVA was conducted on all dependent variables, except for Multivariate ANOVA (MANOVA), for BP to measure the change in participants' stress levels between conditions after completing their assigned conditions, which was needed because systolic and diastolic depend on each other for each participant between independent conditions. Table 1 contains these p-values.

ANOVA was performed to verify no significant difference in physiological or psychological readings between groups of participants before the experimental treatment. The change in a participant's physiological and psychological response was used in this analysis to account for individual physiological and psychological variability. All changes in response were reasonably normally distributed under the standard by Glass et al. [Glass et al. 1972]. All preliminary variability between treatment groups was found to not be statistically significant except for differences in negative PANAS responses ($F(3, 78) = 3.241, p = 0.026$). Tukey's Honestly Significant Difference (HSD) Test for multiple comparisons found that the mean value of the change in negative PANAS responses significantly differed between the moving forest condition and the still forest image condition ($p = 0.038, 95\%\ C.I. = [0.164, 8.217]$). The participants in the moving forest condition reported more negative PANAS responses to the stressor task than participants in the still forest image condition, indicating a higher negative effect.

Table 1: High-level overview of the p-value results. Middle column: t-test comparisons from the stressor task. Right column: ANOVA and MANOVA comparisons between the four conditions. When compared, Tukey's HSD was used to identify which conditions displayed statistical significance. The dagger symbol † demonstrates p-values from the ANOVA tests that were not statistically significant, meaning a Tukey's HSD test was not required to determine the significant conditions. Highlighted green are the p-values that showcased statistical significance.

	T-Tests	(M)ANOVA / Tukey's HSD
Measurements	**Pre-Stress to Post-Stress**	**Post-Stress to Post-Environment**
PANAS Positive	p < 0.001	p = 0.150 †
PANAS Negative	p = 0.034	p = 0.636 †
ZIPERS Positive	p < 0.001	p = 0.019 (Control to Moving)
ZIPERS Negative	p < 0.001	p = 0.728 †
PRS	p = 0.509	p = 0.003 (Control to Moving)
		p = 0.002 (Abstract to Moving)
Heart Rate	p = 0.008	p = 0.017 (Moving to Abstract)
		p = 0.011 (Control to Forest)
		p < 0.001 (Moving to Forest)
Blood Pressure Systolic	p = 0.024	p = 0.288 (The Only MANOVA)
Blood Pressure Diastolic	p = 0.622	

4.1 Stressor Task Results

A t-test between pre-stress HR ($M = 82.859, SD = 10.459$) and post-stress HR ($M = 86.218, SD = 10.069$) was conducted to determine the efficacy of the stressor task at increasing physiological stress. The main effect, rather than between groups, was the only element of the stressor task we were interested in because the same stressor task was provided to all participants. There was an increase in HR among participants ($t(77) = 2.735, p = 0.008$). A t-test between the pre-stress systolic BP ($M = 122.808, SD = 15.055$) and the post-stress systolic BP ($M = 118.256, SD = 16.650$) was conducted to determine the efficacy of the stressor task at increasing physiological stress. There was a decrease in systolic BP among participants ($t(77) = -2.304, p = 0.024$). A t-test was conducted between the pre-stress diastolic BP ($M = 77.603, SD = 13.103$) and the post-stress diastolic BP ($M = 76.885, SD = 14.456$). Diastolic BP did not statistically change significantly after undergoing the stressor task ($t(77) = -0.495, p = 0.622$).

T-tests were conducted on all the psychological results between the pre- and post-stress measures. ZIPERS test for negative affect suggested there was a difference between stress levels before ($M = 1.915, SD = 2.974$) and after ($M = 4.866, SD = 4.348$) the stressor task ($t(81) = 5.841, p < 0.001$). ZIPERS negative affect increased. ZIPERS test for positive affect suggested there was a difference between stress levels before ($M = 7.366, SD = 5.007$) and after ($M = 4.439, SD = 3.824$) the stressor task ($t(81) = -5.789, p < 0.001$). ZIPERS positive affect decreased. PANAS test for negative affect suggested there was a difference between stress levels before ($M = 5.634, SD = 5.227$) and after ($M = 6.866, SD = 6.085$) the stressor task ($t(81) = 2.157, p = 0.034$). PANAS negative responses increased. PANAS test for positive affect suggested there was a difference between stress levels before ($M = 18.768, SD = 7.977$) and after ($M = 12.646, SD = 7.522$) the stressor task ($t(81) = -9.407, p < 0.001$). PANAS test for positive effect decreased. PRS results were not statistically significant ($t(81) = -0.664, p = 0.509$). The stressor task did not change the subject's level of perceived restorativeness.

4.2 Physiological Results

A repeated measures ANOVA was conducted to examine the effects of time and treatment on HR, with participants as a random factor. The HR of each participant from minute 1 to minute 10 of treatment was used in this analysis.

The main effect of treatment was significant ($F(3, 796) = 7.245, p < 0.0001$), with treatment explaining a significant amount of variance in HR. Post hoc comparisons using Tukey's HSD test revealed significant differences between the moving forest ($M = 75.965, SD = 11.097$) and abstract art ($M = 79.010, SD = 12.405$) conditions ($p = 0.017, 95\%\ C.I. = [-5.706, -0.384]$) as well as the control ($M = 78.085, SD = 9.353$) and forest image ($M = 81.290, SD = 7.925$) conditions ($p = 0.011, 95\% C.I. = [0.544, 5.866]$) and the moving forest and forest image conditions ($p < 0.001, 95\% C.I. = [-7.986, -2.664]$). These observations partially support H_1. The analysis did not indicate that time significantly impacted HR among participants or between treatments.

Performing a MANOVA test using diastolic and systolic BP as dependent variables and the conditions as independent variables to compare post-experiment BP between conditions did not have a statistically significant result ($F(6, 148) = 1.254, p = 0.288, Wilk's\ \lambda = 0.905, partial\ \eta^2 = 0.049$). This suggests no statistically significant difference in post-experiment BP between conditions, which also does not support H_1 or H_2.

4.3 Psychological Results

The psychological measures are analyzed by scale, including PRS, PANAS, and ZIPERS, detailed in Section 3.4.2.

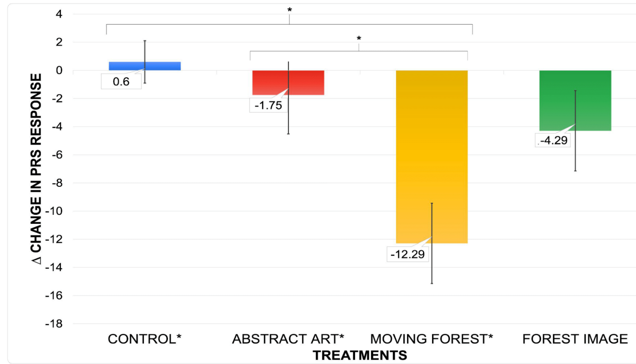

Figure 3: The average change in the sum of participant responses to the PRS survey after completing the treatment task. An increase in effect appears to be a negative change. For example, 5 - 10 is -5. Error bars represent standard error ($SD/\sqrt{(n)}$). Asterisk (*) denoting statistically significant values.

4.3.1 PRS. A one-way ANOVA was performed to compare the effect of each experimental treatment on participant responses to the PRS survey. There was a statistically significant difference between at least two treatment groups ($F(3, 78) = 4.921, p = 0.003$). Tukey's HSD Test for multiple comparisons found that the mean value of the change in responses to the PRS survey before and after the experimental treatment was statistically significantly different between the control condition ($M = 0.600, SD = 6.747$) and the moving forest condition($M = -12.286, SD = 12.760$) ($p = 0.003, 95\%\ C.I. = [3.470, 22.302]$) as well as the abstract art condition ($M = -1.750, SD = 12.362$) and the moving forest condition ($p = 0.002, 95\%\ C.I. = [1.120, 19.952]$). Participants perceived the moving forest VE as statistically significantly more restorative than the control condition and the abstract art VE, partially supporting H_1 and H_2. Figure 3 shows a graph of the restorativeness change between conditions. Participant responses to the PRS survey were quantified and summed to obtain individual levels of restorativeness. The values shown in Figure 3 represent the average change in summed responses after VE exposure/control. Values close to zero suggest a small change in average levels of restorativeness. Negative values suggest restorativeness increased after exposure to the VEs. Positive values suggest average levels of restorativeness decreased.

4.3.2 PANAS. A one-way ANOVA was performed to compare the effect of each experimental treatment on participant responses to the PANAS negative affect survey questions. There was no significant difference between any treatment groups ($F(3, 78) = 0.570, p = 0.636$). A one-way ANOVA was performed to compare the effect of each experimental treatment on participant responses to the PANAS positive affect survey questions. There was no significant difference between any treatment groups ($F(3, 78) = 1.824, p = 0.150$), neither supporting H_1 nor H_2.

4.3.3 ZIPERS. A one-way ANOVA was performed to compare the effect of each experimental treatment on participant responses to the ZIPERS survey questions. For ZIPERS negative affect, there

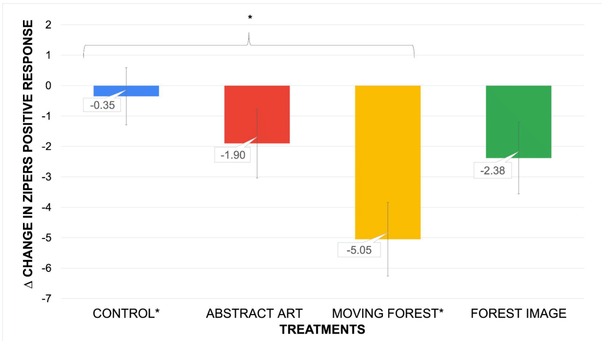

Figure 4: The average change in the sum of participant responses to the ZIPERS positive survey questions after completing the treatment task. Error bars represent standard error ($SD/\sqrt(n)$). Asterisk (*) denoting statistically significant values.

was no significant change between post-stress and post-experiment ($F(3,78) = 0.436, p = 0.728$). The ZIPERS survey questions measuring positive affect did show a statistically significant change between post-stress and post-experiment ($F(3,78) = 3.124, p = 0.031$). Tukey's HSD Test for multiple comparisons found that the mean value of the change in responses to the ZIPERS positive affect survey questions before and after the experimental treatment was statistically significantly different between the control condition ($M = -0.350, SD = 4.209$) and the moving forest condition($M = -5.048, SD = 5.408$) ($p = 0.019, 95\%\ C.I. = [0.581, 8.814]$) as shown in Figure 4. Participant responses to the ZIPERS survey were quantified and summed to obtain individual positive and negative affect levels. The values shown in Figure 4 represent the average change in summed responses after VE exposure/control. Values close to zero suggest a small change in average levels of positive affect. Negative values suggest that the positive effect increased after exposure to the VE. Positive values suggest average levels of positive affect decreased.

4.4 Natural Aesthetic Preference Questionnaire Results

In the nature aesthetic preference questionnaire detailed in Section 3.4.5, each participant was asked to rate six images of still forest images, still forest VEs, and abstract art images using the PRS scale. Experimenters calculated the general restorativeness on a scale from 0 to 72 and compared the mean and standard deviation values. This order of preference does not completely support H_1 because the images of the real environments were rated higher than those of the forest VEs. However, recall that we expected the forest VEs to be rated higher due to their moving characteristics, which cannot be captured in images. This preference order supports H_2 as the abstract image was rated the lowest preferred image.

4.5 Open-Exit Questionnaire Results

Information on the open-exit questionnaire can be found in Section 3.4.5. The following are the results from a thematic analysis performed on the results based on Braun's and Clarke's approach [Braun and Clarke 2006].

To maintain consistency, all participants, including the control condition, were asked whether they experienced cybersickness while in the VE. Most of our participants (78.20%) reported experiencing no cybersickness, with almost equal distribution across conditions. Those who experienced the still forest image VE and the abstract art VE showed higher rates of claimed cybersickness. This suggests potential differences in still images and immersion, as we removed the ability for users to move physically or virtually except for rotation.

Participants provided feedback on what could have been improved about this experiment. Responses focused on enhancing the VEs with requests for more dynamic and nature-oriented environments from the still forest image and abstract art participants, supporting H_1 and H_2. Concerns were also reported regarding the MPATest, claiming the audio was annoying and wanting a variety of math questions and lengths. These concerns highlight the stress and difficulty that arose in participants, as desired.

Lastly, participants shared what they liked about the experiment. They appreciated the VEs' calmness, audio, and interesting visuals. That being said, appreciation for the VEs was notably lower in the abstract art condition, which could potentially support H_2. Additional comments about the stressor task highlighted the challenges, audio, and overall interest.

5 DISCUSSION

Recall from Section 4 that the stressor MPATest compares pre- and post-stress measures, whereas stress reduction involves comparing post-stress and post-environment measures. The measurement and questionnaire results regarding the hypotheses are discussed here.

5.1 Stressor Task Dependent Variable Responses

Five of our dependent variables statistically significantly support the effectiveness of the MPATest, except for PRS, diastolic, and systolic BP. We expect that PRS would not provide statistical significance as it measures perceived restorativeness but was provided for consistency and is less relevant for the MPATest. We would expect a statistically significant increase in both BP values, yet there are many reasons why they did not, including participant characteristics. The open-exit questionnaire highlighted that participants found the MPATest challenging and stressful yet enjoyable. This feedback is considered to support the effectiveness of the MPATest in inducing stress, which aligns with prior literature [Masters et al. 2022].

5.2 Restorativeness Dependent Variable Responses

Our results partially support H_1 and H_2 that the moving forest VE would be perceived as the most restorative and stress-reducing condition, whereas the abstract art VE would be the least. Physiological data showed statistically significant measures in multiple comparisons for HR, which can be observed in Figure 5. HR analysis

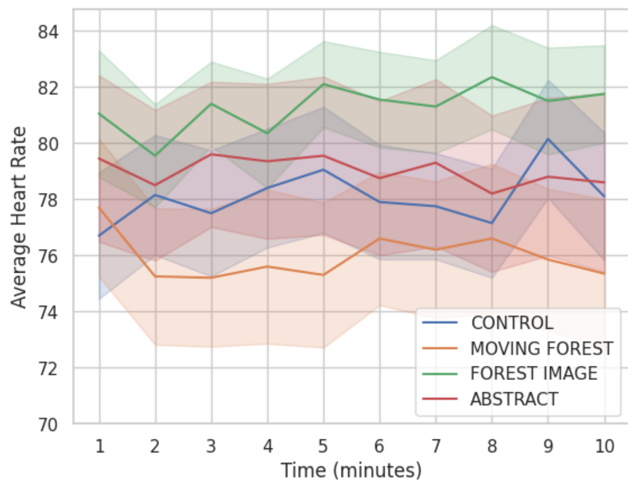

Figure 5: The average change in participant's HR every minute as they experienced each experimental treatment for ten minutes. Error bands represent the SE at each time point.

provided statistical significance between the moving and abstract art conditions, the control and forest image conditions, and the moving forest and forest image conditions. This mostly aligns with the psychologically significant measures where PRS found a statistically significant difference between the moving forest VE and the abstract art VE and control condition. Additionally, ZIPERS positive found a statistically significant difference between the moving forest VE and the control condition. While PANAS is a similar survey to ZIPERS, it may not have demonstrated statistical significance due to the ZIPERS questions being more personalized, including "I" statements. The forest image condition does not appear to align across the perceived psychological results and the physiological measures. This could be attributed to the perceived visual beauty but the lack of realistic movements. The primary takeaway from the preference questionnaire is that abstract art was rated lowest. The thematic analysis found more positive comments in response to the moving and still forest VEs than the abstract art VE.

5.3 Limitations

There are a few limitations to this study. First, we did not measure the movement in the 3D forest VE, yet thematic analysis comments mention too much or insufficient tree movement, indicating that participants notice movement. Future studies should determine how to measure the movement. Second, there are alternative measures future studies should consider using. We measured HR with a Fitbit watch, which has since been reported unreliable in studies after ours [Hajj-Boutros et al. 2023; Ronca et al. 2023]. With stronger equipment, future studies should consider using HR variability and electrodermal activity in exchange for HR and BP as they have been reported as better indicators of stress [Menghini et al. 2019; Zhu et al. 2022]. Additionally, ZIPERS and PANAS are very similar measures, and future studies should consider replacing ZIPERS with Perceived Stress Scale as there is a change in usage throughout literature [Scale 1983]. Third, our VEs were stationary, and users could only rotate due to our concern about cybersickness, which may limit immersion and engagement in the environments. Future studies should consider alternative methods to counter cybersickness while including an established cybersickness questionnaire, such as the VRSQ and the CSQ VR. Lastly, all our participants were from the university community aged 18 to 35, and none selected non-binary or any other gender, so a more diverse pool is needed to see how the VEs would affect a broader population. A larger sample size is also recommended for future studies as our Cohen power analysis result of 0.35, with an effect size of 0.5, is considered inadequate for the number of conditions we utilized.

6 CONCLUSION AND FUTURE STUDIES

Our study aimed to explore whether moving and beauty characteristics in VE influenced stress reduction in users. The Biophilia Hypothesis, ART, and SRT suggest that humans have an innate connection with nature that reduces stress and restores attention. Thus, we explored whether immersion in a VNE could be an effective stress-reduction option for individuals without nature access. Several features could influence VE effectiveness, so we focused on the moving and beauty characteristics. We decided to modify these characteristics since prior literature has also demonstrated success in stress-reducing for individuals viewing abstract art. The results of our chosen VEs imitating a moving forest, a still forest image, and a still abstract art image highlight the importance of the moving and beauty characteristics.

Our results indicated partial support for H_1 and H_2 that the 3D moving forest VE was more stress-reducing than the other three conditions, while the abstract art VE was the least. Statistically significant values from both the physiological and psychological results help demonstrate that virtual forest environments are more stress-reducing than virtual art environments. We also had statistical significance in HR measures that indicated a moving virtual forest was more stress-reducing than a still forest VE. Our purpose is to increase accessibility, not replace real natural environments, but the comparison should be considered in future studies.

Future studies should aim to understand the role of naturalness versus beauty in stress reduction and the optimal design of a stress-reducing VE. Motion and user interaction could improve immersion and reduce cybersickness. This could allow users to explore their environment, yielding interesting results about how nature influences users. If users get more control in the VEs, we can improve how close we can get to replicating real-world experiences. Bringing participants to real-world nature or art in museums could also be an interesting condition to expand on how VEs are perceived as restorative.

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