THESIS

EXPLORING THE ROLE OF BIOMASS DESIGN IN VIRTUAL REALITY FOREST BATHING

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ABSTRACT

EXPLORING THE ROLE OF BIOMASS DESIGN IN VIRTUAL REALITY FOREST BATHING

Stress is an increasingly prevalent problem that has severe health consequences if not managed properly. Every day, people are surrounded by work, health, financial, economic, and a variety of other stressors that deplete cognitive resources and put their nervous systems on high alert. Forest bathing, or nature immersion therapy, has been shown to reduce stress while restoring attentional resources, but despite these benefits, many people lack access to nature for a variety of reasons, including distance and health. VR has the potential to support access to virtual nature environments (VNE's) for people who cannot get into nature, yet the optimal design of biomass or plant life in VNE's is still an active area of research. Additionally, most of these VNE's require high end headsets and computers to run, which is not accessible technology for the everyday consumer. Given the current limitations of popular VR technology such as the Meta Quest 3, it is important to understand the relationship between plant asset realism and a VNE's restorative potential so that a balance can be achieved between a VNE that is deployable on everyday consumer headsets and a VNE that offers restorative benefit. This study was an initial exploration into high and low-realism VNE comparisons, accomplished by a mixed design study that compared two groups of participants, high and low-realism, against each other as well as against their own performance in a control condition where they closed their eyes. Through psychological and physiological measures, stress reduction and perceived attention restoration was assessed as a baseline, after a stressor test, then after the experiment condition to observe potential decreases in stress and increases in attention after the environment. Overall, there was only a significant increase in General Restorativeness in the high-realism environment when compared against the control and the low-realism environment, but trends in the data call for future research on this topic.

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DEDICATION

I dedicate this work to my family, my friends, my advisor Francisco, and my instructor Benjamin Say. To my family, thank you for encouraging me to pave my own way; it has made me confident in pursuing research. To my friends and church life group, thank you for uplifting me and supporting me in times where my health has been challenging; it has helped me pursue my dreams despite my circumstances. To Francisco, thank you for seeing potential in me that I did not see in myself, you fostered that potential over time and helped me become the researcher I am today. To Benjamin Say, thank you for recognizing me and involving me in teaching and research from the time I first started attending Colorado State University; your confidence has guided me to accomplishment.

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Chapter 1

Introduction

1.1 Background

The World Health organization defines stress as "a state of worry or mental tension caused by a difficult situation" [1]. It is an instinctual response to threats in one's environment, and it is an important motivator that drives us to perform. Positive stress, also known as eustress, helps people live day to day life. However, many people experience distress, which is stress beyond what is beneficial for survival, and both acute and chronic forms of distress are detrimental to human health in a variety of ways. Physically, chronic stress can lead to chronic muscle tension, heart problems, metabolic disorders, and gastrointestinal issues among many other problems. Mentally, chronic stress causes fatigue, depression, anxiety attacks [2], and there is evidence that stress is a risk factor for the onset of dementia [3–5]. General adaptation syndrome (GAS), is a response to acute distress [6], characterized by high blood pressure, sleep disturbance, irritability, and more.

Distress has damaging consequences, and people around the world are burdened by stressors that put them at risk of these consequences. Work, relationships, finances, socioeconomic factors, tragedies, and chronic illness are just a few examples of stressors that take a toll on people's health every day [7, 8]. Additionally, isolation during the COVID-19 pandemic has shown that being trapped indoors can cause distress [9–11]. Even before the pandemic, the Environmental Protection Agency's (EPA) National Human Activity Pattern Survey (NHAPS) reported that in 2001, on average, people spent 86.9% of their time indoors and 6% in vehicles [12]. Between work, sleep, commute, and evenings in, only 7% of time was spent outdoors, and with the rise of technology, it is possible that this number has decreased. This makes the concern of stress induced by time spent inside a prevalent issue in our modern society, and the question arises: what can be done to address this stress?

Forest bathing is a therapeutic nature immersion practice that has been shown to reduce stress and restore depleted mental resources [13]. This means that as distress causes fatigue, immersion in nature not only reduces distress but also counters mental fatigue by restoring cognitive resources. In nature research, researchers are still working to understand what elements of nature make it restorative, and much of the literature is aimed at understanding nature's restorativeness [14], partially for the purpose of designing highly effective public greenspaces [15, 16]. Overall, forest bathing has shown positive results for both general populations [17] and specific populations, such as older adults [18] or people struggling with illness [19]. For example, it has promising applications related to dementia as stress is a risk factor for the onset of dementia, and dementia is characterized by a decline in executive functioning [3–5], whereas nature immersion reduces stress and improves executive functioning.

Given the benefits of nature immersion, it is useful to practice regularly for the promotion of good health, so why is only 7% of time spent outside? For many people, the answer is accessibility. For those in big cities without easy transportation, getting into nature may seem impossible. For those who work overtime or the night shift, there may not be an opportunity to travel to a natural area on their break or after work. For those who are in a hospital or nursing home, they may simply not be able to access nature. However, the thing that all of these groups have in common is that the environments they are in elevate their stress: cities, stressful work atmospheres, hospitals [17, 19, 20]. When the people who can benefit the most from forest bathing have the least access, what can be done to bring nature to these groups?

Virtual reality (VR) has the potential to bring nature to people when people cannot be brought to nature. As VR headsets like the Meta Quest 3 become more affordable, accessible, portable, and improve in quality, there is a great opportunity to use the technology for the improvement of health. Virtual environments (VE's) can be used to immerse people in new virtual worlds at any time, any place, even on a work break. Nature VE's (VNE's), if designed appropriately, have the potential to immerse people in a nature environment that may mimic similar stress reduction and attention restoration benefits as real nature. Engaging with this technology, even just on a work or study break, could help improve mental health and productivity over time [21, 22].

The new question is: how do we design VNE's appropriately? If understanding the elements that make nature restorative is still an active area in nature research, then designing VNE's is most certainly a challenge considering the many interacting factors within real nature that researchers do not fully understand. Fortunately, VR can also be of use in exploring nature's restorativeness. VR offers the opportunity to design nature environments from the ground up in a short time, which in turn can allow researchers to observe individual nature elements in a highly controlled way that cannot be achieved by designing a physical greenspace for the same effect, doing so would take far too much time and financial resources. The goal of this research is twofold: contribute to the understanding of which nature elements are essential for the restorative effect, and use that information to design accessible VNE's to supplement people's nature exposure when they are not in a position to access real nature.

1.2 Motivation

There are many different elements of nature that need to be explored to understand their restorativeness, including water, plant life, rocks, particle effects, and the role of multisensory experiences among other topics.

1.2.1 Initial Investigation into Biomass

The first paper this research team published on these topics aimed to investigate the role of biomass, or living plant life, for the restorative effect [23]. This topic was selected because there are multiple nature environments that people enjoy that contain varying amounts of plant life. Examples of high biomass environments include places like Olympic National Park or Sequoia National Park. Examples of low biomass environments include locations such as Canyonlands National Park or Joshua Tree National Park. All of these environments are protected and beautiful, but do they have differences in restorative potential? The initial study compared the restorative potential of a no-biomass canyon and all-biomass forest using psychological measures including the Perceived Restorativeness Scale (PRS), Positive and Negative Affect Schedule (PANAS), and Zuckerman Inventory of Personal Reactions (ZIPERS). Overall, the expectation was that the forest would be more restorative than the canyon, but no significant results were found, only trends towards the forest being more restorative.

1.2.2 Current Research

After observing non-significant trends toward the forest being more restorative, it became evident that the design of high biomass environments is more complex than initially suspected. The forest environment's biggest limitation was that for multiple participants, it may have induced cybersickness due to the complexity of the plant assets and difficulty rendering them without latency. Additionally, while plant varieties that were all prevalent in Olympic National Park were selected, the placement and color combinations of them in the environment, especially juxtaposed with the custom ground material created for the environment, may have had unintended effects that are still not fully understood. Given these unknowns, this research aims to further understand the intricacies of high-biomass VNE design.

1.3 Terminology

The following terms and acronyms are closely related to this research and will be used throughout the rest of this work.

1.3.1 Terms

- Biomass - Biomass is defined as living plant life. This definition does not include animals, bugs, or other humans, only plants.
- Stress - In this context, stress refers to distress because this is the stress the research is aimed at addressing.

- Stress Recovery - Stress recovery is a measurable decrease in distress via psychological and physiological measures. In the experiment setting, acute stress is induced using a mathematical stressor test, and the observed stress recovery is recovery from that acute stress.

- Attention Restoration - For the completed experiment, we only measured how well the participant perceived they were restored [24]. In future work, measurements of executive functioning will also be included.

- Cybersickness - Cybersickness is sickness induced by the VR environment, characterized by similar symptoms to motion sickness [25].

- Immersion - Immersion is how well the VE creates a detailed, realistic model of reality that aligns with people's expectations of what would happen in real life [26].

- Presence - Presence is the feeling of being inside of the VE as if it was real life [27].

- Realism - Realism is the degree to which a VE simulates real life.

1.3.2 Acronyms

- ART - Attention Restoration Theory [28]

- PANAS - Positive and Negative Affect Schedule [29]

- PRS - Perceived Restorativeness Scale [24]

- PSS - Perceived Stress Scale [30]

- SRT - Stress Recovery Theory [31]

- ZIPERS - Zuckerman Inventory of Personal Reactions [32]

- VE - Virtual Environment

- VNE - Virtual Nature Environment

Chapter 2

Related Work

For the purposes of reviewing the biomass design research related to this work, prior literature can be classified into two broad categories: work occurring in the field of nature research and VR nature research.

2.1 Biomass Design In Nature Research

Biomass design is still an active area of study in nature research, with interest especially in different types of environment, the relationship between biodiversity and human health, and the role of vegetation quantity and density.

2.1.1 Environment Types

When people think of nature, they may think of different things depending on their preferences, past experiences, or home. A study by Menser et al. aimed to identify overlap in what people perceived as natural, having participants rank images on how well they represented nature. The photo ranking study revealed that participants perceived mountains, water, and tree canopies to best represent nature [33]. Additionally, Van den Berg et al. evaluated perceived restorativeness and mood in four nature videos with different naturalness: "an urban street, parkland, tended woodland, or wild woods." The natural environments were all perceived more restorative than the urban environment, but there were no significant differences between the natural environments despite high variation in recovery [34]. These results further indicate that preference and perception have a bigger role in this research. Finally, Theodorou et. al. compared lacustrine, arctic, nature, and urban environments on the subjective vitality of participants, finding that participants with high use of cognitive appraisal boosted restorative effects in lacustrine and arctic environments [35]. These results indicate a need both for further work understanding different varieties of nature and indicate a role of the subjective perception of environment stimuli on restorative effects, which is affected by personal factors.

2.1.2 Biodiversity

Biodiversity has been known to have multiple effects on both physical and mental health which researchers are trying to better understand. The Biophilia Hypothesis is a key term describing an innate connection between humans and the living elements of nature [36]. Marselle et al. developed a conceptual framework for how biodiversity affects human health, identifying four pathways: "(i) reducing harm (e.g. provision of medicines, decreasing exposure to air and noise pollution); (ii) restoring capacities (e.g. attention restoration, stress reduction); (iii) building capacities (e.g. promoting physical activity, transcendent experiences); and (iv) causing harm (e.g. dangerous wildlife, zoonotic diseases, allergens)" [37]. With respect to VR, VNE's primarily aim to achieve pathway two without the perception of pathway four.

Another review by Aerts et al. aimed to understand the relationship between biodiversity and human health, finding relationships between ecosystem diversity and immune system support as well as species diversity and physical and mental wellbeing [38]. Species diversity or richness, or the number of distinct living entities in an environment, is key for visual biodiversity, which plays a role in the restorative effect of nature. Wood et al. assessed biodiversity by species richness and habitat structure in 12 urban greenspaces then administered surveys of perceived restorativeness and preference to 128 participants, finding that biodiversity was important for restorative effects [15]. The study provided preliminary evidence that overall biodiversity is important for restoration, which indicates a need for future work specifically on plant biodiversity as well as the difference between actual and perceived biodiversity, which is something that can be controlled for in VR and measured using psychological questionnaire.

Costa investigated the impacts of dispersion: or "proximity and distance between plants" and interspersion: or "intermixing between plants of different species" on landscape preference. Using paired landscape images, participants ranked which they prefered using a 7 point likert scale with each image on one end, and eye tracking was also used. Results indicated that dispersion had a greater effect on landscape preference but high-dispersion, high-interspersion images were prefered both on the likert scale ranking and using eyetracking data [39]. In Costa's experiment, visual biodiversity was desired (high-interspersion), but lower vegetation density was also desired (high-dispersion).

2.1.3 Vegetation Quantity and Density

Costa's finding [39] that lower vegetation density was desired has had mixed findings in other literature. Kim et al. conducted a systematic review on biomass design in the form of stand and canopy density, finding no evidence of the impact of canopy density due to a lack of literature, but finding that lower stand density contributed to the restorative effect of nature [40]. In other words, people found natural areas with less dense trees to be more restorative, which aligned with the findings from Costa. However, in a cross-cultural study on preference for semi-open landscapes, the research instead found that multiple groups valued landscapes with higher vegetation density over semi-open landscapes [41]. This indicates that those participants preferred environments with more trees than open area, which is different than the findings of Kim and Costa. However, this trend may be partially due to vegetation to space ratios. For example, Martinez et al. did an analysis of restorative quality and biophilic elements across 65 Mexican public areas. 470 participants visited the different spaces, took photos, and completed psychological questionnaires, and the results indicated that environments with more space containing more vegetation were perceived as more restorative than historical or more urban areas. In this study, the small park with a lot of vegetation did not perform as well as the landscape with vast vegetation, which had a significant role in increasing restorative effect [42]. This may indicate a preference for a large vegetation quanity, but spread out over a larger area rather than condensed into a small space. Overall, the mixed literature indicates a need for further research into this topic.

2.2 Biomass Design In VR Nature Research

Biomass design in VR is a relatively new field with many unknowns that need explored. Environment types, biodiversity, and biomass realism are the main new topics of interest with respect to biomass design.

2.2.1 Environment Types

Since VR has the capacity to model a variety of different environments, researchers have been interested in modeling different environments for side-by-side comparisons. In a side-by-side comparison of brown and green spaces, Masters et al. compared a VR forest and canyon, finding restorative potential in a green environment, but no significant results, only trends calling for future investigation [23]. Zhang et. al. compared multiple different environments via VR tours in grassland, desert, lake, and forest environments, finding the grassland, then the forest, then desert, then lake was the order of most to least relaxing; however, the lake had the greatest influence on positive affect [43]. It is not completely clear why the grassland was the most relaxing yet the lake influenced positive affect. Given the minimal research regarding environment type, more detailed comparisons are needed to understand how people react to different environments in VR.

One other interesting study in VR involved incorporating different types of plants into VR office spaces. Yin et al. conducted a study in VR where people were exposed to four offices with different biophilic designs, finding that participants in the biophilic offices consistently had better stress recovery, but that the performance within the biophilic offices was not consistent [44]. Overall, more work needs done in this area to understand the nature types that are most conducive to mental resource restoration.

2.2.2 Biodiversity

Biodiversity is also a topic of interest in VR for multiple reasons including the complexity of rendering biodiverse elements as well as the ability to isolate and control levels of biodiversity in a VNE. A study by Jiang et al. compared 360 videos of "grassland, shrubs, grassland and trees, or shrubs and trees" urban greenways across 94 participants, finding that the shrubs and the "grassland and trees" groups performed the best for attentional functioning [16]. Overall, these results indicate that one biodiverse group was effective, but not both, which calls for further work into the intricacies of biomass design, as it is possible that not all biodiversity is perceived the same. The complexity of biodiverse design is further confirmed by Wang et. al., who compared seven different VR forest environments, finding that many design qualities (openness, plants, etc.) could influence restorativeness in ways not fully understood [45].

In a detailed study, Schebella et al. investigated biodiversity in mutisensory, 360 videos with one urban environment and three nature environments: low, medium, and high biodiversity. The environments were created by stitching together videos filmed at the same park on days with similar weather, and videos were layered to increase complexity. Participants completed the Trier Social Stress Test before viewing an environment, and they had electrodermal activity and heart rate taken as well as "Visual Analogue Scales (VAS) for perceived stress, anxiety, insecurity, calmness, and happiness," Biodiversity Experience Index, and a modified telepresence questionnaire. Perceived anxiety recovery and median heart rate recovery were higher in the low biodiversity than the medium, but no other significant results were found when comparing biodiversity [46]. These results may be due to a variety of factors, including participant perception of how the videos were stitched together or layered. Since biodiversity is an emerging field of research in VR, more work is needed into 3D environments controlling for biodiversity to better understand participant reactions.

2.2.3 Biomass Realism

One other study was found on the topic of biomass realism. Newman et al. conducted a study measuring responses to the PANAS, Witmer and Singer Presence Questionnaire, and NR-6 in high and low-realism VNE's. They found that "more realistic VR environments evoked more positive affective and serenity responses, as well as a greater sense of presence." The study differs from the current work as the current work incorporates different psychological and physiological measures, and the high and low-realism assets as well as shadow effects are more similar in structure in the current work [47].

Chapter 3

Biomass Realism Experiment

3.1 Overview

After the first experiment comparing biomass and no-biomass environments [23], cybersickness was identified as a potential confounding variable in the forest environment, caused by difficulty rendering large quantities of high-realism assets without latency as participants moved in the environment. Cybersickness is essential to avoid as it breaks immersion which decreases presence in the environment [25]. Furthermore, cybersickness becomes a more prevalent problem as the realism of the environment increases. For VNE's to be accessible, they need to be deployable on Meta Quest series headsets, as those are the everyday consumer available and affordable option. Most high-realism VNE's require state of the art headsets and high end computers to run, which means that they currently have low accessibility until technology improves. Thus, an important question to investigate is: to what extent does the realism of the nature assets matter for the restorative effect? In other words, can a beautiful, low-realism environment achieve some of the same benefits as a high-realism counterpart. This experiment was an initial investigation into the role of realism for the restorative effect, comparing participant performance in low and high-realism environments, and comparing each participant against their own performance in a control condition.

3.2 The Impact of Nature Realism on the Restorative Quality of Virtual Reality Forest Bathing[1]

3.3 Summary

Virtual reality (VR) forest bathing for stress relief and mental health has recently become a popular research topic. As people spend more of their lives indoors and have less access to the restorative benefit of nature, having a VR nature supplement has the potential to improve quality of life. However, the optimal design of VR nature environments is an active area of investigation with many research questions to be explored. One major issue with VR is the difficulty of rendering high-fidelity assets in real time without causing cybersickness, or VR motion sickness, within the headset. Due to this limitation, we investigate if the realism of VR nature is critical for the restorative effects by comparing a low-realism nature environment to a high-realism nature environment. We only found a significant difference in the perceived restorativeness of the two environments, but after observing trends in our data toward the stress reduction potential of the high-realism environment, we suggest exploring more varieties of high and low-realism environments in future work to investigate the full potential of VR and how people respond.

3.4 Introduction

Stress is a prevalent issue in society at large, yet in some areas, resources to effectively address and mitigate stress are lacking. In fact, some living environments are even conducive to stress increase, and urban, indoor lifestyles have been linked to chronic stress [48]. Furthermore, people spend 86.9% of their time indoors, with 6% more in vehicles, and only 7% outside [12], leading to a lifestyle of increased stress and cognitive overload [49]. Considering the widespread presence of stress and associated negative impacts, innovative ways of relieving stress are essential to research.

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[1] Verbatim From Rachel Nasters, Jalynn Nicoly, Vidya Gaddy, Victoria Interrante, Francisco Ortega. 2024. "The Impact of Nature Realism on the Restorative Quality of Virtual Reality Forest Bathing". *ACM Transactions on Applied Perception. Association for Computing Machinery, New York, NY, USA, 18 pages. https://doi.org/10.1145/3670406*

A key technique for countering the mental resource exhaustion and stress of cognitive overload is forest bathing. Forest bathing is a mental health practice where one becomes immersed in a forest environment to experience stress reduction and mental resource restoration [13]. While the benefit of the practice is perfect for counteracting the stress of indoor life, many people have little access to the nature needed for the practice. For example, people in large urban areas or nursing homes cannot access nature at any time. Thus, the people with the most dire need for this nature practice have rare access to it. Virtual reality (VR) has the unique potential to deliver highly immersive nature environments to people without access to live nature.

Research into the potential of VR is even more prevalent now that affordable VR head-mounted displays (HMDs) like the Oculus Quest 2 are accessible. At the same time, engines like Unity and Unreal Engine are improving to offer more lifelike experiences. Through the immersivity of VR and the continually improving graphics offered by game engines, it is possible to create an effective nature environment in VR. In fact, a subject of current research investigates what benefits VR forest bathing can provide for those with limited access to nature [50]. While VR nature immersion experiences can provide benefits similar to those of real nature, VR nature does not provide the exact benefits of real nature. Regardless, VR can act as a substitute when real nature is not directly accessible. Then, the question becomes how to create an optimally effective virtual nature experience.

Since VR nature is different than real nature due to its technical aspect, there are issues that call for research when investigating an optimal environment. One of these issues is realism [47]. Due to technological limitations, it is impossible to reproduce reality exactly in VR. Despite this, since VR is an immersive experience of another 'world,' it is possible that realism operates differently when creating an immersive experience. For example, while VR games are not entirely realistic and sometimes even contain very low detail models, they can be very immersive and enjoyable. Similarly, high-realism models can cause users to become disoriented and experience VR motion sickness, known as cybersickness, due to the "visual flow" of the environment [51]. However, the biophilia hypothesis, the creation of psychologist Erich Fromm [52], implies that the connection that humans have to nature is a connection to the living organisms in nature. It is unclear how our connection to living plants translates into VR, or if the realism affects how 'alive' people perceive the plants to be. This paper investigates future work proposed by Masters et al. [23], contributing new knowledge on the role of plant realism in VR nature environments for the restorative effect.

Since realism is a complex issue not yet addressed in detail with respect to VR nature, it is necessary to investigate. This work examines the question: to what extent is the benefit of VR nature dependent on the realism of the virtual environment? In the following sections of this work, we cover existing literature on VR forest bathing and VR realism factors, then detail the methods for our experiment, then present our results, and discuss their implications. All supplementary materials associated with this work, including our surveys and the stressor test, are available on GitHub at https://github.com/NuiLab/NatureProjectV2.2.

In the rest of this work, related literature, methodology, results, discussion of results, experiment limitations, and direction of future work are all presented.

3.4.1 Contributions

1. We contribute deeper understanding of the importance of realism for the immersive and restorative qualities of a virtual forest bathing application.

2. We explore which level of realism participants prefer and how well that level matches with realistic nature, further investigating how VR simulations compare and differ.

3. We uncover knowledge on how realistic nature needs to be for people to derive benefits, which can potentially spur the creation of optimized nature environments for accessible platforms to help more people find stress relief.

3.5 Related Work

Two key theories are critical for nature restoration research. Attention Restoration Theory (ART), created by Kaplan and Kaplan, is related to cognition and the idea that extended focus can exhaust mental resources, and passive interest, or 'fascination' can restore those mental resources [28]. Furthermore, Kaplan and Kaplan associate nature with having the ability to engage people in a way where they are passively interested in their surroundings, and that 'nearby nature,' which refers to keeping plants in non-natural spaces like urban and indoor areas, can elicit a similar, yet less impactful response [53]. In response to Kaplan and Kaplan, Hartig et al. developed a scale to measure the impact described by ART called the Perceived Restorativeness Scale (PRS) [24]. It has four categories: Being Away, Extent or Coherence, Fascination, and Compatibility [28, 53], all of which contain Likert scale questions and measure the restorative quality of an environment. Stress Reduction Theory (SRT) is the other critical theory for this research, and it is based on the concept that natural areas can alter people's emotional experiences for stress reduction and restoration [31]. Recently, there has been more interest in SRT and ART related to how nature can be used to improve quality of life [54]. Relevant topics include stress reduction within nature [13], in VR nature [55], and comparisons between the two [54]. There is also interest in using VR as a nature supplement for those who lack access to nature [56]. This interest presents the topics of nature realism's relationship with stress reduction and immersion [47], optimal environment designs, and issues caused by HMDs like VR sickness [57].

3.5.1 Nature Influencing Stress Reduction

The restorative potential of nature has been a research topic of interest for some time. Research has been conducted with a variety of nature environments, comparing them to urban areas, to investigate the effect of nature on stress and restoration. Forest bathing, or shinrin-yoku, was a term specifically invented to describe the restorative impact of immersion in forest environments [13]. Furthermore, the biophilia hypothesis also describes the biological need that people have for nature interaction [58]. Research by Brown et al. and Park et al. has shown that natural environments have greater stress reduction and mental resource restoration qualities than urban environments [13, 58]. The presence of biomass, or living green plant life, has also shown a positive, restorative effect both in natural environments and in indoor spaces. [40, 44]. Additionally, the diversity of green plant life may also play a role in perceived restorativeness, though more research is needed on the topic. Marselle et al., Aerts et al., and Wood et al. investigated biodiversity and found indications of potential restorative benefit, but the study by Wood et al. was the only study of the three to report that biodiversity predicted restorative benefit [15, 37, 38]. Research thus far shows that nature has the promising restorative benefits outlined by shinrin-yoku and the biophilia hypothesis. However, the essential components of restorative nature experiences need further investigation to understand.

3.5.2 Virtual Reality as a Nature Supplement

Despite the great benefits that nature immersion can provide, some individuals may not have the opportunity to experience the outdoors as often or at all. Several studies have been conducted on the potential of VR to aid populations that struggle to get outdoors, such as those in residential care facilities [56], graduate students [55], and even during the COVID-19 quarantine [59]. All three studies found that VR nature environments have the potential to positively influence individual well-being. Additionally, Mattila et al. and Reese et al. found that VR nature environments have the potential to restore moods and increase physiological arousal to a similar extent to real nature in as little as five minutes within a headset [54, 60]. The use case of VR as a nature supplement is promising, and many questions surround the components and qualities of an optimally restorative nature environment given the limits of the technology. For example, in order to have an accessible nature supplement, it has to be deployable on a portable, affordable headset like the Oculus Quest. Since the Oculus Quest struggles to render high-realism environments efficiently, it is worth exploring the importance of realism in the simulation.

3.5.3 Realism Within VR Design

When designing any VR environment, three primary concerns are immersion [26], presence [27], and realism [47]. VR is unique because it uses virtual worlds to transport people into different realities. Immersion, presence, and realism are all critical elements of delivering a VR environment that will affect people. Immersion describes how well the computer simulation delivers a realistic and detailed depiction of reality and involves aligning simulations with expectations of what would really happen [26]. Presence is the response that people have to immersion, or a feeling of being inside of the simulation [27]. Realism is how well a simulation mirrors real life.

Immersion is a critical variable in understanding how realism is related to stress reduction. Immersion influences stress reduction in the sense that if an individual's immersion remains consistent during a virtual natural environment, there are positive results in the treatment of trauma and stressful symptoms [61]. Kaplan's [53] ART has demonstrated the benefits and consequences of relying on immersion for a therapeutic reaction. The benefits include the recovery of stress when immersed in natural environments. Unfortunately, consequences include immersion being previously proven to be broken easily due to distractions, consistent direct attention, or when the participant perceives danger. Thus, it is essential to explore the extent to which biomass realism may be influencing nature immersion, as it will ultimately influence stress restoration.

Realism impacts immersion in the sense that the more real a nature environment appears, the stronger the immersive effects are. This was demonstrated in a study done by Newman et al. [47] where his team had shown that a high-realism environment produced a greater sense of both presence and restoration than a low-realism environment. There is both conflicting and supporting evidence of this in the study completed by Gisbergen et al. [62], who discovered that certain elements of realism may or may not induce immersion. For example, as demonstrated in Gisbergen's experiment, participants moving their bodies intensified the realism aspect, whereas the avatars did not due to their failed attempt at looking as realistic. This brings up an interesting conflict known as the uncanny valley [63], the uneasy human response to an object that has a humanistic resemblance. This relationship shows that virtual assets may not behave the same as their real counterparts, which calls for further work investigating how realism matters.

Realism design in our virtual environments was also considered in the design of audio, lighting, and camera angle. It is argued that since humans are multi-modal beings, we may be more immersed when several senses are being addressed, such as audio [64]. Multiple studies have shown that the addition of relevant audio in virtual environments strengthened the individual's presence [65–67]. One study conducted by Annerstedt et al. [68] showed that besides audio strengthening presence, it also allowed for a sense of safety, which is the same result as daytime lighting.

Lighting in VR environments will play an important role in the decision of the time of day utilized as brightness levels not only influence degrees of safety but also stress recovery speed. Li et al. [69] demonstrated that high amounts of light promoted perceived safety and stress recovery via psychophysiological responses when using VR headsets. This finding of bright light-induced stress recovery and safety is consistent with the finding that humans prefer bright and sunny nature in the real world [70]. Comparing the lighting between real-world and virtual environments is valid since it has been demonstrated that VR lighting is similar to real-world lighting, at least for well-lit scenes [71]. Daytime lighting is beneficial for virtual scenes not just for stress recovery and a sense of safety but also for the ease of camera work.

Camera work within the virtual world is an essential consideration when maintaining realism. Christie et al. [72] advise that camera rules and properties are addressed from the beginning to address aesthetic and cognition properties. Without the option of having an avatar to refer to for camera position, the properties include angles, orientation, distance from objects, and height location. Ultimately, all camera characteristics, especially from a first-person perspective, influence emotional response according to Christie et al [72]. Besides an emotional response, camera positions can influence cybersickness.

3.6 Methods

In this experiment, our goal was to test if the realism of the biomass in a VR nature environment impacts restorative quality via comparing the restorativeness of two environments, one high-realism and one low-realism. We accomplished this through inducing stress followed by observing the restorative benefits of the environments. This experiment was approved by the Institutional Review Board (IRB). Our hypotheses are as follows:

H_1. Both nature environments are more restorative than the control condition.

Figure 3.1: High-realism Nature Environment

H_2. The high-realism nature environment is more restorative than the low-realism nature environment.

3.6.1 Participants

48 student participants were recruited from the Colorado State University community after exclusion. Participants were excluded if their self-reported vision was below 20/60, if they had a previous self-reported history of heart conditions, or if they had a history of seizures, all of which were detailed in the participant recruitment message as well as the consent form. 27 participants were male (56.3%), 20 participants were female (41.7%), and one participant was non-binary (2.1%). The mean age for participants was 23 years old with a standard deviation of four years. 81.3% of participants had used a VR headset before, and 18.8% had not. Participants were also asked to report the average number of hours per week spent on the computer, which yielded a mean

of 40.2 hours and a standard deviation of 20.2 hours. Participants reported how many hours per week they spend using VR, and 12 reported a non-zero number. The mean was 1.17 hours with a standard deviation of 2.82 hours.

3.6.2 Materials

The experiment was conducted at a desk using an Alienware computer with 128 GB memory, an Nvidia GeForce RTX 3090 graphics card, and an 11th Gen Intel i9-11900F processor. The experiment was conducted using an HTC Vive Pro 2 VR headset in a lab environment. The environments were created and administered using Unreal Engine 4. All questionnaires were administered via Google Forms and completed at the desk on an HP Pavilion laptop. There was an air vent blowing cool air at the experiment location, simulating an outdoor breeze.

3.6.3 Procedure

Psychological and Physiological Measurements

The PRS was used to measure presence in the environments [24]. The Positive and Negative Affect Schedule (PANAS) [29] and the Zuckerman Inventory of Personal Reactions (ZIPERS) [32] were used to measure people's emotional responses to the environments. All questionnaires were Likert scales, integrated into Google Forms [73] for easy administration. For PANAS, participants were asked to report how they felt at the current moment that they were taking the survey. In addition to the psychological measures taken, blood pressure and heart rate were also taken as indicators of stress. We also measured electrocardiogram (ECG) and electrodermal activity (EDA) but could not get reliable readings for all participants due to the technology and could not use the data as a result.

Stressor Test

The stressor test we used was an adaptation of the MPAtest [74]. It is a researched math stressor test that induces stress via delivering challenging problems that take a lot of mental energy followed by easy problems that keep users motivated to finish the test. We used the implementation of the test used in [23].

Figure 3.2: Low-realism Nature Environment

Virtual Environments

Two virtual nature environments (VNEs) were created using Unreal Engine, one with high-realism as seen in Figure 3.1 and one with low-realism as seen in Figure 3.2. The low-realism environment used the "Dreamscape Nature : Meadows - Stylized Open World Environment" package from the Unreal Engine marketplace [75]. The high-realism environment referenced from the tutorial offered by Serge Ramelli Photography [76]. The user was stationary in the environments, sitting on a stump surrounded by a virtual forest. Originally, the idea was to make the experience more immersive by giving participants hands and an avatar despite the fact that there were no controls or movement allowed. However, after implementing the avatar and hands, we realized that neither were as realistic as the real forest condition and may have led to some uncanny valley effects, so we removed the avatar and hands and positioned the camera to give the user the appearance of sitting on a stump. The forest included ground plants and trees that moved, making the environment dynamic though the user was stationary. During the creation of the virtual environments, similar looking assets were found for each environment in order to ensure that realism was the only environmental difference. Different asset packs of different realism yet similar shape and color were used for the different environments with the goal of making both as equal in beauty, rather than reducing the level of detail of the high-realism assets to create fuzzy trees that were not beautiful. The high-realism map was created first. The low-realism map was made by copying the high-realism map and then replacing the trees and ground cover assets individually. This was done to ensure the maps were structured identically aside from realism. Both environments were constructed using identical daytime lighting because VR lighting has been shown to be similar to real-world lighting for well-lit environments [71], and identical fog effects were used to make the background forest seem endless since it was difficult to render large amounts of highly realistic trees in VR. After taking these measures to create the environments while maintaining reasonable performance, the high-realism environment had an average frame rate of 90 frames per second (FPS) and the low-realism 115 FPS.

Control Condition

In order to compare the restorative potential of a virtual environment to the alternative of having no special treatment for stress reduction, a control condition was created. After careful consideration of introducing a VR control condition, we decided that the goal of our control condition would be to simulate the absence of stressful visual stimuli in the absence of VR, since the goal of our VR environments was to introduce the presence of relaxing visual stimuli via VR. We wanted to model what a potential solution for handling everyday stress would be given no helpful alternatives or guidance. Thus, for the control condition, we had participants close their eyes and do nothing, very much like how one may close their eyes to take a break from the stressful visual stimuli on their computer screen and the stress of the task they were given in everyday life [77].

Preference Questionnaire

Ideally, having a control condition where people are compared to their own performance should be enough to control for any personal preference differences. However, the preference questionnaire was included as a check to ensure that personality preferences were not skewing the results, as prior research has shown that personal experience can affect the ways that people react to different nature environments [78]. Our preference questionnaire was implemented similarly to [23], but we changed the images to be more fitting to the context of our experiment. We included two real images taken of the forest in Olympic National Park, two images of less realistic video game forests, an image of the high-realism forest environment, and an image of the low-realism forest environment.

Open Response Exit Survey

An open-response exit survey was suggested in the pilot of this experiment to collect feedback and insights from participants. In order to further observe participant experience and how it affects results, we created a three-question exit survey. We asked the participants what they liked, what could be improved, and if they experienced cybersickness. We chose to incorporate cybersickness into the open response questionnaire rather than administering a full sickness questionnaire in order to avoid survey fatigue and give the participants the opportunity to elaborate on the details of their experience. These questions gave us further insight into how participants perceived their experience as well as if their experience was confounded by VR sickness, which breaks immersion and can cause stress.

Experiment Procedure

This experiment followed a mixed design. Each participant was randomly exposed to one of the two environments and the control condition in random order. Thus, there was a within-subjects comparison between how participants reacted in the control environment versus the experiment condition they were assigned to, then there was a between-subjects comparison between the two different nature environments. Participants completed two sessions of the experiment on different days, one in the control condition and one in the environment condition.

Participants arrived at the laboratory and were informed that physiological measures and psychological measures would be collected. Before participating in the experiment, subjects were informed of the potential risks and benefits of participation in the experiment and that they could leave the experiment at any time. The subjects then signed an informed consent form. The experiment 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. The participant began by filling out a demographics questionnaire. Then, their ECG, EDA, blood pressure, and heart rate were taken, and then they filled out the baseline psychological questionnaire. After this, they completed the math stressor test, had their ECG, EDA, blood pressure, and heart rate measured again, and filled out a post-stressor psychological questionnaire. Then, they entered either an environment or the control condition. Exposure time in both environments and for the control condition was ten minutes, and heart rate was measured at each minute of the exposure time. After exposure, the participant had their ECG, EDA, blood pressure, and heart rate measured and completed the psychological questionnaire for the respective environment or the control condition. At the end of the second session, participants completed two more steps. They filled out a preference questionnaire where they rated different real, realistic, and low-realism nature environments using the PRS. After this, they answered an open-ended exit survey where they gave feedback on the experiment. They were then debriefed and dismissed. The experiment lasted approximately one hour per session for two sessions on different days (environment and control), so the total experiment duration was two hours.

3.7 Results

We had two hypotheses: H_1 Both nature environments are more restorative than the control condition. H_2 The high-realism nature environment is more restorative than the low-realism nature environment. Each participant had physiological measures taken three times during each session of the experiment: once after entering the room (baseline), once after completing the MPAtest (post-stressor), and once after the experiment condition they were exposed to, whether that be the control (post-control), the high-realism environment (post-high), or the low-realism environment (post-low). We were able to measure heart rate and blood pressure, but ECG and EDA were not usable as we could not get readings for every participant. Each participant also completed the psychological questionnaire with the ZIPERS, PANAS, and PRS three times after the physiological measures were recorded. The responses from these surveys were analyzed separately for the ZIPERS, PANAS, and PRS.

ZIPERS can be split into positive and negative emotion scoring. ZIPERS is a 5-point Likert scale that has six positive affect and six negative affect questions. To compute positive and negative subscale scores, we summed the scores from the questions in the respective subscales. Both the positive and negative subscales has a range from 0-30. PANAS is similarly divided into Positive and Negative Score, and each subscore has ten questions that are added up to calculate the subscale score. PANAS is also a 5-point Likert scale with subscore ranges from 0-40. PRS is a more complex measure. The PRS is also a 5-point Likert scale, but it has four subcategories, Being Away, Fascination, Coherence, and Compatibility, with component questions that are added to calculate the subscale score. Being Away has a range of 0-12 and measures if the experience is an escape experience. Fascination has a range from 0-30 and measures passive attention in the environment. Coherence has a range from 0-24 and assesses if the environment is overwhelming. Compatibility has a range from 0-30 and measures how well the user fits in with the environment. While these subscale scores can be observed by themselves, in the case of this paper, General Restorativeness is a more relevant score to consider. General Restorativeness is calculated by summing the subscale scores from Being Away, Fascination, and Compatibility to measure the overall restorative quality of the experience on a scale from 0-72.

3.7.1 Data Analysis

Python was used to clean, sort, and visualize the results. Specifically, the pandas, numpy, and scipy statistics libraries were used to sort and clean the data, then the seaborn library was used to visualize the data. We used a linear mixed model (LMM) fit by REML with estimated marginal means contrasts, and we adjusted p-values using a Bonferroni correction to investigate the interaction effects between Treatment and Time. R was used for these analyses. Before analyzing experimental results related to the hypotheses, we verified that the MPAtest induced stress via comparing baseline and post-stressor results. To observe H_1, the low-realism and high-realism results were compared to control. Then, to observe H_2, the measures for low-realism and high-realism are compared. The variance between participants and within participants was high for a random effect. We did not analyze any additional demographic effects because we had no hypotheses that related to the responses of different groups, and people were verified against their own performance in this experiment.

3.7.2 Verifying the Stressor Test

To verify that the MPAtest induced stress, baseline and post-stressor scores were compared. For ZIPERS negative affect, the estimated marginal means contrast revealed a statistically significant difference ($p < 0.0001$), indicating that participants scored higher on the ZIPERS Negative Affect survey after exposure to the MPAtest than their baseline scores ($estimate = 2.06, SE = 0.328, t = 6.294$). Additionally, for ZIPERS positive affect, the estimated marginal means contrast revealed a statistically significant difference ($p < 0.0001$), indicating that participants scored lower on the ZIPERS Positive Affect survey after exposure to the MPAtest than their baseline scores ($estimate = -3.215, SE = 0.57, t = -5.636$). There were no significant differences in PRS General Restorativeness scores or PANAS scores for participants between their baseline and post-stressor. A significant difference was found for systolic blood pressure ($p = 0.017$).

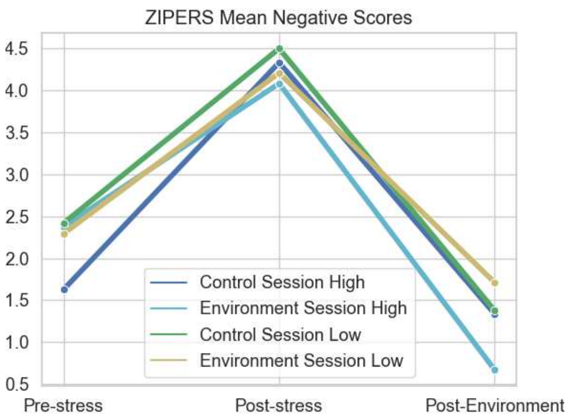

Figure 3.3: ZIPERS Mean Negative Affect Scores

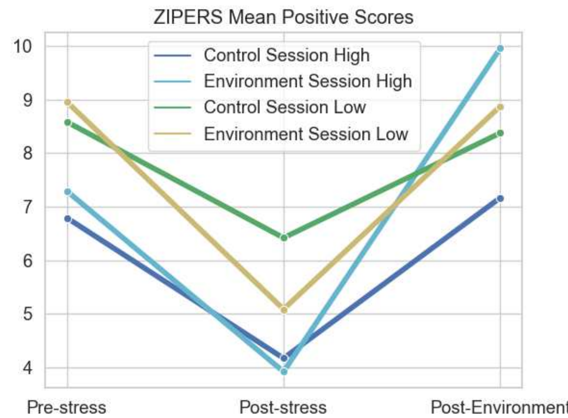

Figure 3.4: ZIPERS Mean Positive Affect Scores

The contrast test revealed that systolic blood pressure decreased after the stress test ($estimate = -3.19, SE = 1.25, t = -2.564$). Heart rate and diastolic blood pressure showed no significant differences.

3.7.3 Comparing Low-realism to Control

To observe H_1, The low-realism environment was compared to the control environment. No significant results were found doing this comparison on ZIPERS, PANAS, and PRS responses. There were also no significant differences in heart rate or blood pressure between the control and low-realism environment for participants.

3.7.4 Comparing High-realism to Control

In addition to comparing the low-realism environment to the control environment, the high-realism environment was compared to the control environment. For PRS General Restorativeness, after applying Bonferroni correction for multiple comparisons, a significant difference was observed between the control and high-realism conditions, with an adjusted significance level set at $\alpha = 0.05/3 = 0.017$. The estimated marginal means contrast revealed a statistically significant difference ($p < 0.001$), indicating that participants subjected to the control condition exhibited a marked decrease in General Restorativeness compared to their scores in the high-realism treatment ($estimate = -9.121, SE = 1.95, t = -4.684$). Additionally, for ZIPERS Positive Affect, the estimated marginal means contrast revealed a statistically significant difference ($p = 0.0121$), indicating that participants subjected to the control condition provided lower positive affect scores compared to their scores in the high-realism treatment ($estimate = -2.833, SE = 0.976, t = -2.902$). Other surveys did not show significant results. There were no significant differences in heart rate or blood pressure between the control and high-realism environment for participants.

3.7.5 Comparing Low and High-realism

To observe H_2, the low and high-realism environments were compared. For PRS General Restorativeness, the estimated marginal means contrast revealed a statistically significant difference ($p < 0.006$), indicating that participants subject to the high-realism condition exhibited a marked increase in General Restorativeness compared to those in the low-realism condition ($estimate = 7.576, SE = 2.43, t = 3.113$). There were no other significant differences.

3.7.6 Preference Questionnaire

One of the final steps in the procedure for the participants was to complete the preference questionnaire, which included six different images depicting both nature environments from the experiment, real nature images from Olympic National Park [79], and lower realism VNEs from games. Each participant rated the images using the PRS, which we then used to calculate the General Restorativeness for each image on a scale of 0-72. This preference questionnaire was administered to understand user preference better and observe any influence personal preference may have had on the results. The mean and standard deviation for General Restorativeness were calculated for each image provided. The highest-rated image was an open area in a video game forest from the game Legend of Zelda, Breath of the Wild [80] (M= 42.25, SD= 7.042). The second highest preference rating was an image of an open area in a real forest in Olympic (M= 41.13, SD= 7.207044). The third highest preference-rated image was a similar image of a forest path in Olympic (M= 38.17, SD= 8.563488). This was followed by the realistic forest VE screenshot (M= 33.10, SD= 7.697028). The second to last preferred rated image was a lower realism virtual forest path from the game World of Warcraft [81] (M= 32.00, SD= 8.079393). Finally, the lowest rated image was

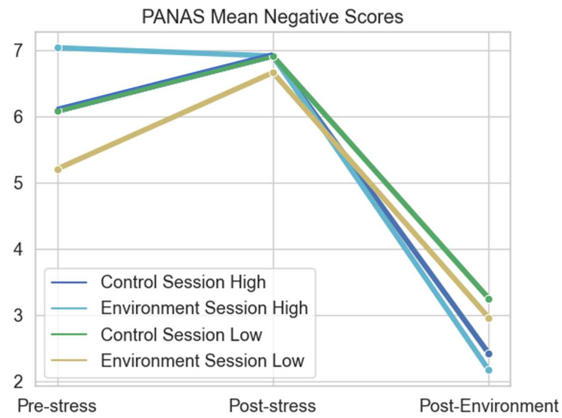

Figure 3.5: PANAS Mean Negative Affect Scores

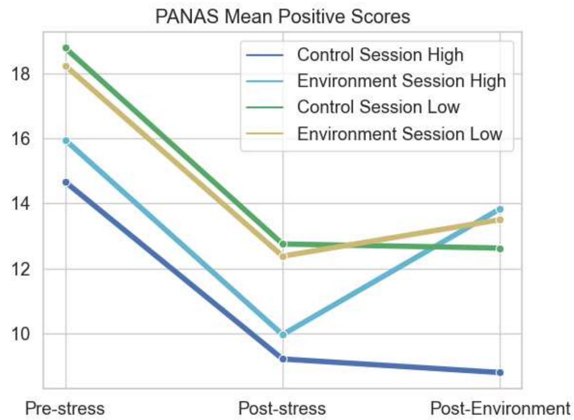

Figure 3.6: PANAS Mean Positive Affect Scores

the screenshot of the low-realism nature environment (M= 28.06, SD= 7.820884). These preferences illustrate that all high-realism images, including the high-realism screenshot, were preferred to the low-realism screenshot, which follows Section 3.7.5 where the high-realism environment performed better than the low-realism with respect to PRS General Restorativeness. Additionally, it is interesting that the low-realism environment screenshot ranked below other low-realism VNEs. This may indicate that future work is needed to better understand the design of low-realism environments, since one of the low-realism environments ranked highest and our screenshot ranked lowest, and this trend may also contribute to the lack of significant results between low-realism and control. Overall, more work is needed to understand the merits of different realism levels in VNEs.

3.7.7 Open Response Exit Survey

At the end of the experiment, an open-ended exit survey was administered in order to gain additional insights into the experiment design and process from participants. Three questions were administered, asking about cybersickness, improvements to the experiment, and things participants liked about the experiment. A thematic analysis following the approach of Braun and Clarke [82] was performed on the responses and is detailed below for each question.

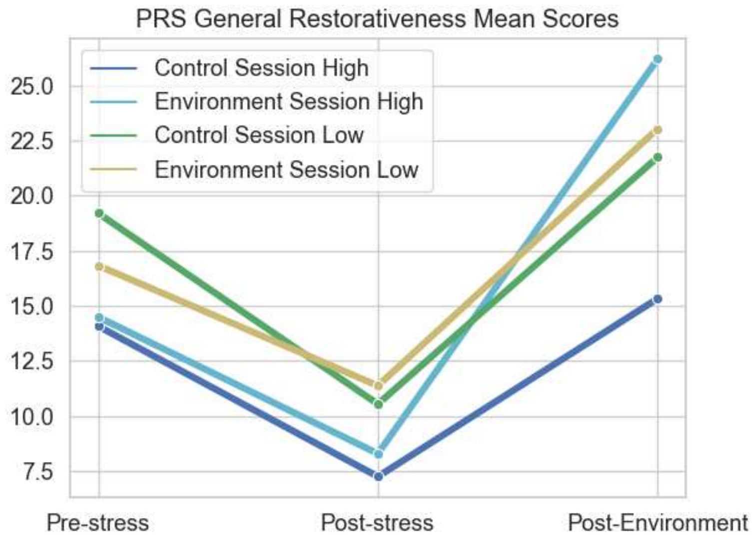

Figure 3.7: PRS General Restorativeness Mean Scores

Did you experience any cybersickness?

Cybersickness, or motion sickness within a VR environment, is important to minimize as it can cause stress and confound results, as explained in section 3.4. The question for all participants was, ‘Did you experience any cybersickness?’. All 48 participant responses were recorded. Participants were asked if they experienced cybersickness in order to observe the extent to which cybersickness may have affected experimental results. A thematic analysis was performed on the open-ended questionnaires that our participants received to understand better what type of environment introduces cybersickness. 72.92% of our 48 participants claimed they did not experience cybersickness, 48.57% of which underwent our low-realism environment. 25% of our participants claimed that they experienced some cybersickness, 50% of which underwent our low-realism environment. Our remaining participant, 2.08%, claimed to experience cybersickness within the low-realism environment. These results indicate that the participants who claimed to experience some cybersickness were almost evenly distributed between the high and low-realism environments.

What could be improved about this experiment?

A thematic analysis was performed on suggestions to improve the experiment in order to discover the limitations of our study better. The question for all participants was, ‘What could be improved about this experiment?'. All 48 participant responses were recorded. Some participants answered the open-response questions with multiple different features that could be improved. These seven responses with multiple areas of improvement were broken into 19 responses. There are 60 total responses for features that could be improved. The improvement areas are almost equally dispersed among experiment design, room distractions, arithmetic test, VR environment design, psychological questionnaire, and one comment on the control condition. Making up 13% of responses are experiment design concerns with instruction clarity, informing participants about the math test, having to wear a Fitbit, and duration. This is the most diverse group of responses, invoking us to review instructions better. However, not informing participants about the math test and wearing the Fitbit are necessary features of the study in order to prevent priming. The participants were informed about the duration of the experiment in both the advertisement and consent forms. Another 13% of responses requested that we remove other people from the experiment space as it introduced distraction and discomfort. This prompted us to acquire a more isolated room for the other experiments at the time and for future experiments. An additional 13% of responses had comments about the math test being stressful, too long, and including annoying car sounds. This was the intent of the math test and helped demonstrate the arithmetic test's success. However, one participant requested that we have more variation in the questions as they remember the question being asked. Another participant asked if we could show the correct answer. This is odd as we do flash the correct answer on the screen after every user input, which may contribute to the users memorizing answers from previous sessions. 5% of responses were in regard to the psychological questionnaire, one of which also mentioned that they found themselves memorizing previous answers. To reduce the need for memorization, we plan to randomize the order of questions on the questionnaire each time it is given. One response was providing a suggestion for the control condition to include audio that had nature sounds or white noise. Audio is mentioned in 31.6% of responses that were in regard to the VR nature environments. These improvements are not necessarily considered limitations but things to consider for future studies. The audio came from a response where they could not tell if the audio or the environment was relaxing. This prompts future considerations of a control condition with audio. Multiple users requested a way to move in the environment. This feature was not included in order to minimize cybersickness but prompts future work to incorporate movement in a way that does not induce sickness. Three responses were in regard to poor performance and how blurriness, black borders, and poor optimization may have influenced their restorativeness. All three of these responses are from individuals that were in the high-realism environment. Thus, this may be a limitation for the restorativeness experienced in the high-realism environment. As for visual appearance in the environments, there were several requests for animals, details for observation, and even water sources, all of which are things that we plan to look further into for future designs.

What were some things you liked in this experiment?

A thematic analysis was performed on the features participants enjoyed to discover this study's strengths and personal preferences. The question for all participants was, 'What were some things you liked in this experiment?'. All 48 participant responses were recorded. Some participants answered the open-response questions with multiple different aspects that they enjoyed. These 14 responses with multiple comments about things they liked were broken into 30 responses. Thus, there were 64 total responses for features that participants enjoyed. The areas that participants liked most about the experiment were the overall ease, the struggle of the math challenge questions, the relaxation of the conditions, and mostly the VR experience. The overall design of the experiment in terms of user ease and the two-day structure was promoted in this section by 9.3% of responses. Noting that no one mentioned these areas for improvement, this is a structure we may continue to utilize for future studies. Other design features include 7.8% of participants enjoying the devices and frequency of measurements. It is unclear if the participants appreciated the physiological or psychological measurements. However, 3.1% of participants did note that they liked the preference questionnaire survey with varying images. Beyond experiment design, 15.6% of participants were found trying to find explanations for the arithmetic test, claiming that although they enjoyed it, it was stressful, which they determined was the point. Users claimed that they were focused on answering, trying to figure out tricks, acknowledging personal improvement, and being displeased with themselves when they were wrong, all of which contribute to stress and help support that the arithmetic test induced stress. Most of the responses, 42.18%, claimed they enjoyed the VR experience the most. There is some variety in what VR experience may mean. 44.4% of these are generalized to mean the virtual experience, such as getting to wear the Vive Pro, using VR for the first time, or enjoying the time spent in VR. Whereas the remaining 55.6% of participants are referring to the environment of itself, such as the nature ambiance, features in the distance, landscape, trees, lighting, and colors. 40% of the responses regarding appreciation of the environment are from individuals who experienced a low-realism environment. This encourages that there are some differences in participant preference that individuals may prefer the high-realism environment more than the low-realism. This finding provides some support for H_2, that the high-realism environment is perceived as more restorative than the low-realism environment.

3.8 Discussion

The MPAtest was observed to induce some stress, as there were significant results between the baseline and post-stressor consistently on ZIPERS Positive and Negative Score, verifying the findings of Masters et al. [23]. However, the lack of significant findings on the PANAS and PRS as well as the significant decrease in systolic blood pressure indicate that the stressor may need redesigned for greater efficacy in the future. H_1 yielded mixed results. When comparing the low-realism condition to the control condition, there were no significant results, which indicates that there was no difference in the restorative quality of the low-realism condition versus the control condition. When comparing the high-realism and control conditions, there were significant results. A significant increase in ZIPERS Positive Affect as well as PRS General Restorativeness was observed, indicating that the high-realism environment had higher perceived restorative value than the control condition, which provided some support for H_1. However, given the mixed results, H_1 is not fully supported. H_2 is also complex. Comparing the two environments yielded a significant increase in PRS General Restorativeness in the high-realism environment when compared to the low-realism environment, partially supporting H_2. However, due to the lack of significant results on other surveys, future work is needed to better understand the role of realism for the restorative effect. Also, since the low-realism environment was not better than the control, whereas the high-realism environment did show some restorative potential, the low-realism environment would likely need to be redesigned before a valid comparison between the two can be made, which could be an avenue for future work.

Additionally, since the variance between participants and within participants was high for a random effect, more work is needed to understand individual affective states. While random intercepts generated by the LMM account for individual differences, they may not capture all sources of variability. Individuals may have unique baseline affective states that influence their responses independently of treatment and time effects, and by understanding and modeling individual variability, future results are more likely to generalize to broader populations or settings beyond this specific sample.

3.8.1 Limitations

There are a few limitations in this experiment that may have had an effect on the mixed results observed. First, since the Fitbit was not recording data reliably, in some cases, participants did the EDA and ECG tests multiple times before getting results. Since heart rate and blood pressure were taken after EDA and ECG, the time taken to record EDA and ECG may have had unintended effects on the readings of heart rate and blood pressure, and participants may have experienced additional stress trying to get the technology to work. Also, since the Fitbit itself is designed for a single wearer, it is unclear whether it is reliable enough to use in future studies. Another thing that may have affected physiological data was the posture of the participants. Some crossed their legs while their blood pressure was being taken, and some moved their arms around while in the environment, which may have affected heart rate readings. Thus, the physiological data may not be fully reliable. However, given this limitation, it is also important to recognize that decreases in physiological measures are not necessarily congruent with stress reduction and attention restoration. For example, while stress reduction can be reflected in low blood pressure and heart rate, attention restoration may involve excitement about the experience, which can correspond to increased heart rate.

Additionally, the open exit survey provided some insights into participant experience that exposed some limitations. First, some people reported being affected by people and noise in the room during the experiment. This may have caused stress and broke immersion, which could confound results. Some reported that movement would improve the experience, so it is possible that if people were more actively involved, then they may have had a different experience. The ability to be more active without getting sick in environments that are less visually complex may be the advantage that those environments have over high-realism environments. Given that people still experienced cybersickness, it is worthwhile in future studies to explore the tactful incorporation of motion in order to capture passive attention. Additionally, the lighting in the low-realism environment was identical to the high-realism environment, but that lighting may be non-optimal for lower resolution assets. A lot of low-realism nature experiences in VR use very intentional lighting that is manipulated to create atmosphere, which may have been necessary for the comparison of two equally beautiful environments yet lost in this experience. Finally, in the high-realism forest, the trees were at such a level of detail that the user could identify more places where the light passed through the trees, and more of the background trees were visible.

3.8.2 Future Work

Since the results of this experiment are mixed, it is worth observing trends in the raw psychological data that indicate a need for further investigation. ZIPERS and PANAS both measure stress via affective responses. Figures 3.3 and 3.4 plot the means for ZIPERS Negative and Positive Scores across surveys and across conditions, and Figures 3.5 and 3.6 plot the means for PANAS Negative and Positive Scores. The first main trend is that Negative Score increased and Positive Score decreased after the math test, followed by Negative Score decreasing and Positive Score increasing after all conditions. These trends are more pronounced on the ZIPERS than the PANAS, which may indicate a future need to consider which survey provides the most relevant information on stress responses. The overall shapes of these graphs show that the stressor is stressing people, and people are recovering from the stress to some extent, which follows from the work done by Masters et al. [23]. For ZIPERS Negative Scores, the participants in the high-realism group were slightly less negative in the high-realism environment than the control condition, but not significantly so. This trend is also reflected in PANAS Negative Scores, as illustrated in Figure 3.5. This trend extends to ZIPERS Positive Scores and PANAS Positive Scores, where participants in the high-realism group were more positive in the high-realism environment than in the control condition, though only ZIPERS was significant. Additionally, for ZIPERS Negative Score, participants in the low-realism trend towards being slightly less negative in the control environment than the low-realism environment, which is also reflected in PANAS Negative Scores. This is a surprising trend that needs future investigation to better understand why it occurred, as there is currently little research on aesthetic, lower realism VNEs. Additionally, this trend does not extend to the ZIPERS and PANAS Positive Scores, as participants in the low-realism group were more positive in the low-realism environment than in the control condition. Results across all surveys show trends of participants being more positive and less negative in the high-realism environment than the low-realism environment, but not significantly so across many surveys. Furthermore, since the results are mixed, future work that focuses on environment realism in additional detail is needed in order to truly understand the trends and the extent to which they are meaningful.

The PRS measures restoration as shown in Figure 3.7. Overall, the noteworthy trends are that both the high and low-realism groups were more restored in the virtual environment than the control condition, but only the high-realism was significant. Also, the high-realism group was significantly more restored than the low-realism group. These trends are what we expected, but we expected the differences to be significant. One reason mixed results may be occurring is due to the design of the environments, calling for future work into the details of the design of beautiful high and low-realism environments. Future work can also aim to improve upon the limitations of this work in order to minimize potentially confounding variables. One interesting avenue would be to understand how physiological and psychological measures deliver different insights into the restorative quality of the experience. Another interesting avenue would be to research aesthetics to understand what beauty means for virtual assets and design environments that are equally beautiful, which may also clarify some of the results observed on the preference questionnaire. Finally, work is needed to understand, control for, and report how individual differences in affective states affect experiences in the environment, which can help contextualize results for a broader audience. This may look like using more specific psychological questionnaires or carefully crafted open response questions to understand personal experience. Overall, this contribution serves as a starting point for the research on the role of realism in restorative VNEs, and there are many future paths to pursue before understanding optimal VNE design.

3.9 Conclusion

In conclusion, some results were expected, and some were not. Results partially supported the efficacy of the MPAtest, which was expected, but the MPAtest also decreased systolic blood pressure, which was surprising. The high-realism environment was expected to be more restorative than the control condition, which results partially supported. It was unexpected that the low-realism environment did not outperform the control condition, and it was also unexpected that the high-realism environment only significantly outperformed the low-realism environment on PRS General Restorativeness. Given these results, it is important to address key challenges, opportunities for future improvement, and the next steps in this line of research. A variety of factors can be improved and investigated in future experiments, which are detailed in our limitations and future work. Overall, this research contribution is an initial investigation into the importance of realism for VNEs that effectively reduce stress and restore mental resources, and it opens new avenues for deeper research into the topic.

Chapter 4

Discussion and Future Work

4.1 Addressing Limitations in Future Work

The limitations of this study exposed important changes that need to be applied in future studies. First, since we could not reliably collect ECG with the Fitbit, for future studies it is necessary to use different equipment. The BioPac ECG system is better to use, as it provides respiratory sinus arrhythmia, which contains heart rate variability measured with respiration, which is a better measure for stress than heart rate [83]. The BioPac ECG should replace the Fitbit for future studies.

Additionally, rather than using the ZIPERS and PANAS, which both overlap, ZIPERS will be replaced by the Perceived Stress Scale (PSS) [30]. The PSS is a more commonly used psychological measuremement of stress, and having a direct measurement of stress may help clarify the difference between excitement and stress in physiological reactions to the environments. In the future, the Trail Making Test Parts A and B [84] will be used to measure attention directly in addition to the PRS. This change is necessary because perceived restoration and measured restoration are not always congruent with one another [85].

In future studies, sound design should play a greater role as it is critical for immersion, presence, and reaction in the environments. The sounds should not include any natural elements that can be perceived as a threat. It is also essential to ensure that the experiments are ran in an isolated, quiet room to prevent any external noise interference.

There are a few other takeaways from this experiment to apply to future experiments. It is critical to make sure the lighting matches both the environment that it is applied to and matches across environments to control for lighting effects. Additionally, it is important when selecting assets to select ones with similar foliage density or increase the number of low-density assets in an environment when the goal is to compare different types of assets that are intended to look similar. However, it is best to chose assets with the most similar canopy and stand density possible.

4.2 Proposed Future Research Directions

Inspired by this research as well as the work from the original experiment [23] and a follow up experiment on biomass beauty [86], there are a few new studies that are planned.

4.2.1 Plant Biodiversity Study

One developing area of research is how plant biodiversity affects the restorative potential of VNE's. In real nature environments, biodiversity has a variety of health benefits; primarily related to diverse microbiomes and their effects on physical health [87]. Since microbiomes cannot be modelled in VR, a deeper understanding of how visual plant biodiversity affects mental health in VR is essential for creating VNE's with the visual requirements to maintain passive attention, which is a key element of perceived restorativeness [24].

To understand biomass diversity and its influence, this study will observe two different levels of plant biodiversity: homogenous and diverse biomass. Participants will experience both environments in separate sessions in a within-subjects design. The first environment experienced will be selected using random assignment. For each session, the experiment design flow will model the experiment in Section 3.2. An additional group will experience a between-subjects control condition where they will close their eyes instead of being in VR. Much like Section 3.2, psychological and physiological measures will be assessed before and after a stressor, and then after VNE, but with the new measures in Section 4.1.

It is expected that the environment with greater biomass diversity will be more restorative and improve stress recovery moreso than the environment with more homogeneous biomass, because more visually interesting environments should be better at capturing passive attention, which is a key element of perceived restorativeness [24].

4.2.2 Biomass Color Realism Study

The PRS measures how well an environment is an escape from everyday life [24]. It is possible that only modeling green spaces in VR may be eliminating other nature options that are much more difficult to find in real life, and creating natural environments that people do not see often in real life may also have restorative effects. This experiment aims to answer the question: is biomass required to be green for the restorative effect? Color theorists suggest that green and purple both have relaxing qualities [88]. There will be two environments, one with green biomass and one with purple biomass, which are both colors that have positive and relaxing color theory associations. The experiment design is the same as Section 4.2.1. Research on 'nearby nature,' or nature in everyday life, suggests that green plants specifically provide restorative benefits [28, 53], so the hypothesis is that the green environment is more restorative and will improve stress recovery moreso than the purple environment.

4.2.3 Biomass Realism in Office Spaces

Kaplan's concept of 'nearby nature' states that bringing nature into non-natural areas helps reduce stress and improve mental health to an extent [28, 53], though not to the extent of real nature. Examples of the use of 'nearby nature' include greenery in workspaces and house plants. However, not all nearby nature is real, fake plants are often used when real plants are messy or difficult to maintain, yet fake plants are popular as a substitute that many people enjoy. One research area in VR nature immersion is the role of realism for the restorative effect [47]. VR plants are also fake, and little is known about how real people perceive VR plants to be.

In this study, the aim is to investigate the unanswered question: how real do people perceive VR plants to be? Using real nearby nature, fake nearby nature, and VR nearby nature, we will be able to understand how people react to VR, and whether that reaction is more similar to a real nature reaction or a fake nature reaction. There will be three conditions: a real office with real plants, a real office with fake plants, and a VR rendering of the office with VR plants. The design will be within-subjects, following the experiment flow from prior experiments.

The experiment shall follow a similar protocol as Section 4.2.1, where psychological and physiological measures are assessed before and after a stressor. However, in this study, participants will be randomly assigned to either real-world office with real world office with fake plants, or VR office with VR plants—not all participants will be in VNE. The same psychological and physiological methods will be assessed a third time, as in prior work, but will be compared across the VNE and the real-world conditions.

Since similar studies have not yet been conducted, the results of this study will provide interesting information. The hypothesis is that, due to the immersivity of VR, the VR models of real plants may have potential to induce response more similar to real plants.

4.3 Other Subjects of Future Research

There are a few other interesting avenues of future work that could be pursued based on the results and limitations from this study. First, additional work can be done into sound design to discover which natural sound combinations are the most relaxing for certain environments. Additionally, different lighting techniques can be explored within different environments to understand how lighting affects restorativeness and how lighting differences translate across environments.

On the subject of biodiversity, there are two interesting potential avenues of research. One would investigate plant assets that increase in complexity to see if there is a relationship between asset complexity and restorative potential. Another would investigate increasing number of shades of green in an environment to understand the relationship between green plant color diversity and restorative potential.

Finally, as mentioned previously, personal preference and life experience have a role in people's reaction to environments. It would be fascinating to design a study across universities that models multiple different nature environments, then test the environments with individuals that are native to that area and not native to that area.

Chapter 5

Conclusion

Biomass design is a topic of active research in both nature and VR nature research. VR has the capacity to support modeling highly specified nature environments without the time and resources required to grow them in real life, expediting the process of researching different types of plant life and informing the design of real experimental greenspaces. Furthermore, VR supports access to VNE's for people who cannot get into nature for a variety of reasons. Given the current limitations of popular VR technology such as the Meta Quest 3, it is important to understand the relationship between plant asset realism and a VNE's restorative potential so that a balance can be achieved between a VNE that is deployable on everyday consumer headsets and a VNE that offers restorative benefit. Additionally, low-realism VNE's are worth exploring in and of themselves as VR offers the potential to transport users into fantasy worlds that are a full escape experience from real life, and researchers do not yet understand the effects of those types of environments either.

This study was an initial exploration into high and low-realism VNE comparisons, accomplished by a mixed design study that compared two groups of participants, high and low-realism, against each other as well as against their own performance in a control condition where they closed their eyes. Through psychological and physiological measures, stress reduction and perceived attention restoration was assessed as a baseline, after a stressor test, then after the experiment condition in order to observe potential decreases in stress and increases in attention after the environment. To observe potential personal preference effects, participants evaluated multiple real and virtual nature environments using the PRS, and they completed an open response exit survey to understand their perspective of their experience. Overall, there was only a significant increase in PRS General Restorativeness in the high-realism environment when compared against the control and the low-realism environment. However, much like the first study [23], trends were observed towards high-realism that call for further investigation in future work.

In addition to future work inspired by the study, other future work into the intricacies of biomass design is needed. Color variation in greenspaces and non-greenspace nature are two topics of interest. Additionally, investigation of ‘nearby nature’ [28, 53] design in office spaces and the perception of the differences between ‘nearby nature’ in a real office versus a virtual office is another topic that has yet to be explored. A final interesting topic that is complex and needs more research is the role of biomass beauty for restorative effect, beauty being a term that would need carefully defined according to state of the art aesthetics research.

Bibliography

[1] World Health Organization. Stress, 2021.

[2] APA. Stress effects on the body.

[3] Lena Johansson, Xinxin Guo, Margda Waern, Svante Östling, Deborah Gustafson, Calle Bengtsson, and Ingmar Skoog. Midlife psychological stress and risk of dementia: a 35-year longitudinal population study. *Brain*, 133(8):2217–2224, 2010.

[4] Connor Liston, Bruce S McEwen, and BJ Casey. Psychosocial stress reversibly disrupts prefrontal processing and attentional control. *Proceedings of the National Academy of Sciences*, 106(3):912–917, 2009.

[5] Diana M Orem, Diane C Petrac, and Jeffrey S Bedwell. Chronic self-perceived stress and set-shifting performance in undergraduate students. *Stress*, 11(1):73–78, 2008.

[6] APA. General adaptation syndrome.

[7] Xiaole Ma, Zeheng Li, and Furong Lu. The influence of stressful life events on procrastination among college students: multiple mediating roles of stress beliefs and core self-evaluations. *Frontiers in psychology*, 14:1104057, 2023.

[8] Biao Chen, Lu Wang, Biao Li, and Weixing Liu. Work stress, mental health, and employee performance. *Frontiers in psychology*, 13:1006580, 2022.

[9] Florian Javelle, Sylvain Laborde, Thomas Jean Hosang, Alan James Metcalfe, and Philipp Zimmer. The importance of nature exposure and physical activity for psychological health and stress perception: evidence from the first lockdown period during the coronavirus pandemic 2020 in france and germany. *Frontiers in psychology*, 12:623946, 2021.

[10] Susana Rodríguez, Antonio Valle, Isabel Piñeiro, Rocío González-Suárez, Fátima M Díaz, and Tania Vieites. Covid-19 lockdown: key factors in citizens' stress. *Frontiers in Psychology*, 12:666891, 2021.

[11] Janet Loebach, Donald A Rakow, Genevieve Meredith, and Mardelle McCuskey Shepley. Time outdoors in nature to improve staff well-being: examining changes in behaviors and motivations among university staff in the use of natural outdoor environments since the emergence of the covid-19 pandemic. *Frontiers in Psychology*, 13:869122, 2022.

[12] Neil E Klepeis, William C Nelson, Wayne R Ott, John P Robinson, Andy M Tsang, Paul Switzer, Joseph V Behar, Stephen C Hern, and William H Engelmann. The national human activity pattern survey (nhaps): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Science & Environmental Epidemiology*, 11(3):231–252, 2001.

[13] Bum Jin Park, Yuko Tsunetsugu, Tamami Kasetani, Takahide Kagawa, and Yoshifumi Miyazaki. The physiological effects of shinrin-yoku (taking in the forest atmosphere or forest bathing): evidence from field experiments in 24 forests across japan. *Environmental health and preventive medicine*, 15(1):18–26, 2010.

[14] Lærke Mygind, Eva Kjeldsted, Rikke Hartmeyer, Erik Mygind, Matt P Stevenson, Daniel S Quintana, and Peter Bentsen. Effects of public green space on acute psychophysiological stress response: a systematic review and meta-analysis of the experimental and quasi-experimental evidence. *Environment and Behavior*, 53(2):184–226, 2021.

[15] Emma Wood, Alice Harsant, Martin Dallimer, Anna Cronin de Chavez, Rosemary RC McEachan, and Christopher Hassall. Not all green space is created equal: biodiversity predicts psychological restorative benefits from urban green space. *Frontiers in psychology*, 9:2320, 2018.

[16] Xiangrong Jiang, Xiaocan Wang, Linxin He, Qingrui Gu, Xin Wei, Mengfei Xu, and William C Sullivan. Effects of virtual exposure to urban greenways on mental health. *Frontiers in Psychiatry*, 15:1256897, 2024.

[17] Tsukasa Kimura, Tatsuya Yamada, Yohko Hirokawa, and Kazumitsu Shinohara. Brief and indirect exposure to natural environment restores the directed attention for the task. *Frontiers in psychology*, 12:619347, 2021.

[18] Kimberly J Miller, Brooke S Adair, Alan J Pearce, Catherine M Said, Elizabeth Ozanne, and Meg M Morris. Effectiveness and feasibility of virtual reality and gaming system use at home by older adults for enabling physical activity to improve health-related domains: a systematic review. *Age and ageing*, 43(2):188–195, 2014.

[19] Rui Song, Qujing Chen, Ying Zhang, Qing'an Jia, Hongyun He, Tian Gao, and Ling Qiu. Psychophysiological restorative potential in cancer patients by virtual reality (vr)-based perception of natural environment. *Frontiers in Psychology*, 13:1003497, 2022.

[20] JWH Mathijs Nijland, Wim Veling, Bart P Lestestuiver, and Catheleine MG Van Driel. Virtual reality relaxation for reducing perceived stress of intensive care nurses during the covid-19 pandemic. *Frontiers in Psychology*, 12:706527, 2021.

[21] Donald A Rakow and Dorothy C Ibes. Campus nature rx: How investing in nature interventions benefits college students. *Frontiers in Psychology*, 13:960370, 2022.

[22] Maura Pilotti, Eric Klein, Devon Golem, Eric Piepenbrink, and Katie Kaplan. Is viewing a nature video after work restorative? effects on blood pressure, task performance, and long-term memory. *Environment and Behavior*, 47(9):947–969, 2015.

[23] Rachel Masters, Victoria Interrante, Madeline Watts, and Francisco Ortega. 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, New York, NY, USA, 2022. Association for Computing Machinery.

[24] Terry Hartig, Kalevi Korpela, Gary W Evans, and Tommy Gärling. *Validation of a measure of perceived environmental restorativeness*. University of Göteborg, Department of Psychology, 1996.

[25] Joseph J LaViola Jr. A discussion of cybersickness in virtual environments. *ACM Sigchi Bulletin*, 32(1):47–56, 2000.

[26] Mel Slater and Sylvia Wilbur. A framework for immersive virtual environments (five): Speculations on the role of presence in virtual environments. *Presence: Teleoperators & Virtual Environments*, 6(6):603–616, 1997.

[27] Wijnand A IJsselsteijn. *Presence in depth*. Technische Universiteit Eindhoven Eindhoven, The Netherlands, 2004.

[28] Rachel Kaplan and Stephen Kaplan. *The experience of nature: A psychological perspective*. Cambridge university press, 1989.

[29] David Watson, Lee Anna Clark, and Auke Tellegen. Development and validation of brief measures of positive and negative affect: the panas scales. *Journal of personality and social psychology*, 54(6):1063, 1988.

[30] S Cohen. Perceived stress scale (copyright© 1994 by sheldon cohen), 1994.

[31] Roger S Ulrich. Aesthetic and affective response to natural environment. In *Behavior and the natural environment*, pages 85–125. Springer, 1983.

[32] Marvin Zuckerman. Development of a situation-specific trait-state test for the prediction and measurement of affective responses. *Journal of Consulting and clinical psychology*, 45(4):513, 1977.

[33] Terri Menser, Juha Baek, Jacob Siahaan, Jacob M Kolman, Domenica Delgado, and Bita Kash. Validating visual stimuli of nature images and identifying the representative characteristics. *Frontiers in Psychology*, 12:685815, 2021.

[34] Agnes E Van den Berg, Anna Jorgensen, and Edward R Wilson. Evaluating restoration in urban green spaces: Does setting type make a difference? *Landscape and Urban Planning*, 127:173–181, 2014.

[35] Annalisa Theodorou, Giuseppina Spano, Gregory N Bratman, Kevin Monneron, Giovanni Sanesi, Giuseppe Carrus, Claudio Imperatori, and Angelo Panno. Emotion regulation and virtual nature: cognitive reappraisal as an individual-level moderator for impacts on subjective vitality. *Scientific Reports*, 13(1):5028, 2023.

[36] Stephen R Kellert and Edward O Wilson. *The biophilia hypothesis*. Island press, 1993.

[37] Melissa R Marselle, Terry Hartig, Daniel TC Cox, Siân de Bell, Sonja Knapp, Sarah Lindley, Margarita Triguero-Mas, Katrin Böhning-Gaese, Matthias Braubach, Penny A Cook, et al. Pathways linking biodiversity to human health: A conceptual framework. *Environment International*, 150:106420, 2021.

[38] Raf Aerts, Olivier Honnay, and An Van Nieuwenhuyse. Biodiversity and human health: mechanisms and evidence of the positive health effects of diversity in nature and green spaces. *British medical bulletin*, 127(1):5–22, 2018.

[39] Marco Costa. Vegetation dispersion, interspersion, and landscape preference. *Frontiers in Psychology*, 13:771543, 2022.

[40] Eunsoo Kim, Sujin Park, Soojin Kim, Yeji Choi, Junghee Cho, Sung-il Cho, Hae-ryoung Chun, and Geonwoo Kim. Can different forest structures lead to different levels of therapeutic effects? a systematic review and meta-analysis. *Healthcare*, 9(11), 2021.

[41] Caroline M Hägerhäll, Åsa Ode Sang, Jan-Eric Englund, Felix Ahlner, Konrad Rybka, Juliette Huber, and Niclas Burenhult. Do humans really prefer semi-open natural landscapes? a cross-cultural reappraisal. *Frontiers in psychology*, 9:822, 2018.

[42] Joel Martínez-Soto, Luis Alfonso de la Fuente Suárez, and Salvador Ruiz-Correa. Exploring the links between biophilic and restorative qualities of exterior and interior spaces in leon, guanajuato, mexico. *Frontiers in psychology*, 12:717116, 2021.

[43] Shuangquan Zhang, Yimin Tan, Yongde Zhong, Jianqiong Yuan, and Ying Ding. Psychological recovery effects of 3d virtual tourism with real scenes–a comparative study. *Information Technology & Tourism*, 25(1):71–103, 2023.

[44] Jie Yin, Jing Yuan, Nastaran Arfaei, Paul J Catalano, Joseph G Allen, and John D Spengler. Effects of biophilic indoor environment on stress and anxiety recovery: A between-subjects experiment in virtual reality. *Environment International*, 136:105427, 2020.

[45] Xiaobo Wang, Yaxing Shi, Bo Zhang, and Yencheng Chiang. The influence of forest resting environments on stress using virtual reality. *International journal of environmental research and public health*, 16(18):3263, 2019.

[46] Morgan Faith Schebella, Delene Weber, Lisa Schultz, and Philip Weinstein. The nature of reality: Human stress recovery during exposure to biodiverse, multisensory virtual environments. *International Journal of Environmental Research and Public Health*, 17(1):56, 2020.

[47] MARK Newman, B Gatersleben, KJ Wyles, and E Ratcliffe. The use of virtual reality in environment experiences and the importance of realism. *Journal of environmental psychology*, 79:101733, 2022.

[48] World Health Organization. Regional Office for Europe. Urban green spaces and health. Technical documents, World Health Organization, 2016.

[49] Gary R. VandenBos. *APA Dictionary of Psychology*. American Psychological Association, 2007.

[50] Y.A.W. de Kort, A.L. Meijnders, A.A.G. Sponselee, and W.A. IJsselsteijn. What's wrong with virtual trees? restoring from stress in a mediated environment. *Journal of Environmental Psychology*, 26(4):309–320, 2006.

[51] Arttu Tiiro. Effect of visual realism on cybersickness in virtual reality. *University of Oulu*, 350, 2018.

[52] Erich Fromm. *Psicoanálisis de la sociedad contemporánea: hacia una sociedad sana*. Fondo de cultura económica, 1964.

[53] Stephen Kaplan. The restorative benefits of nature: Toward an integrative framework. *Journal of environmental psychology*, 15(3):169–182, 1995.

[54] Osmo Mattila, Arto Korhonen, Essi Pöyry, Kaisa Hauru, Jani Holopainen, and Petri Parvinen. Restoration in a virtual reality forest environment. *Computers in Human Behavior*, 107:106295, 2020.

[55] TN Berezina, A Temirkanova, AV Litvinova, and AV Kokurin. Using virtual reality techniques to alleviate cognitive fatigue in graduate students working while in college. *European Journal of Contemporary Education*, 11(1):36–46, 2022.

[56] Rikard Lundstedt, Carita Håkansson, Mare Lõhmus, and Mattias Wallergård. Designing virtual natural environments for older adults in residential care facilities. *Technology and Disability*, Preprint:1–14, 2021.

[57] Séamas Weech, Sophie Kenny, and Michael Barnett-Cowan. Presence and cybersickness in virtual reality are negatively related: a review. *Frontiers in psychology*, 10:415654, 2019.

[58] Caroline Brown and Marcus Grant. Biodiversity and human health: What role for nature in healthy urban planning? *Built Environment*, 31(4):326–338, 2005.

[59] Giuseppe Riva, Luca Bernardelli, Matthew HEM Browning, Gianluca Castelnuovo, Silvia Cavedoni, Alice Chirico, Pietro Cipresso, Dirce Maria Bengel de Paula, Daniele Di Lernia, Javier Fernández-Álvarez, et al. Covid feel good—an easy self-help virtual reality protocol to overcome the psychological burden of coronavirus. *Frontiers in Psychiatry*, 11:563319, 2020.

[60] Gerhard Reese, Jasmin Stahlberg, and Claudia Menzel. Digital shinrin-yoku: Do nature experiences in virtual reality reduce stress and increase well-being as strongly as similar experiences in a physical forest? *Virtual Reality*, pages 1–11, 2022.

[61] Sharon Frost, Lee Kannis-Dymand, Vikki Schaffer, Prudence Millear, Andrew Allen, Helen Stallman, Jonathan Mason, Andrew Wood, and Jalasayi Atkinson-Nolte. Virtual immersion in nature and psychological well-being: A systematic literature review. *Journal of Environmental Psychology*, 80:101765, 2022.

[62] Marnix van Gisbergen, Michelle Kovacs, Fabio Campos, Malou van der Heeft, and Valerie Vugts. *What We Don't Know. The Effect of Realism in Virtual Reality on Experience and Behaviour*, pages 45–57. Springer International Publishing, Cham, 2019.

[63] Angela Tinwell. *The uncanny valley in games and animation*. CRC press, 2014.

[64] Mel Slater, Beau Lotto, Maria Marta Arnold, and Maria V Sanchez-Vives. How we experience immersive virtual environments: the concept of presence and its measurement. *Anuario de psicología*, 40(2):193–210, 2009.

[65] Marcus Hedblom, Bengt Gunnarsson, Behzad Iravani, Igor Knez, Martin Schaefer, Pontus Thorsson, and Johan N Lundström. Reduction of physiological stress by urban green space in a multisensory virtual experiment. *Scientific reports*, 9(1):1–11, 2019.

[66] Jøran Rudi. Designing soundscapes for presence in virtual reality exhibitions: A study of visitor experiences. *Visitor Studies*, 24(2):121–136, 2021.

[67] Russell L Storms and Michael J Zyda. Interactions in perceived quality of auditory-visual displays. *Presence: Teleoperators & Virtual Environments*, 9(6):557–580, 2000.

[68] Matilda Annerstedt, Peter Jönsson, Mattias Wallergård, Gerd Johansson, Björn Karlson, Patrik Grahn, Åse Marie Hansen, and Peter Währborg. Inducing physiological stress recovery with sounds of nature in a virtual reality forest—results from a pilot study. *Physiology & behavior*, 118:240–250, 2013.

[69] Chang Li, Changan Sun, Minkai Sun, Yu Yuan, and Pengcheng Li. Effects of brightness levels on stress recovery when viewing a virtual reality forest with simulated natural light. *Urban Forestry & Urban Greening*, 56:126865, 2020.

[70] Femke Beute and Yvonne AW de Kort. Let the sun shine! measuring explicit and implicit preference for environments differing in naturalness, weather type and brightness. *Journal of Environmental Psychology*, 36:162–178, 2013.

[71] S Rockcastle, M Danell, E Calabrese, G Sollom-Brotherton, A Mahic, K Van Den Wymelenberg, and R Davis. Comparing perceptions of a dimmable led lighting system between a real space and a virtual reality display. *Lighting Research & Technology*, 53(8):701–725, 2021.

[72] Marc Christie, Patrick Olivier, and Jean-Marie Normand. Camera control in computer graphics. *Computer Graphics Forum*, 27(8):2197–2218, 2008.

[73] Google. Google forms, 2021.

[74] Madelon L Peters, Guido LR Godaert, Rudy E Ballieux, Marja Van Vliet, Jacques J Willemsen, Fred CGJ Sweep, and Cobi J Heijnen. Cardiovascular and endocrine responses to experimental stress: effects of mental effort and controllability. *Psychoneuroendocrinology*, 23(1):1–17, 1998.

[75] Polyart Studio. Dreamscape nature : Meadows - stylized open world environment in environments - ue marketplace, Oct 2021.

[76] Serge Ramelli. Unreal engine beginner tutorial making a forest with the new quixel megascans trees, Jan 2022.

[77] Tian Gao, Tian Zhang, Ling Zhu, Yanan Gao, and Ling Qiu. Exploring psychophysiological restoration and individual preference in the different environments based on virtual reality. *International Journal of Environmental Research and Public Health*, 16(17), 2019.

[78] Vincenzo Paolo Senese, Aniello Pascale, Luigi Maffei, Federico Cioffi, Ida Sergi, Augusto Gnisci, and Massimiliano Masullo. *The Influence of Personality Traits on the Measure of Restorativeness in an Urban Park: A Multisensory Immersive Virtual Reality Study*, pages 347–357. Springer Singapore, Singapore, 2020.

[79] National Park Service. Olympic national park washington, May 2023.

[80] Nintendo. The legend of zelda: Breath of the wild, March 2017.

[81] Blizzard Entertainment. World of warcraft, November 2004.

[82] Virginia Braun and Victoria Clarke. Using thematic analysis in psychology. *Qualitative research in psychology*, 3(2):77–101, 2006.

[83] BIOPAC. Ecg: Cardiology: Research: Biopac, Dec 2023.

[84] Ralph M Reitan. Trail making test results for normal and brain-damaged children. *Perceptual and motor skills*, 33(2):575–581, 1971.

[85] Katherine A Johnson, Annabelle Pontvianne, Vi Ly, Rui Jin, Jonathan Haris Januar, Keitaro Machida, Leisa D Sargent, Kate E Lee, Nicholas SG Williams, and Kathryn JH Williams. Water and meadow views both afford perceived but not performance-based attention restoration: Results from two experimental studies. *Frontiers in Psychology*, 13:809629, 2022.

[86] Jalynn Blu Nicoly, Rachel Masters, Vidya Gaddy, Victoria Interrante, and Francisco Ortega. The restorative influence of virtual reality environment design. In *ACM Symposium on Applied Perception 2024*, pages 1–10, 2024.

[87] Hakkan Lai, Emily J Flies, Philip Weinstein, and Alistair Woodward. The impact of green space and biodiversity on health. *Frontiers in Ecology and the Environment*, 17(7):383–390, 2019.

[88] Ümit Demir. Investigation of color-emotion associations of the university students. *Color Research & Application*, 45(5):871–884, 2020.

Appendix A

Demographics Questionnaire

1. Age: _____
2. Sex: Male Female Other:_____
3. What is your current academic standing? Freshman Sophomore Junior Senior Graduate Student Faculty/Staff Other
4. What is your major (if applicable)? _____
5. Have you ever used a Virtual Reality headset? Yes No
6. Are you currently wearing corrective lenses (contacts or glasses)? Yes No
7. Indicate the average number of hours per week you spend using computers (personal and work combined): _____
8. Indicate the average number of hours per week you spend engaging with virtual or augmented reality (personal and work combined): _____
9. Indicate the average number of hours per week you spend playing video games: _____
10. If applicable, list the genres of video games you play: _____
11. If applicable, list the video games you play the most: _____

Appendix B

Psychological Questionnaires

B.1 Positive and Negative Affect Schedule (PANAS)

Rate the following items on a five point likert scale.

interested	irritable
distressed	alert
excited	ashamed
upset	inspired
strong	nervous
guilty	determined
scared	attentive
hostile	jittery
enthusiastic	active
proud	afraid

B.1.1 Zuckerman Inventory of Personal Reactions (ZIPERS)

Rate the following items on a five point likert scale.

1. My heart was beating fast.

2. I was breathing fast.

3. I felt angry or defiant.

4. I felt fearful.

5. I felt sad.

6. I felt carefree or playful.

7. I felt affectionate or warmhearted.
8. I felt elated or pleased.
9. I felt attentive or concentrating.
10. I felt like acting friendly or affectionate.
11. I felt like hurting or "telling off" someone.
12. I felt like getting out of this situation or avoiding it.
13. I felt like getting further into this situation and completing it.

B.2 Perceived Restorativeness Scale (PRS)

1. Being Away
   (a) It is an escape experience.
   (b) Spending time here gives me a good break from my day to day routine.
2. Fascination
   (a) The setting has fascinating qualities.
   (b) My attention is drawn to many interesting things.
   (c) I would like to get to know this place better.
   (d) I want to explore the area.
   (e) I would like to spend more time looking at the surroundings.
3. Coherence (Extent)
   (a) There is too much going on.
   (b) It is a confusing place.

(c) There is a great deal of distraction.

(d) It is chaotic here.

4. Compatibility

   (a) I can do things I like here.

   (b) I have a sense that I belong here.

   (c) I have a sense of oneness with this setting.

   (d) Being here suits my personality.

   (e) I could find ways to enjoy myself in a place like this.

B.3 Perceived Stress Scale (PSS)

Rate the following items on a five point likert scale.

1. How 'cheerful' were you in this period?

2. How 'happy' were you in this period?

3. How 'angry/frustrated' were you in this period?

4. How 'nervous/stressed' were you in this period?

5. How 'sad' were you in this period?

Appendix C

Open Response Exit Survey

1. Did you experience any cybersickness?

2. What could be improved about this experiment?

3. What were some things you liked in this experiment?

Appendix D

Preference Questionnaire Images

Figure D.1: Realistic Nature Photo 1

Figure D.2: Realistic Nature Photo 2

Figure D.3: Low-realism Nature Photo 1

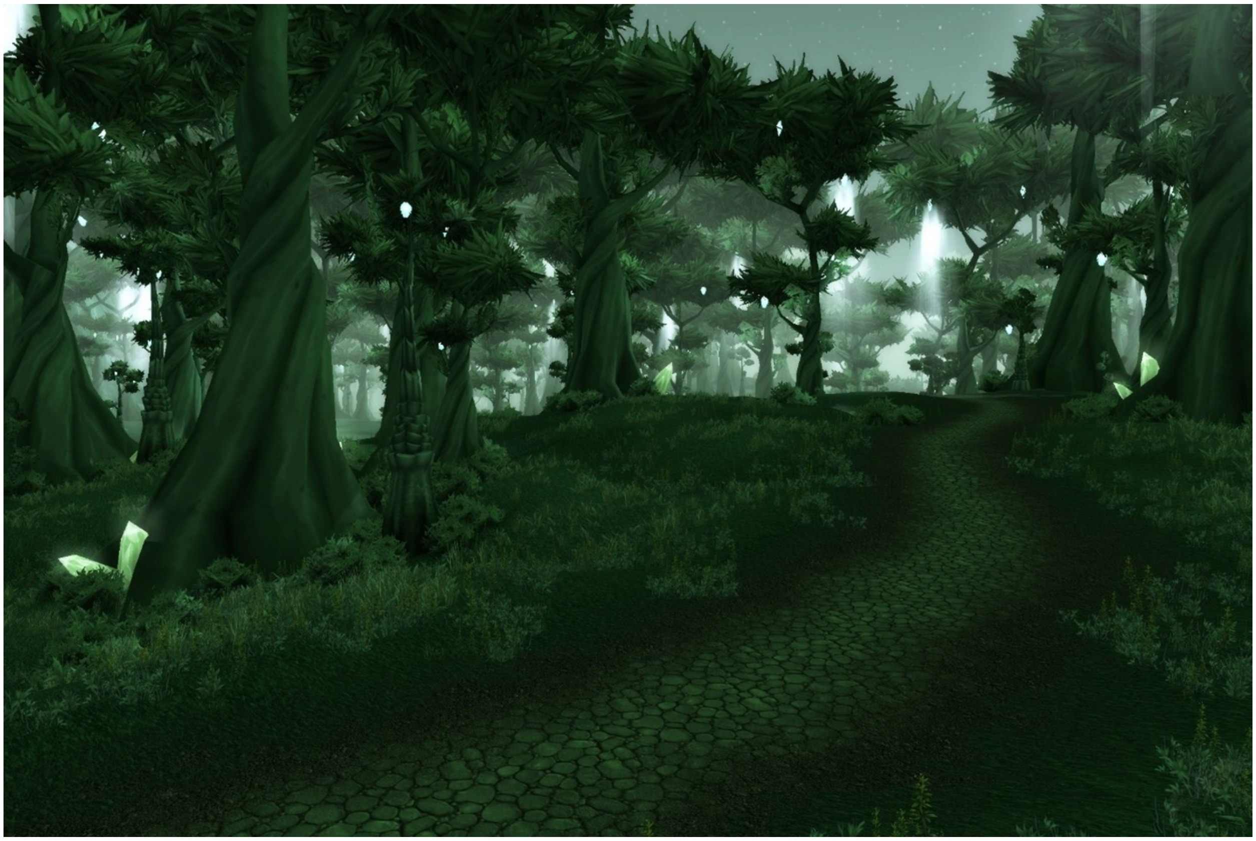

Figure D.4: Low-realism Nature Photo 2