Virtual Nature: Investigating The Effect of Biomass on Immersive Virtual Reality Forest Bathing Applications For Stress Reduction

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ABSTRACT

Shinrin-yoku, also known as forest bathing, is a nature immersion practice that has been shown to have restorative effects on mental health. Recently, applications of shinrin-yoku in virtual reality (VR) have been investigated as means of providing similar mental health benefits to people that do not have direct access to nature. These applications have shown similar health benefits, although not to the extent of real nature. The factors that make VR nature immersion effective are little researched to date. This paper investigates the Biophilia Hypothesis in the context of a VR-based nature immersion experience. Twenty-six participants were immersed in a computer-generated virtual natural environment that was either high in biomass (forest) or devoid of biomass (canyon), after experiencing an arithmetic stressor task. We compared multiple restorative outcomes between the high and low biomass groups, as well as preference ratings for real and virtual high and low biomass scenes among all participants. Our results call for further investigation into data trends we observed.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **Virtual reality**.

KEYWORDS

Virtual Reality, Forest Bathing, Biophilia, Affect, Nature Immersion

ACM Reference Format:
Rachel Masters, Victoria Interrante, Madeline Watts, and Francisco Ortega. 2022. Virtual Nature: Investigating The Effect of Biomass on Immersive Virtual Reality Forest Bathing Applications For Stress Reduction. In *ACM Symposium on Applied Perception 2022 (SAP '22), September 22–23, 2022, Virtual Event, USA.* ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/3548814.3551459

SAP '22, September 22–23, 2022, Virtual Event, USA

ACM ISBN 978-1-4503-9455-0/22/09…$15.00
https://doi.org/10.1145/3548814.3551459

1 INTRODUCTION

According to the National Human Activity Pattern Survey issued by the Environmental Protection Agency (EPA), people spend 86.9% of their lives indoors [Klepeis et al. 2001]. Living in large cities, this number increases, and stress levels increase in tandem, often causing cognitive overload [Bong et al. 2016; Sweller 1988]. Urban life has been linked to chronic stress [for Europe 2016]. The effect of stress on mental and physical wellbeing is an under-addressed yet large problem in working society. The American Psychological Association states that stress affects "nearly every system of the body, influencing how people feel and behave" [VandenBos 2007]. Additionally, increased stress is damaging to both mental and physical health, leading to decreased quality of life [VandenBos 2007]. Cognitive overload occurs when the mental work an individual is given exceeds the limit of what the individual's mind can handle [VandenBos 2007]. This phenomenon can occur in workplaces and high stress environments, often leading to depleted mental resources for the person subject to the overload.

Shinrin-yoku, or forest bathing, is a practice that helps counteract stress and restore mental resources. Termed by the Japanese Ministry of Agriculture, Forestry, and Fisheries in 1982, Shinrin-yoku can be defined as contacting and immersing oneself in the atmosphere of a forest [Park et al. 2010]. Nature contact has shown great restorative potential both psychologically and physically [for Europe 2016], but many people do not have the ability to contact nature and engage in this practice. In actuality, the urban lifestyle continues to deprive people of the benefits of immersive nature experiences [Soga and Gaston 2016]. Virtual reality (VR) has the potential to remedy some of the negative effects of urban life.

As head mounted displays (HMDs) like the Oculus Quest 2 become more affordable, portable, and accessible, and VR becomes a household and workplace item, it becomes pertinent to investigate the benefits VR can offer to people who spend 86.9% of their lives in the household or workplace [Klepeis et al. 2001]. In fact, research on health applications of VR has been steadily increasing. There is potential for an optimally immersive nature experience to offer stress reducing and mentally restorative benefits [Voigt-Antons et al. 2021].

VR has the unique ability to offer greater immersive experiences. Researchers have been actively investigating the potential benefits of providing VR forest bathing simulations to people who have restricted access to nature. Working people, people in nursing homes, hospital patients [Ashley Verzwyvelt et al. 2021], people who live in large cities, and people who live in apartments [de Kort et al. 2006] could all potentially benefit. Extensive research on the details that can make nature immersion in VR effective is a necessary step in reaping the benefit of VR technology.

Biomass is one detail that may contribute greatly to an effective shinrin-yoku VR simulation. In this paper, we use the term "biomass" to refer to organic living material, specifically: plants. The biophilia hypothesis, introduced in 1964 by psychologist Erich Fromm [Fromm 1964], and elaborated in 1984 by biologist Edward Wilson [Kellert and Wilson 1993], posits that humans have "a genetically based, evolutionarily determined attractions to specific landscapes and natural elements that create a propensity to affiliate with other living organisms". These ideas are reflected in the Japanese practice of shinrin-yoku (forest bathing), which has been widely linked to multiple measures of physical and mental well-being.

How the Biophilia Hypothesis applies in VR is more complicated and little researched. According to the biophilia hypothesis, people should feel more restored after being immersed in a real-world environment that is rich in biomass than in a real-world environment that is devoid of biomass, all other things being equal. In VR, where nothing is actually alive, to what extent will biomass continue have this predicted advantage? The presented work aims to examine the question: to what extent is the benefit of VR nature immersion dependent on biomass. In the following sections of the paper, we present related work, the design of our experiment, the results, and discussion of results. Additionally, some limitations and directions of future research are presented at the end of this paper. All the surveys, math test, and additional material to replicate this work is published on https://github.com/NuiLab/NatureProject1Resources.

1.1 Contributions

(1) We expand the understanding of where realistic virtual forests fit in between reality and technology when used for stress relief, specifically by investigating if the Biophilia Hypothesis holds when biomass looks real but is not real.
(2) We uncover knowledge on whether people can feel connected enough to virtual nature to receive restorative benefit, which can help many people who suffer from stress and lack of real nature access. Even a ten-minute, virtual nature break at work could restore enough mental resources to have a more productive day.
(3) Our findings contribute to the knowledge of how to create an optimally effective virtual nature experience. A similar study was conducted by environmental psychologists Yin et al. comparing real world forest and desert environments that were integrated into 360 video, and they found that while there was no significant difference in stress recovery between the environments, there was also a lower preference for the desert environment [Yin et al. 2022]. Our work expands the findings from this work by investigating a similar topic using virtual trees that more closely model real trees with wind and particle effects.

2 RELATED WORK

2.1 Biophilia Hypothesis

The Biophilia Hypothesis is the concept that humans have an innate connection with living things [Kellert and Wilson 1993]. Currently, research is being conducted on what positive environmental exposures look like, and evidence suggests that plants, landscapes, wilderness, and animals can all cause positive exposures that improve health. [Frumkin 2001]. Gardens have been shown to help people with stress due to illness [Ulrich 1999]. Additionally, nature exposure has been shown to generate a biophilic response and have a restorative effect [Hartig et al. 1991; Ulrich 1993].

2.2 Stress and Restoration Theories

Two theories exist as the basis for detecting stress reduction and restoration in natural environments. Stress Recovery Theory (SRT), is a psycho-evolutionary theory stating that contact with nature helps people recover from stress with responses based on affect rather than cognition [Ulrich 1983]. The theory verifies that affect responses can be detected through psychological and physiological measures [Ulrich et al. 1991]. SRT also proposes three mechanisms that improve health through reducing stress: physiological and psychological, evolutionary theories, and learning theories [Ulrich and Parsons 1992]. Of these, physiological and psychological metrics have been commonly applied to research on how affect changes after nature experiences. Attention Restoration Theory (ART) is a second, cognition based theory used in tandem with SRT. According to ART, the act of focusing can deplete attention capacity which causes fatigue. This capacity can be restored by 'involuntary attention' or 'fascination,' where one's attention is drawn to many things that are interesting in and of themselves [Kaplan and Kaplan 1989]. Attention is restored via four particular components: Being Away, Extent or Coherence, Fascination, and Compatibility [Kaplan and Kaplan 1989; Kaplan 1995]. Being away is how separated a person feels from daily life concerns. Coherence describes how well one fits comfortably in the environment. Fascination is the act of paying attention without exerting effort in an environment. Compatibility is how well one enjoys or prefers an environment. This theory suggests that natural environments have restful qualities, and introduces the concept of "nearby nature," which is the practice of keeping natural elements nearby in non-natural areas. The Perceived Restorativeness Scale (PRS) was developed as a valid measure of restorativeness to aid the linking of environmental factors to psychological outcomes. Using ART as the basis, the 16 question PRS was developed and split into the categories: Being Away, Coherence, Fascination, and Compatibility. This scale was tested, verified effective, and is used as a common way to measure restorativeness [Hartig et al. 1996].

2.3 Forest Bathing

Shinrin-yoku, or forest bathing, is a practice intended to improve mental and physical state through contact with and immersion in a forest atmosphere. In a study completed by Park, urban environments were shown to elicit stress, whereas forests promoted parasympathetic and reduced sympathetic nerve activity [Park et al. 2010]. This effect illustrated that the forest promoted relaxation, but it suggested that other natural environments could have the same effect because human function resonates with nature. Since other nature environments could generate similar effects, Park's work calls for new research to investigate which parts of nature are essential for restorative effects.

2.3.1 Multisensory Nature Approaches. Since the human experience is multisensory, researchers have started studying the interactions between the senses and nature. These interactions may be an essential part of the restorative effect of nature. Hedblom et al. studied a combination of sight, sound, and smell engagement in an urban environment and two green environments, and the green environments were found more restorative with odor having a significant effect [Hedblom et al. 2019]. Conniff and Craig analyzed current research on the restorative effects of green space and proposed a research agenda where they recommend using sight and sound elements in conjunction with eyetracking in future research [Conniff and Craig 2016]. Research has also found that a forest virtual environment (VE) with sound improved stress recovery more than a forest VE without sound, and that not having sound in a forest VE may have negative connotations that could indicate predator presence [Franco et al. 2017]. From existing multisensory research, there is a clear benefit to incorporation of fitting sounds into nature VE applications, so the VEs for this research were built to use sound.

2.3.2 Biodiverse Nature Approaches. The importance of biodiversity to human health is also becoming a more popular research topic [Aerts et al. 2018; Brown and Grant 2005; Marselle et al. 2021; Wood et al. 2018]. Biodiversity refers to the number of species and abundance of those species within an ecosystem. While most of this research is in the context of the superior air quality and microbiome created by biodiversity, there have been more limited investigations into improved mental state, stress, and restoration. Biophilia is a subconscious, biological need for nature interaction [Brown and Grant 2005]. Brown and Grant analyzed a variety of different sources to investigate whether urban health policies should include biodiversity. Brown found that urban nature applications such as parks improved psychological health, but it was unclear whether biodiversity was responsible for the effects [Brown and Grant 2005]. These findings reveal that the question of which nature components are essential to restoration remains unanswered. Marselle et al. found that perceived biodiversity may have a stronger correlation with well-being than actual biodiversity [Marselle et al. 2021]. Similarly, Aerts et al. found positive associations between self-reported psychological wellbeing and biodiversity [Aerts et al. 2018]. Aerts et al. and Marselle et al. found that the way people perceive the environment and wellbeing may be important to the restorative effect. However, Wood et al. found that biodiversity predicted restorative benefit regardless of gender, age, and ethnicity [Wood et al. 2018], and those perspective shaping characteristics had little effect on the way people reacted to biodiversity. Although the effects of biodiversity on restoration have been researched, the results are mixed and need further investigation.

2.4 Virtual Nature

Recently, VR has been presented as a platform that has the potential to deliver virtual forest bathing experiences. Kaplan and Kaplan introduced a concept called 'nearby nature,' where pieces of nature are kept in non-natural settings so that people can still receive some of nature's benefits [Kaplan and Kaplan 1989]. The primary form of 'nearby nature' thus far has been indoor plants. Lee found that indoor plants relieve psychological and physiological stress [Lee et al. 2015]. Since keeping greenery indoors improves psychological condition, it is possible that VR greenery could have similar effects. Furthermore, an intentional VR application of the 'nearby nature' concept that [Kaplan and Kaplan 1989; Kaplan 1995] introduced could have stronger effects through greater immersion in a green environment.

2.4.1 Immersion, Presence, and Realism. VR is unique in that it can deliver life-like experiences via a virtual world. Immersion, presence, and realism are factors in the delivery of the experience that can affect the attachments people make with their experience. Immersion can be described as the extent to which computer simulation can deliver a realistic and detailed depiction of reality [Slater and Wilbur 1997]. Presence can be described as the response that humans have to immersion and relates more closely to the experience [IJsselsteijn 2004]. De Kort completed a study to determine the effects of different screen sizes on the immersivity of a video of a digital nature environment [de Kort et al. 2006]. The results were inconclusive, but since De Kort's medium was limited, De Kort suggested using VR for immersive effect in future work. Our study is novel as it created a unique VE considering factors that could affect immersion and presence, and prioritized realism by incorporating photo-realistic plant and rock formations. Realism is the accuracy of a depiction. Appleton researched a potential 'sufficient' level of realism for computer images for the purpose of understanding how people relate to digital images. The level of detail of a variety of computer images was manipulated, and foreground vegetation and type of ground cover had significant effects on ratings [Appleton and Lovett 2003]. While Appleton did not find a 'sufficient' level of realism, realism ratings increased with the level of detail, and as realism ratings increased, people felt more strongly that they could relate to the environment depicted by the image [Appleton and Lovett 2003]. A consideration in the creation of the VEs for our study was the importance of ground cover and vegetation since every detail of a real environment could not be rendered in an interactive way.

2.4.2 Benefits. In areas where nature access is limited or nonexistent, VR has the potential to act as a nature substitute that provides restorative benefits similar to real nature. Franco et al. found that immersive nature VEs with fitting nature sounds were found to improve stress recovery [Franco et al. 2017]. Similarly, Hedblom found that green VEs with sound and smell delivered via 360 video in VR helped lower stress [Hedblom et al. 2019]. It is known that nature, indoor plants, and urban nature applications can all help reduce stress and restore attention in some capacity. Furthermore, intentional, multisensory stimulation has the potential to aid in the positive effect of nature immersion. In VR, 360 video and sound have shown potential for reducing stress similar to real nature, although not to the same extent. A more interactive, immersive VE with 3D, rendered objects that look realistic could further bridge the gap between 360 video and real nature. The specific natural components necessary for a relaxing and restorative VE remain unknown. Further investigation into this subject is crucial for the creation of a nature VE with the potential to help people. Our work intends to fill the knowledge gap about the importance of biomass components in a nature VE.

3 METHODS

The goal of our experiment was to test if the Biophilia Hypothesis holds in a VR shinrin-yoku simulation. Specifically, the goal was to test how the restorativeness of a VE with only living biomass (forest) compared to that of a non-living nature VE (canyon) designed with the same layout and aesthetic appeal. Our hypotheses are as follows: H1. The stressor test will effectively induce stress under the condition that the Markus & Peters Arithmetic test is used. H2. The biomass environment is more restorative than the no biomass environment under the condition that the Biophilia Hypothesis holds in VR.

3.1 Participants

Twenty-six participants total were recruited from the university community at Colorado State University after reporting exclusion criteria. Participants were excluded if self-reported vision was below 20/60, if they had previous self-reported history of heart conditions, or if they had history of seizures. The gender breakdown included 46.2% of participants were female, and 53.8% of participants were male (no one reported any other gender). The mean age was 22 with a standard deviation of 3.7.

3.2 Materials

The experiment was conducted at a desk with an Alienware computer, a Samsung Galaxy Tab 4 tablet, an Oculus Rift S, and headphones in a lab environment. The VR environment was executed on a machine with an Intel i9 CPU, 64 GB RAM, and an Nvidia GeForce 3090 GPU. All questionnaires were hosted on Google Forms [Google 2021] and administered via tablet at the desk. The stressor task and VEs were administered via PC and completed at the desk. Participants navigated the nature VE using the joystick on the Oculus Rift S controller.

3.3 Virtual Environments

To capture the effect of biomass on restorativeness, two nature VEs were created using Unreal Engine 4 [Games 2021] to be as identical as possible, one with biomass and one without biomass. With this goal in mind, canyon and forest VEs were created using the same map design, path layout, path structure, path width, overall brightness, amount of visible sky, and equivalent aesthetics. First, the VE map was created. Then, the VE map was used to create a canyon by placing rocks in the map shape. Then, the canyon was duplicated, and the rocks were replaced with trees of the same height positioned in the exact same location, to guarantee that the map layouts were identical aside from biomass. The following maps were created using assets from Quixel Megascans, a company that uses 3D cameras to scan real world objects into virtual assets [Megascans 2011]. The Unreal Engine terrain tool was used to construct the ground of both VEs as it allowed for more detailed sculpting. Both VEs were created to be as realistic as possible.

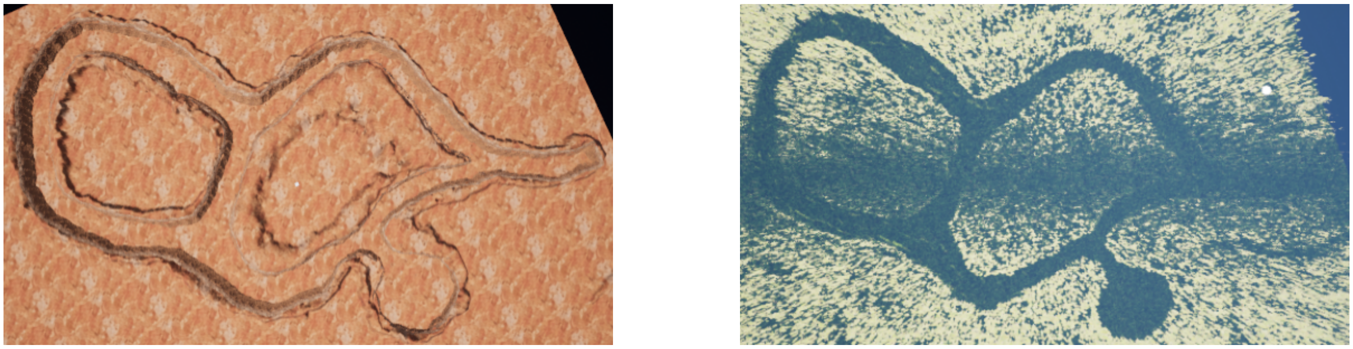
3.3.1 Environment Map. To create a greater sense of immersion, features were added to the map to cover a variety of preferences. Specifically, the map was created to have features that would keep users engaged and exploring the environment for the immersion period. Bends in the path were added to create a sense of mystery and novelty that encouraged participants to explore, as shown in Figures 1a and 1b. A narrow pathway into a large clearing was incorporated to simulate the enclosed and open spaces found in real nature. Wide path widths were used so that the canyon would not feel claustrophobic. The large loop at the back of the map was created to make the map feel continuous and new to participants for the ten minute period they spent in the VE. Environmentally appropriate sounds were incorporated to try to make the experience more realistic and immersive while mitigating potential stress that could be caused by being in a silent nature VE [Annerstedt et al. 2013].

3.3.2 Forest. The forest, as shown in Figure 2b, was created using only green biomass components. Green biomass was used because green is associated with life as well as heightened relaxation and lower anxiety [Jacobs and Suess 1975]. After analyzing the varieties of plants found at Olympic National Park [Service 2021b], asset packs were selected from the Unreal Engine Marketplace that were most comparable to the plants in Olympic National Park. The Temperate Vegetation: Fern [Nature 2021a], Temperate Vegetation: Ground Foliage [Nature 2021b], and Temperate Vegetation: Spruce Forest [Nature 2021c] asset packs were used. Assets included trees, ferns, clover, and a moss ground. The assets were painted onto the VE using the Unreal Engine terrain tool. The moss ground did not come from an asset pack and was created as a custom material. The accompanying sound included the rustling of leaves as well as other fitting forest sounds [for Pets 2018].

3.3.3 Canyon. The canyon, as shown in Figure 2a, was created using only rocky components. After analyzing the types and formations of rock found in Canyonlands National Park [Service 2021a], asset packs were selected from the Unreal Engine Market Place that had similar sandstone rock formations and ground textures. The Megascans – Sandstone Desert [Megascans 2021b], Quarry Collections [Megascans 2021c], and Megascans – Quarry [Megascans 2021a] asset packs were used. Gravel and sand ground were used as well as different variations of sandstone rocks. All biomass was absent from this VE. The canyon walls were created by hand-placing assets and rotating the assets to fit together. Wind sounds were used as well. [Nature 2018].

3.4 Procedure

3.4.1 Experiment Procedure. Participants arrived at the laboratory and were informed that psychological measures would be collected. Before participating in the experiment, participants were informed of the potential risks and benefits of participation in the experiment and that they could leave the experiment at any time. The participants then signed an informed consent form. The experiment was approved by the Institutional Review Board. The experiment



(a) Bird's Eye View of Canyon Map **(b) Bird's Eye View of Forest Map**

Figure 1: Comparison of Forest and Canyon Maps

(a) View Inside Canyon **(b) View Inside Forest**

Figure 2: Environments from Participant Perspective

was completed with no more than one participant in the room at one time. The participants were each assigned an experiment number that they used to fill out the questionnaires. All psychological questionnaires contained the Positive and Negative Affect Schedule (PANAS) [Watson et al. 1988], Zuckerman Inventory of Personal Reactions (ZIPERS) [Zuckerman 1977], and Perceived Restorativeness Scale (PRS) [Hartig et al. 1996]. First, a demographics questionnaire was completed, followed by a psychological questionnaire that measured baseline psychological state. After these, the participants completed the Markus & Peters Arithmetic stressor test [Peters et al. 1998], then completed the next psychological questionnaire to measure the effectiveness of the stressor on mood. Using a random number generator, the participants were then randomly assigned and evenly split between the forest or canyon VE. They were allowed to explore the VE for ten minutes, then completed the final psychological questionnaire. Participants filled out the preferences questionnaire, then were debriefed and dismissed. The experiment lasted approximately one hour.

3.4.2 Psychological Measurements. Two validated and common scales were administered to measure emotion, the Zuckerman Inventory of Personal Reactions (ZIPERS) [Zuckerman 1977] and the Positive and Negative Affect Schedule (PANAS) [Watson et al. 1988]. Additionally, another validated scale, the Perceived Restorativeness Scale (PRS) [Hartig et al. 1996], was used to measure the levels of restoration people felt in the VE. These scales were used in a questionnaire that participants completed before the stressor task, after the stressor task, and after the nature VE walkthrough. This questionnaire was administered using Google Forms [Google 2021]. ZIPERS is a five-point Likert scale consisting of thirteen questions about feelings in the context of a certain environment or situation. PANAS is a five-point Likert scale that rates ten measures of positive affect and ten measures of negative affect. PRS is a seven-point Likert scale that measures how people perceive their presence in the experience through a series of questions that belong to four question categories: Being Away, Fascination, Coherence, and Compatibility.

3.4.3 Stressor Task. We utilized the Markus & Peters Arithmetic Test (MPATest) [Peters et al. 1998] to increase participant stress levels before participants entered the VE. This test was implemented using the PsychoPy psychological test administration software [Ltd 2021]. The stressor consisted of 20, one minute trials. In each trial, the participant had 40 seconds to answer a multiplication problem consisting of the multiplication of two, two digit numbers (like 20 x 95). After answering, the correct answer flashed on the screen in green text. Then, the participant had ten seconds to do a simple, one digit addition or subtraction from the green answer. The correct answer to the simple operation then flashed on the screen in green text. Last, the user had ten seconds to do another simple addition or subtraction from the previous correct answer. The participant answered, the correct answer flashed in green, and then the next trial began. This process repeated for 20 trials. Participants were not allowed to use pencil or paper to help with the calculations. For the duration of the stressor, industrial noise [Pals 2016] played through headphones that the participants wore while taking the stressor test. Participants entered their answers on a number pad on a standard keyboard, pressing the enter key after entering their answers. If they entered in a shorter time than the trial time, they were allowed to move on to the next question early. The stressor task took between 15 and 20 minutes, the variation due to how long participants took to complete each question and how much effort was exerted to get the correct answers on the difficult multiplication question.

3.4.4 Preference Questionnaire. This questionnaire was used as an exit survey to ensure that personality preferences would not skew the results. Participants were shown 6 images and rated them all using the Perceived Restorativeness Scale [Hartig et al. 1996]. The questionnaire included photographs of an open forest, a narrow forest, an open canyon, a narrow canyon, a screen capture of the forest VE, and a screen capture of the canyon VE. Since previous research has shown that personality preferences can affect results [Senese et al. 2020], this questionnaire was administered to gather extra data that could be insightful. That data was then analyzed to observe if the preference for the forest or canyon observed in the experiment was also observed in the preference questionnaire.

4 RESULTS

We hypothesized that H1. The stressor test will effectively induce stress under the condition that the MPATest is used. H2. The biomass environment is more restorative than the no biomass environment under the condition that the Biophilia Hypothesis holds in VR. Each participant completed the same survey three times throughout the course of the experiment; before and immediately after completing the MPATest (baseline and post-stressor) and once after spending ten minutes in one of the two VEs (post-forest, post-canyon). Survey responses were used to analyze PANAS, PRS, and ZIPERS scores throughout the experiment.

The PANAS was used to compare positive and negative affect. The PANAS is a series of five-point Likert scale questions asking participants about certain feelings and can be split into two subcategories, positive affect and negative affect. Positive affect questions measure positive emotions like interest and excitement. Negative affect questions measure negative emotions like distress and fear. The subcategory scores for each participant were calculated by summing the points answered on the questions in the respective category. For both subcategories, the minimum score possible was zero and the maximum was 50. The PRS was used to measure perceived restoration. The PRS has five-point Likert scale questions as well and is split into four subscales: being-away, fascination, coherence, and compatibility. Being-away, fascination, and compatibility can be combined into one subscale called general restorativeness. Being-away assesses if the environment is an escape from everyday life and has a score range from 0-12. Fascination assesses if the environment captivates attention through interesting features and ranges from 0-30. Coherence assesses if the environment is too chaotic and ranges from 0-24. Compatibility assesses how well the user fits into and gets enjoyment from the environment and ranges from 0-30. General restorativeness assesses the positive aspects of restoration and is calculated by summing the scores from being-away, fascination, and compatibility. The ZIPERS was used to measure emotional response using positive and negative scores. ZIPERS is a five-point Likert scale, and the positive and negative subscale scores are calculated by adding the points from the questions in the subscales. The positive subscale has a score range from 0-30, and the negative subscale has a score range from 0-30. Baseline and post-stressor were compared to verify H1. For each participant, their post-stressor score was subtracted from their post-VR score to compute a difference score. These difference scores were compared between the forest and canyon groups to observe H2. Since we did not have any hypotheses related to individual characteristics aside from biomass preference, we did not analyze any gender or race effects but did try to get as even of a distribution of gender as possible.

4.1 Data Analysis

All results were analyzed using RStudio Cloud [RStudio 2020] and were visualized using Microsoft Excel [Corporation 2021]. Since we were comparing two instances of the same survey category (baseline and post-stressor, post-stressor and post-forest/post-canyon, post-forest difference and post-canyon difference), ANOVA was not needed, and t-tests were used to compare the data between the surveys and VEs. A t-test was performed between the baseline and post-stressor scores across all 26 participants because all participants experienced the same thing up to this point in the experiment. Then, for each of the two nature groups, a t-test on the difference between the post-stressor and post-environment scores was performed, comparing the canyon participants (n=13) to the forest participants (n=13). Due to the large number of t-tests performed for each survey across the two conditions, a Bonferroni-Holm Correction was performed on the results before reporting, only accepting p-values less than 0.05 / (m − i + 1), m being the number of p-values (ten in this case), and i counting up from one to ten for each p-value from smallest to largest. All p-values and corresponding t-statistics are reported in Table 1. Each questionnaire was broken into subcategory scores for each participant. The subcategory scores for each participant were calculated by summing the scores of the questions in the subcategory. The mean subcategory scores and standard deviations were calculated by averaging the participants' subcategory scores, then plotted in Figures 3, 4, and 5.

Table 1: Statistical Analysis Results

		Baseline/ Post-Stressor (n=26)		Post-Stressor/ Post-VR Delta (n=13/13)	
		t	p	t	p
PANAS	Positive Affect	3.137	0.001	-0.432	0.335
	Negative Affect	-1.245	0.109	0.936	0.179
ZIPERS	Positive Score	2.942	0.002	-1.312	0.101
	Negative Score	-2.630	0.006	1.513	0.072
PRS	General Restorativeness	2.986	0.002	-0.650	0.261

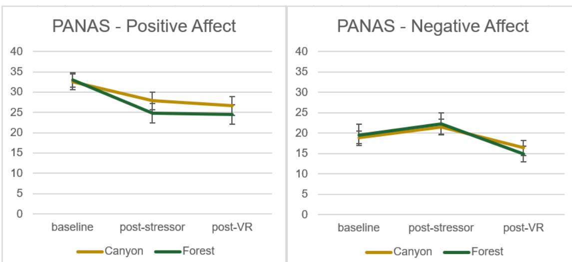


Figure 3: PANAS Mean Scores

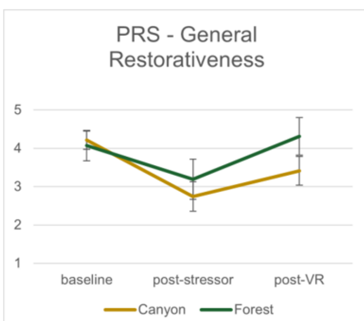


Figure 4: PRS Mean Scores

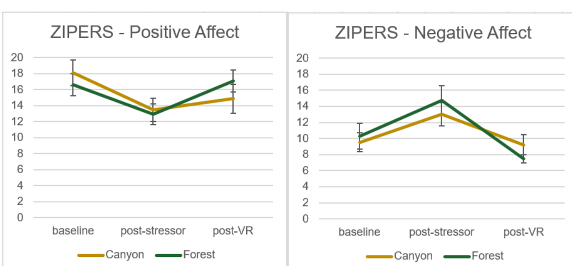


Figure 5: ZIPERS Mean Scores

4.2 Stressor Test

To compare baseline and post-stressor, a t-test was performed on the group of all participants between the two survey times. For PANAS, there was a statistically significant decrease in positive affect ($t(50) = -3.137, p = 0.001$), supporting H1. For ZIPERS, there was a significant decrease in positive score ($t(50) = 2.942, p = 0.002$) as well as a significant increase in negative score ($t(50) = -2.630, p = 0.006$), supporting H1. PRS general restorativeness also decreased significantly ($t(50) = 2.986, p = 0.002$), supporting H1. Additional, overall trends for the forest and canyon groups between baseline, post-stressor, and post-VR are viewable in Figure 3 for PANAS, Figure 5 for ZIPERS, and Figure 4 for PRS. In these figures, points represent mean score, and error bars represent standard error.

4.3 Forest and Canyon Comparison

To compare the forest and canyon, post-stressor scores were subtracted from post-forest/canyon scores for each participant, then the resulting scores were compared for the two environments. No results were significant after the Bonferroni-Holm Correction; however, trends in the data are expressed for PANAS and ZIPERS in Figure 6 and PRS in Figure 7. A complete view of the statistical tests performed is available in Table 1. In these figures, points represent the mean of the participant differences between post-stressor and post-vr, and error bars represent standard error.

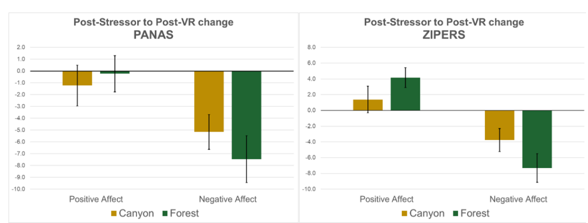


Figure 6: ZIPERS and PANAS Post-VR Change

4.4 Preference Survey

The PRS was administered and analyzed for the preference survey in order to ensure that personal preference for the canyon was not affecting the results. Since the preference survey is observing a response to a given photo, the total PRS score was calculated for each participant by summing the points on each PRS question, then the mean and standard deviations were calculated for each photo. The data collected from the preference survey showed that the real forest photo had the highest preference rating among participants

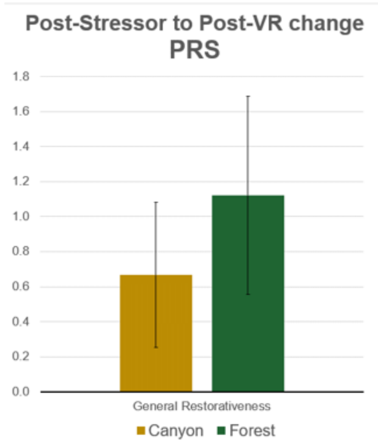


Figure 7: PRS Post-VR Change

(M= 40.18, SD= 8.336519), the real canyon had the second highest preference rating (M= 31.86, SD= 9.419931), followed by the forest VE screenshot (M= 27.24, SD= 8.828363), and the lowest preference rating was reported for the canyon VE screenshot (M= 26.84, SD= 8.369986). This order of preferences supports H2 and the trend that biomass environments are preferred overall.

5 DISCUSSION

Due to the significant decrease in positive scores on both the PANAS and ZIPERS and decrease in PRS general restorativeness, as well as a significant increase in ZIPERS negative affect, survey results suggest the MPATest successfully supported H1 and increased stress levels in participants compared to their baseline data. Inducing heightened stress prior to the VR immersion enabled us to more effectively assess the stress-reduction potential of the immersive VEs. Using the same questionnaires between the baseline and post-stressor periods as between the post-stressor and post-immersion periods established a common context within which we were able to robustly quantify and compare the changes in affect. Due to the lack of significant results when observing differences in restorativeness between the canyon and forest environments, we fail to reject H2; however, in Figures 3, 4, and 5, the forest performs better than the canyon across all questionnaires, just not significantly better. Additionally, ratings on the preference survey were higher for the images of the real forest and canyon environments when compared to the screen-captured images of the virtual forest and canyon environments, and the virtual forest was rated more highly than the virtual canyon. These results follow the same trends observed in the experimental data. While our results fail to support H2, they do call for further work to observe the extent of the trend expressed by the experiment data. Additionally, as our study aimed only to compare our two environments with respect to each other, we cannot draw any conclusions about the restorative impact of our virtual environments compared to alternative relaxation procedures, including just sitting with one's eyes closed.

5.1 Limitations and Future Work

While data trends suggest that a high-biomass nature environment may be more restorative than a nature environment that has no-biomass, the difference observed was not significant. These trends call for further work to investigate the extent to which biomass impacts restorativeness. Research by Appleton and Lovett suggests that differences in the inherent difficulty of accurately simulating some environmental aspects relative to others may impose different limitations on the realism of the computer images that are achievable in some VEs versus others [Appleton and Lovett 2003]. There were many limitations to this study, but three key things that would help further understand these results would be adding additional comparison groups, adding physiological measures, and redesigning the forest. Adding a control group who simply sit quietly would help us better understand how VR immersion compares to other relaxation possibilities. Adding physiological measures could help track recovery speed. The forest could have been designed to be more aesthetically appealing. The trees and ferns in the forest were difficult to simulate, requiring complicated light maps and wind effects that were not present in the canyon. Additionally, the biggest limitation of this study was the ability to render large quantities of highly complex virtual assets in VR. Latency became an issue as participants were looking and moving around, and as a result, the movement speed had to be dramatically restricted, camera panning had to be disallowed, and billboarding techniques had to be used to lower the number of trees. These affordances may have compromised the environment's appearance, and the forest may have not correctly reproduced the intended biomass. Future work calls for a few avenues of additional research into virtual biomass while solving this rendering issue. Investigating the importance of biomass realism for the restorative experience, using better technology, and making the experience a stationary immersive experience are the main directions of future work. Additionally, since the goal of virtual forest bathing is used to counteract stress, important future testing involves testing this device long-term in real-life, stress-inducing situations, such as workplaces or universities.

6 CONCLUSION

This study compared multiple measures of the restorative impact of immersive experience in two structurally similar nature VEs that significantly differed in their biomass content. Although our results do not show a statistically significant difference in the restorative impact of the forest vs canyon environment, the consistent trends in our data call for further investigation into this question. While a direct comparison of the restorative effects of the forest vs the canyon did not show statistical significance, our findings nevertheless suggest intriguing potential differences and indicate a need for further research examining the effects of a variety of well-simulated biomass. Overall, this study shows promise that biomass could affect the restorativeness of a virtual nature simulation, and future work can further investigate the role of biomass when creating a VE.

ACKNOWLEDGMENTS

We would like to acknowledge the National Science Foundation for grant numbers: 2106590, 2016714, 2037417, 1948254, 2050540.

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