The effect of a virtually generated, traversable environment on the brain regions of stress of the university students

by

Sultan Omirbayev

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Abstract

For mental health interventions, virtual reality (VR) presents exciting new modalities, especially for stress reduction in populations with limited access to natural settings. In this study, university students' stress-related EEG markers are examined to determine the neurophysiological effects of a fully navigable, procedurally generated virtual nature environment. The EEG signals of eight participants, **four men and four women**, were recorded prior to and after two VR exposure sessions using an experimental design within the subject. Alpha power, theta power, frontal alpha asymmetry, theta/alpha ratio, and frontal midline theta were all important stress-related indicators that were extracted using a complete EEG preprocessing pipeline that included ICA and several filtering stages. Although statistically significant differences were not found by the paired t-tests, small to moderate effect sizes were observed in a number of domains, indicating possible trends. Interestingly, the mean **theta power showed a slight increase** after exposure, suggesting increased cognitive relaxation and potential memory involvement, while the **mean alpha power remained constant**. This pilot study establishes the foundation for scalable, non-pharmacological interventions in student mental health and shows that immersive virtual reality and EEG-based stress analysis are feasible. To confirm and build on these findings, more studies with larger sample sizes and longer exposure times are necessary.

Thesis Supervisor: Berdakh Abibullaev
Title: Associate Professor

Acknowledgments

I would like to acknowledge the efforts of my mother. My mother was and is the pillar of our family and has sacrificed a lot for me and my brothers. I would like to acknowledge the grit and perseverance that my mother taught me. My mother's actions and her words of wisdom made me who I am today.

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And finally, I would like to thank myself for not giving up when it felt like giving up was the easy way out.

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Chapter 1

Introduction

1.1 Background and Motivation

According to the World Journal of Psychiatry [12], on average across all continents, university-grade students experience disproportionately higher levels of stress, suicidal thoughts, and depression than the average member of the general population. During the period 2007-2018, the percentage of college students who have taken mental medications of any kind has increased significantly [14]. Especially given the recent pandemic outbreak, it was reported that in the years 2020 and 2021, the rates of mild anxiety among Asian students have increased nearly five times [30]. The residual effects of stress still affect students, who are more prone to stress given their lack of autonomy and independence [23]. This makes stress one of the most prominent problems in young adults of the current generation.

One well-documented intervention for stress reduction is exposure to natural environments. Stress Recovery Theory (SRT) states that humans have an evolutionarily ingrained preference for natural settings. Nature is a long-known stress reduction tool. It is well-established that people who have adapted to live in the wilderness for generations have found that spending time in nature has a calming and invigorating effect. An hour spent in nature may have beneficial effects on stress-related brain regions and lower amygdala activity, according to recent molecular psychiatry research [22]. Consequently, walking outside can reduce the detrimental effects of urban environments on stress-related brain regions, which may be a preventive measure against the development of mental illness.

1.2 Problem Statement

Although nature has many beneficial effects, the sociopolitical landscape of today makes it impossible or inconceivable to conserve it. According to Guandong Li et al. [11] it is estimated that by the year 2100 11 to 33 million hectares of natural habitat will have been lost. The main driver is the large fragmentation of natural habitat caused by the increasing urban growth.

As a result of this rapid urbanization, people, especially students, are becoming more isolated from nature. Gradual urbanization progresses and interferes with the natural landscapes around them, denying the students the psychological benefits that nature brings. In addition, students are also feeling more stressed as a result of social pressures, financial pressures, and academic demands.

1.3 Research Objectives

The research aims to see how virtually generated environments can be a possible substitution for genuine interaction with nature. The goal is to provide an objective measurement of the impact of the simulated traversable environment on the stress markers of university-level students. The paper will briefly describe the potential of using a **virtually generated environment (VGE)** as a supplementary intervention for people with stress and anxiety disorders and discuss possible ways to enhance current treatment modalities. The paper aims to address the gaps in the current research by testing the traversable environment instead of pre-recorded settings and by optimizing systems to reduce VR sickness.

1.4 Research Questions and Hypotheses

The research aims to see the viability of using procedurally generated controllable 3D environments as the drivers of relaxation for university students with limited access to nature. The hypothesis is that participants exposed to immersive VR nature environments in which they can actively participate will exhibit increased alpha power (8–12 Hz), reduced theta power (4–8 Hz) and decreased theta/alpha ratios, consistent with previous EEG stress studies [1, 9]. In addition, it is also expected that the alpha asymmetry of the frontal cortex will shift toward left hemisphere dominance, indicating a transition to a more relaxed and positive affective state [8].

1.5 Structure of the Thesis

This thesis will look at the current state of research on the effects of nature on stress indicators. In addition, the paper will look at how virtual reality can enhance the accessibility of nature benefits and potentially address current limitations in the scope of research. The research will then recount the experimental setup and the methods used to derive the results. Finally, the paper will end with some suggestions on how this pilot study can be improved and what needs to be done to potentially improve the gathered results.

Chapter 2

Literature review

2.1 Stress Reduction Modalities

There is a case for other forms of intervention when it comes to stress or anxiety disorders among students. There are solutions available, such as pharmacology or therapy, that are widespread and are used to address these problems. However, that is not the focus of this paper.

It is true that medication and therapy work. However, each has their own set of problems. Depression can be taken as an example of an extreme state of stress response. According to World Psychiatry in 2021 [7], they have identified that there are not many options when it comes to effective treatment solutions to deal with depression in young adults. They have noted that among tested pharmacological solutions, fluoxetine is one of the few effective and safe evidence-based medications available to treat depression in young people. The researchers note that other medications such as imipramine, nortriptyline, and venlafaxine should be avoided due to their poor acceptance, tolerability, and safety. However, even fluoxetine has considerable possible negative effects on the cardiovascular and hepatic systems [3].

Alternatively, there are other forms of intervention that do not rely on pharmacology. Interventions, such as **cognitive behavior therapy (CBT)** and **mindfulness-based stress reduction (MBSR)**, are known as types of psychosocial interventions. The main downside to these psychosocial interventions is that they have limited accessibility. These therapies often require money, time commitment, and the availability of a therapist in the vicinity. When treatments are switched to online to reduce entry barriers, there are still cases where two-thirds of students drop out of therapy [18].

As there is no solution that can meet all the needs of students, this research will focus on the supplementation-first approach. Instead of considering VGE as a substitution for the aforementioned treatments, the aim is to create a more accessible addition to the arsenal for students to manage stress in their academic life. Before that, we will focus on the two theories on the effect of nature on stress and, based on that, extrapolate possible applications of those effects in a virtually simulated environment.

2.1.1 Stress Reduction Theory (SRT)

According to Stress Reduction Theory (SRT), spending time in natural settings can improve the psychological states of people. Exposure to open spaces and greenery can help someone recover from stress and mental exhaustion [13]. According to the hypothesis, this reaction has roots in the evolutionary history of humans. For more than a hundred years, people have adapted to their environment, which has signified safety and offered all the necessary resources for survival. Because of this, according to SRT people have developed an instinctive inclination towards natural surroundings rather than man-made ones. Resulting in the sense of familiarity and comfort when placed in settings closely related to that of their ancestors.

According to SRT, natural environments promote a sense of calm and familiarity. Consequently, this reduces the physiological arousal caused by stress. However, urban environments usually require prolonged periods of focused attention and expose people to a lot of stimuli. This in turn can cause cognitive overload and fatigue that elevate stress indicators. SRT has found growing support in recent decades [13]. According to studies, people who spend time in green, open and "non-oppressive" spaces report feeling less stressed than people who spend time in urban settings. The access to the **open sky** and the presence of **visible greenery** were the most important factors.

2.1.2 Biophilia Hypothesis

Similarly to the SRT theory proposed by Roger Ulrich, the biophilia hypothesis proposed by Wilson in 1986 states that people have an innate need to associate with nature because it is connected to our evolution [25]. According to Willson, it is the "innate tendency to focus on life and lifelike processes" that humans have. Wilson states that there is a clear benefit in being near or around nature. In addition to being beneficial, increased exposure to nature is also required to support mental health and postpone the onset of mental diseases. Today in scientific circles, there is increasing agreement that exposure to nature has significant positive effects on mental health. According to experimental evidence, people who spend time in natural settings report feeling 33% less anxious and 37% less depressed [5].These findings suggest that nature can promote emotional resilience, greatly enhance psychological well-being and reduce the global incidence of mental illness.

This has been confirmed by researchers Tanja Schiebel, Jürgen Gallinat, and Simone Kühn [19], who built on Wilson's ideas. According to their research, spending time in nature can protect people from a number of psychological problems that could develop in later years of life. According to their research, encouraging frequent time spent in nature may be good for general mental health.

2.2 Virtual Reality (VR) as a Tool for Mental Health

2.2.1 VR Applications in Stress Reduction

The positive effects of nature on humans are well documented. However, since nature is very limited in urban settings, a modern approach is needed to access these benefits. Given the limitations of conventional stress reduction techniques and the limited availability of natural settings, researchers have been prompted to investigate virtual reality (VR) as a possible avenue to carry out additional stress reduction. People can experience natural environments in a controlled digital world by using Virtual Generated Environments (VGE). According to studies, virtual reality environments that mimic nature can promote emotional health, reduce stress, and promote relaxation.

Several meta-analyses cover the effects of simulated nature as a means of improving the stress and mood indicators of various patients, healthy adults, and university students. In the meta-analysis of 10 studies [9], research suggests that there is a large possibility of using digital nature to recover from stress and improve stress markers as a result. The study has shown that in cases where people lack access to nature, the subjective mood of participants is elevated after using head-mounted displays (HMD). In addition, another systematic review [21] looked at 59 recent studies on the subject of VR environments and their effects. Similarly to previous researchers, the review found that exposure to the digital nature is beneficial in improving psychological markers in participants. Furthermore, in the same study, researchers have shown that exposure to virtual indoor or urban environments has shown a weaker positive impact on participants compared to participants who have experienced a virtual open and green environment. This is in line with the findings of SRT and biophilia theories in the real world. However, there are some things that the current state of research overlooks.

2.2.2 Immersion and Presence in VR

A key factor influencing the effectiveness of the VR environment is the degree of immersion the participant has. Research has shown that the use of HMD demonstrated a higher level of immersion compared to smartphones and computer screens [28]. Furthermore, the work of Mostajeran et al. has found that exposure to 360$\circ$ videos of the forest was found to reduce fatigue compared to 2D images that had no effect when the same vegetation was viewed in different modes. This suggests that increased immersion can enhance the benefits associated with SRT. Moreover, another study [29] has compared multiple immersion modules to test this theory. The test was conducted under one of three experimental conditions: 2D video watched on a high-definition TV screen; 360 video VR (360-VR) viewed on a head-mounted display (HMD); or interactive computer-generated VR (CG-VR), also viewed through an HMD and interacted with via a hand-held controller. The visual and audio materials were closely matched between different experimental setups. Although all three situations resulted in equal decreases in boredom, CG-VR was associated with considerably higher gains in stress reduction based on self-reported data. However, all of these investigations have a glaring problem. The research carried out lacks the use of more objective metrics to interpret the data, such as the use of BCI technologies, namely EEGs, to understand how brain waves change given the interaction with different environments.

2.3 EEG as a Neurophysiological Measure of Stress

2.3.1 EEG Frequency Bands and Stress Markers

The electroencephalogram (EEG) can be used to acquire brain wave data that would allow us to see the effect of VGE on stress indicators. To express stress data, the pilot study will look at frequency bands such as Alpha (8–12 Hz) for relaxation and Theta (4–8 Hz) for sustained focus. Primary stress EEG indicators include a reduction in alpha wave activity and a decrease in frontal alpha asymmetry [1] [15]. To take into account the possible effect that stress has on emotional systems, theta waves were also considered. Theta waves are needed to identify how stress elevates cognitive demands. This is related to the functions of the hippocampus and the frontal midline, both of which generate theta oscillations that are further recorded. In addition, increases in acute stress tend to also increase anxiety and demand more emotional regulation, which is reflected in increased theta power, particularly in the frontal and temporal lobes [26].

2.3.2 Prior Studies Combining VR and EEG

A growing body of research has begun to use EEG to provide more objective and quantifiable data. Although relatively new, the combination of EEG and VR is becoming more and more relevant because it allows researchers to track brain activity in real time and get concrete information on the state of the subject, allowing them to better understand and amplify the effects VR has. Closest research shows [31] that short-term exposure to virtual reality-generated immersive nature reduces stress and improves cognitive performance. At the same time, rhythmic brain activity during exposure to nature suggested improved attentional states.

In one study [32], participants were exposed to alternating stress-inducing and relaxing VR scenes while recording their EEG signals. The researchers found significant changes in the activity of the alpha and theta during exposure to different environments and used these markers to classify stress levels with high precision. The use of frontal and parietal electrodes showed that alpha suppression and theta enhancement were reliable indicators of cognitive and emotional states under immersive conditions. The digital aspect of stress recovery implied that among the most credible neurophysiological markers of relaxation were EEG-derived indices such as the alpha to theta and alpha to beta ratios [16].

But even with these promising advances, there is still an absence of extensive understanding in the literature about the interactions of fully navigable, procedurally produced virtual environments. Most studies so far have relied on fixed, passive exposure paradigms or limited neurophysiological channels. As such, this thesis aims to contribute to the field by implementing a more dynamic VR system while using a full 16-channel EEG array to measure stress-relevant activity. This includes, but is not limited to, the analysis of frontal alpha asymmetry, theta/alpha ratios, and changes in beta activity across temporal and central regions, which have previously been identified as key stress markers in laboratory and real-world simulations.

2.4 Limitations in Existing Research

Most of the currently available research uses self-reported stress reduction techniques, such as surveys and questionnaires. Despite providing useful subjective data, these methods are not sufficiently objective in completely understanding how virtual reality affects the subject's brain's underlying mechanisms. The use of objective markers such as EEG can improve our understanding of the effect that a VR environment can have on stress markers in a controlled environment. Few existing studies have used BCI technology to quantify brain activity related to stress and relaxation. Consequently, the study lacks a comprehensive understanding of the effects of the virtual reality environment on neural structures.

Furthermore, 360° outdoor videos and other passive experiences are dominant in the current research landscape and may not offer the same immersive and participatory advantages as fully navigable virtual reality environments. The use of pre-recorded 360° videos in many VR studies restricts user engagement and may even increase the risk of motion sickness [17].

Since the recorded video is not controlled by the subject, the different pace of movement and shake of the camera could lead to increased motion sickness in the participants [4]. In other words, the disconnect between the operator's gate and the participant creates an imbalance in the information that the brain receives. To improve this, participants should have complete control over their pace and movements in a digital environment [6]. By addressing these issues at the theoretical level, it is possible to create a more holistic research protocol that allows us to introduce new data to the current conversation of using virtually generated nature as a non-pharmacological tool to work with stress in university students. This will mean that stress relief could be achieved through a more immersive strategy that includes fully navigable virtual reality settings that allow users to travel and explore natural surroundings or demonstrate whether VR can serve as a comparable alternative to real-life nature.

Chapter 3

Methodology

3.1 Study Design

In this study, a pre-post experimental design within the subject was used to assess how immersive virtual reality (VR) nature experiences affected stress markers in university-level students neurophysiologically. This pilot study involves 8 university students. For this study, 4 male and 4 female students were chosen to conduct the experiment. Each participant served as their own control to minimize interindividual variability and improve sensitivity to intervention effects. The within-subject format allowed for direct comparison of neurophysiological stress markers, including alpha and theta power, frontal alpha asymmetry, and theta/alpha ratios between time points (pre- vs. post-exposure) within the same individuals. This design was chosen for its particular effectiveness for small-sample studies where interparticipant variability has a high effect on the research outcome.

Inclusion and Exclusion Criteria

For the purposes of this research, university students were required. To include a wide range of student participants, the age range between the undergraduate and graduate levels was established. As a result, participants were required to be between **18 and 25 years of age** to be eligible for this study while representing a variety of educational levels. The following standards were used to protect the integrity of the experimental processes and reduce any possible discomfort:

Inclusion Criteria: Healthy participants with no health complications who met the age criteria, were part of the student body and signed a consent form were included in the study. Furthermore, subjects with *normal or corrected-to-normal vision* (e.g., eyeglasses or contact lenses) were eligible to participate.

Exclusion Criteria: Participants with a history of *significant visual impairment* were excluded. The rationale was that lack of visual acuity would affect the way VR content is perceived and raise the possibility of *VR-induced motion sickness*. As experiments rely heavily on the ability to perceive VGE, this resulted in this criterion. That is why participants were expected to be able to view and interact with the virtual reality environment comfortably. Each participant also had the option to leave the experiment at any time, in which case any information collected would be immediately excluded.

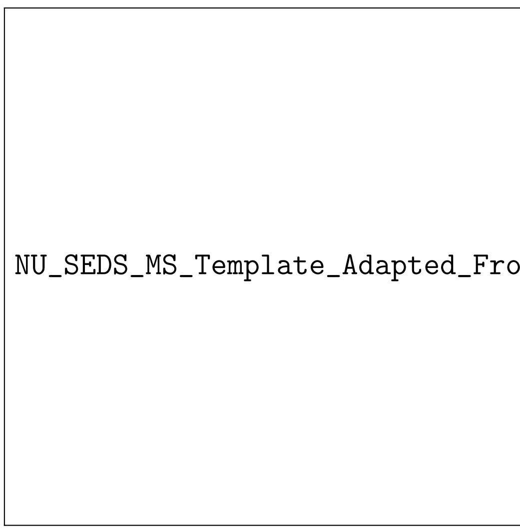
3.1.1 Experimental Procedure

The study was divided into three main sessions per participant:

- **Baseline (Pre-Exposure) Session:** Participants were seated comfortably in a neutral indoor environment (quiet environment without outside interferences such as AC or wind). To obtain clean baseline EEG recordings, participants were instructed to reduce any movements that could cause artifacts in the EEG during data collection. To collect stress data, the EEG was active while the subjects tried to solve time-bound mathematical questions to gather the initial stress markers to compare after two sessions. This session served as a control condition to capture stress-related brain activity in the absence of VR exposure. The flowchart with steps can be seen in Figure 3-10c.

- **First VR Nature Session:** Participants were given time to roam inside the procedurally generated environment for 5 minutes to get used to the VR environment. This session also served as a buffer to identify if any of the participants experienced motion sickness during VR exposure.

- **Second VR Nature Session:** For the last session, participants repeated the virtual nature walk on a different day under similar conditions. After the VR walk, EEG data were again collected to examine the aggregate effects of repeated immersion in VGE. The flowchart with steps can be seen in Figure 3-10b.



(a) Pre-Exposure setup, Day 0

(b) Post-Exposure setup, Day 2

Figure 3-1: The process of setting up and running the experiment during different sessions on different days.

3.2 Ethical Considerations

3.2.1 Ethical Approval

The research was approved by the Institutional Research Ethics Committee of Nazarbayev University (NU IREC).

3.2.2 Informed Consent

All participants received written consent forms, which they signed after their questions were answered.

3.2.3 Confidentiality and Data Protection

All data gathered in this experiment have been encrypted. All personal identifiers from the participant data have been removed. Due to participants' wishes, only the resultant graphs and EEG data are presented in this paper.

3.3 Experimental Setup

3.3.1 Virtual Environment Development

Since nature is a multisensory experience, it is difficult to recreate due to current technological limitations. However, the aim of the paper is not to create a one-to-one replica of nature but to develop virtual environments that serve as surrogates for natural settings. The initial idea was to create an environment that is high resolution and filled with 3D objects to recreate the sense of forest Figure 3-2. The use of hyperrealistic terrain within a procedurally generated space performed suboptimally. Constantly updating terrain, in addition to the ray-traced shadow and reflection generation, required more processing power than was available at the time of making this paper. This resulted in delays that made the environment more difficult to navigate without inducing nausea.

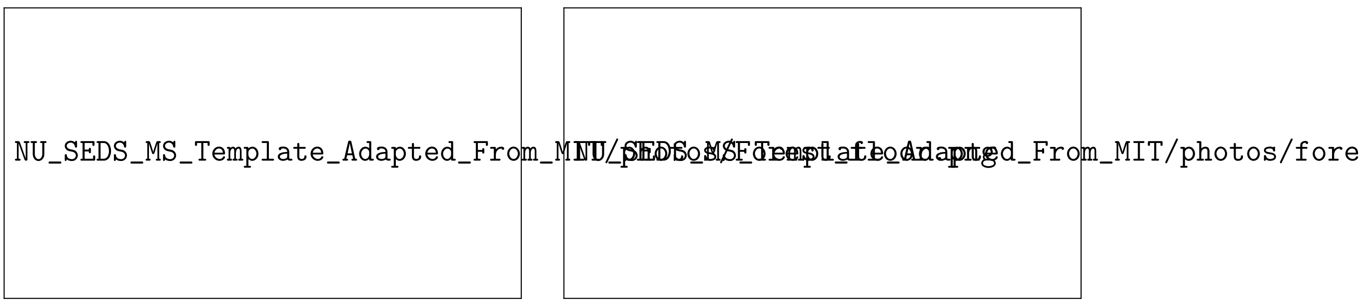
There are two options to solve this problem. Option one was to create a set world and remove the procedural generation, creating a world that is locked and is not changing. This would allow loading only a set-dimensioned environment that will need fewer computational resources after initial processing of the map. However, this will result in participants using the same environment and might reduce the novelty effect after initial exploration during the first session.

The second option was to create a procedurally generated environment with a lower polygon count, which made the computation of created surfaces more efficient. The rendering of each polygonal face in a 3D model carries a computational cost. Without a strong GPU to process the rendering of meshes, the 3D objects having a high polygonal count were not computationally feasible. To minimize latency and maintain performance, low-poly models were adopted. Using a lower polygonal structure, we can guarantee a faster rendering time [24]. Given the limited computational resources used during this research, a choice needed to be made. Since a large number of polygons make it difficult to render large-scale 3D models on mobile VR headsets [27], it was decided that the graphics needed to be simplified. So, for this research, a low polygonal environment was generated.

An important aspect of the virtual natural environment's design was the lighting. The original plan was to use a dense forest canopy and dim foliage to create a genuine and engrossing forest setting. But early in the research process, it was found that these small areas and dim lighting could increase the likelihood of motion sickness in virtual reality. To solve this issue, it was decided that the VR environment needed to be an open space with a lot of light and no constrictions visually, or to be "non-oppressive." To maintain visual interest, the environment included three different types of trees in addition to elements such as flowing water, distant mountain peaks, and scattered vegetation. Although green forests have a positive impact on stress levels according to SRT, a preference was given to more open spaces.

A skybox with painted clouds was utilized to create the illusion that the globe was larger in scale. As seen in Figure 3-4, the final effect was a serene and visually beautiful setting with vivid hues.

A procedural generation method based on Perlin noise was used to create a dynamic and efficient landscape. Naturalistic terrain variations were created using Perlin noise, a gradient-style pseudo-random function. To model terrain features such as hills, slopes, and flatlands, the algorithm specifically produced a two-dimensional noise map with values ranging from 0 to 1. To make the computation smoother, the created maps were divided into chunks. In this case, the chunk is the smallest rendered part of the virtual environment. This allowed for the creation of the terrain as the subject explored. To further optimize performance, a Level-of-Detail (LOD) system was implemented. By prioritizing the chunks closer to the user, they were rendered in higher detail, while distant regions were rendered with lower LOD for distant portions of the mesh. Based on the participants' proximity and the camera's range of vision in the 3D space, LOD was utilized to modify the rendering quality of each piece. This strategy was used in order to mitigate latency, keep the application running smoothly, and drastically reduce processing power without sacrificing the visual fidelity of the VR nature experience. The creation process can be fully seen in 3-3.



(a) Hyper realistic canopy with the lighting (b) Rendered light and atmosphere

Figure 3-2: Concept designs of proposed forests

3.3.2 VR Hardware (Oculus Quest 2)

Several commercially available virtual reality (VR) headsets were taken into account for this investigation. Due to their extensive use, strong developer support, and accessibility, the Meta Oculus series stood out as the most practical among consumer-grade options.

The Oculus Quest 2 and the Oculus Rift S were two versions in the Oculus collection that were highly relevant. Both devices provided similar degrees of immersion and user experience, making them appropriate for research involving virtual nature, and Quest 2 is affordable. Previous studies have shown that these two headsets had negligible differences in perceptual immersion [20]. Oculus Quest 2 was selected for this study for these reasons.

NU_SEDS_MS_Template_Adapted_From_MIT/photos/Noise.png

(a) Perlin noise used to create a topology of averaged values

NU_SEDS_MS_Template_Adapted_From_MIT/photos/Colo

(b) Applied color map to the generated noise to define different biomes

NU_SEDS_MS_Template_Adapted_From_MIT/photos/Mesh.png

(c) Developed mesh that transcribes the values of the Perlin noise into 3D vertices

NU_SEDS_MS_Template_Adapted_From_MIT/photos/Real

(d) Final generated virtual environment with low poly plain

Figure 3-3: Steps in terrain generation: (a) Perlin noise, (b) applied color map, (c) 3D mesh, and (d) final virtual environment.

NU_SEDS_MS_Template_Adapted_From_MIT/photos/oculus.png

Figure 3-4: Real-time procedural world generation using Unity

Another advantage of choosing the Oculus series was the ease of integration that the Meta products had with the Unity Engine. For this project a special set of prefabs of rocks and trees was made to optimize the performance of the application without sacrificing the visual appeal. In order to connect and run an application on Quest 2, a specific application in the form of Meta Link was required. Since Quest 2 has Type-C capabilities, it enabled high-speed data transfer using a 5-meter Type-A to Type-C cable in the lab, where the weak Internet connection caused frame drops during testing. Figure 3-5 illustrates the connection method used during development.

The Quest 2 VR headset has a frame rate of 60–120 Hz, a resolution of 1920 $\times$ 3664, and 773 PPI. The integrated cameras on the front side prevent participants from leaving the approved area, ensuring user safety, allowing participants to move unrestricted within a large open space inside the lab. This can be seen in Figure 3-6.

3.3.3 EEG Hardware and Setup

For this research, the g.USBamp and g.GAMMAbox active electrode driver boxes were used. The setup consisted of connecting the 16 electrodes to the ['Fp1', 'Fp2', NU_SEDS_MS_Template_Adapted_From_MIT/photos/Hardware testing.png

Figure 3-5: Oculus Quest 2 connection and setup

NU_SEDS_MS_Template_Adapted_From_MIT/photos/cable.jpg

Figure 3-6: Oculus Quest 2 in the laboratory setting

'F7', 'F3', 'Fz', 'F4', 'F8', 'C3', 'Cz', 'C4', 'T7', 'T8', 'P3', 'Pz', 'P4', 'Oz']. The rationale for choosing these placements came from Aspiotis et al. [2], Fz, F3, F4, Cz, C3, C4, T7, T8, Pz, P3, P4, P7, P8, O1, O2, A1, A2, F7, F8, Fp1 and Fp2. These electrodes were chosen as standard EEG 10-20 electrode placements. From these, a few modifications were made. To ensure that frontal alpha could be calculated, F3, F4, F7, and F8 were retained. In order to meet the 16-channel quota, the occipital lobe electrodes have been removed and replaced with the Oz electrode placement. Instead of checking the rest state for both eyes (O1, O2) the general state of the eye was preferred, which Oz allowed to do. A1 and A2 were removed because they serve as a reference in the standard electrode placement. In the g.tech g.GAMMAbox reference, a separate channel was included in the form of a reference clip attachment, allowing one to forgo the A1 and A2 electrodes. In terms of ground conditions, AFz was used. The mapping of the electrodes is shown in Figure 3-7. The general setup took around 30 minutes, taking into account gel applications to reach the desired impedance. For this research, the aim was to keep the impedance below 5 kilo-ohms to obtain optimally clean data. In Matlab, additional filters with a cutoff frequency in the 0.5-30 Hz range as well as a 48-52 Hz bandwidth filter were applied. The gel application example can be seen in Figure 3-8.

NU_SEDS_MS_Template_Adapted_From_MIT/photos/EEG.png

Figure 3-7: EEG setup: 16 channels and a ground

3.4 Data Acquisition

Before the experiment, participants were given time to review the consent form. The study process was briefly explained at the beginning of the initial session. During

Figure 3-8: EEG gel application to get a desirable impedance of 5kΩ

this process, questions from participants were addressed.

Following the paperwork, the participants were placed in front of a laptop running the **Montreal Imaging Stress Task (MIST)** [10]. For this paper, we have adapted the MIST to the mental arithmetic task (MAT). Participants were given a set of questions that required them to sum the two-digit numbers. The participants were given 3 choices. The choices were separated by increments of 10. By having a step difference of 10 in the answers, this added difficulty to participants who might otherwise rely on guessing the answers based on the sum of the final digits. The choices were mapped on the 1, 2, and 3 keys on the standard laptop keyboard's numpad to reduce the travel distance for the finger. This was done to minimize muscle artifacts that were acquired during the acquisition of EEG data. The wrong choices were accompanied by loud noises to increase stress induction. The time was limited to 5 seconds per question and 1 second for the result of their choice. The task consisted of two blocks with 15 questions each and a break in between. In the beginning and after each MAT session, 20 seconds of EEG background noise was collected, which was later used in data processing.

When it came to EEG data, there were many things to take into account. For example, the sampling rate. Although 256 Hz is a commonly used sampling rate in EEG research, it was decided that the data will be acquired at 512 Hz to provide higher temporal resolution. At 512 Hz, the algorithms have richer temporal information. Therefore, since MAT introduces muscle artifacts, increasing temporal resolution helps to identify and isolate artifacts, which is crucial for accurate stress analysis.

After the participants had found a comfortable position that allowed them to sit and reduce the number of movements, an electrode cap with 16 preset electrodes was placed. To achieve the best resolution before data collection, the amplifier configuration was run. In the MATLAB simulink the g.tech MASTER amp was routed through a buffer and connected to the output file that contained 17 channels. In these 17 channels, the first corresponded to the time, and the following 16 were the channels of interest for this research. The placement of electrodes is shown in Figure 3-7.

There were instances where participants had actively started to move during the experiment, which might have added to the noise and artifacts in the resultant data.

3.5 Data Processing

To clean the data, a combination of MATLAB and Google Colab IDEs was used. Data were recorded as a (**.mat**) file. The working data was then uploaded to Google Colab for further processing. One of the first steps taken was the application of filters. For this setup, the filters mentioned in Table 3.1 have been used. The main aim was to reduce the drifts and artifacts that were generated while collecting the data.

As mentioned in Data Acquisition, the MAT required participants to press the numbers on a numpad to select the correct options. This introduced numerous muscle artifacts. As can be seen in Figure 3-9, there is a fair share of noticeable blinking artifacts and drifts. This could be due to the prolonged nature of data collection that results in the displacement of the electrodes. Because the electrodes also require gel for better conductivity, the time in the room without ventilation might have resulted in the occurrence of sweat and changes in electrode conductivity due to their shifting position.

Step	Type	Parameters	Purpose
High-Pass	Butterworth (4th order)	0.5 Hz cutoff	Remove slow drifts
Notch	IIR Notch	50 Hz, Q = 30	Remove electrical interference
Band-Pass	Butterworth (4th order)	1–40 Hz	Focus on EEG frequency bands
ICA	FastICA	16 components	Remove eye/muscle artifacts

Table 3.1: Summary of filtering and artifact removal steps applied in the EEG pipeline.

3.6 Data Analysis

A wide range of statistical analyses were performed on processed EEG data in order to assess the possible neurophysiological impacts of exposure to the virtually generated environment (VGE). To determine whether variations in stress-related EEG markers, including mean alpha power, mean theta power, frontal alpha asymmetry, theta/alpha ratio, and frontal midline theta, before and after VR exposure were statistically significant within participants, paired samples (t-test) were the main inferential tool utilized. The resilience of this approach in identifying mean differences in small sample numbers and its applicability to experimental design within the subject led to its selection.

Cohen's d was determined for each EEG marker to support the significance testing and offer a gauge of practical impact. In the context of limited statistical power due to the small participant pool ($N = 8$), this effect size provides an offering of a nuanced interpretation of the observed changes, independent from sample size. Several significant effect sizes were found, especially in theta power ($d = 0.39$) and alpha asymmetry ($d = 0.15$), indicating directional tendencies worth more research, although none of the EEG measurements achieved statistical significance at traditional levels ($p > 0.05$).

When applicable, these statistical techniques were applied with multiple comparisons and normality adjustments. This analytical paradigm balances the exploratory usefulness of effect size interpretation in early-stage VR-EEG research with the limitations of a pilot study, ensuring that the data are interpreted conservatively but informatively. The results of the analysis can be seen in the interpreted in Table 4.1

NU_SEDS_MS_Template_Adapted_From_MIT/photos/eeg16.png

Figure 3-9: Channels Before and After Data Processing

NU_SEDS_MS_Template_Adapted_From_MIT/photos/hardware.jpg

(a) Pre-Exposure setup, Day 0

NU_SEDS_MS_Template_Adapted_From_MIT/photos/sub1.jpg

(b) Post-Exposure setup, Day 2

NU_SEDS_MS_Template_Adapted_From_MIT/photos/sub

(c) Post-Exposure setup, Day 2

Figure 3-10: Participants worked on the MAT during the experimental phase on various days

Chapter 4

Discussion

After running the code in Google Colab, the results showed a statistical insignificance, as can be seen in Table 4.1 Despite the lack of significant group-level differences ($p > 0.05$ across all EEG markers) in the statistical analysis, a close examination of the effect sizes and individual trends provides useful information.

Table 4.1: Statistical Analysis of EEG Stress Markers (Paired t-tests, $n = 8$)

EEG Marker	t-statistic	p-value	FDR-corrected	Cohen's d	Normality p
Mean Alpha Power	-0.863	0.4165	0.8447	0.305	0.3644
Mean Theta Power	-1.100	0.3076	0.8447	0.389	0.7409
Theta/Alpha Ratio	0.563	0.5910	0.8447	-0.199	0.3113
Frontal Alpha Asymmetry	-0.436	0.6758	0.8447	0.154	0.0735
Frontal Midline Theta	-0.048	0.9628	0.9628	0.017	0.1063

- **Alpha Power:** Higher alpha power is typically associated with lower cortical arousal and greater relaxation. The mean alpha power of the study remained constant at 0.13 both before and after, indicating that arousal at the group level did not decrease significantly after VR exposure. However, the modest Cohen $d = 0.31$ suggests that VR exposure did have some positive effects on some participants.

- **Theta Power:** Cohen's $d = 0.39$ suggests an increase in theta power (from 0.13 to 0.14). This suggests improved internal processing, emotional control, or memory retrieval processes after VR.

- **Asymmetry of Frontal Alpha (FAA):** FAA shows a decrease from -0.57 to -0.38 which is in line with the patterns found in previous research suggesting less stress or anxiety.

- **TAR: Theta/Alpha Ratio:** The TAR decreased slightly from 1.09 to 1.06, indicating a slight trend towards a reduction of stress. The directionality is consistent with relaxation, even though Cohen's $d = -0.20$ is negative.

- **Theta of the Frontal Midline (FMT):** FMT (0.14 before and after) did not show a change, suggesting that greater cognitive load or extended VR exposure may be needed to result in measurable changes in this marker.

Although the results have not been statistically significant, there are places where the effect is noticeable. Nonetheless, the experiment contributes a novel data point to the field. By presenting a procedurally produced and traversable virtual reality environment, the study pushes the field beyond the static or passive 360° video approaches that were prevalent in earlier literature. Unlike previous work that relies heavily on self-reports or low-density EEG, this study employs a 16-channel setup and a rigorous preprocessing pipeline, including FastICA, high-pass filtering (0.5 Hz) and bandpass filtering (1–40 Hz), ensuring clear and interpretable EEG signals.

Limitations

1. **Sample Size:** The small sample size containing 8 participants reduced the potential to acquire statistical power and generalizability of the findings. There is a possibility that stratification by gender, baseline stress levels, and VR sensitivity could have been achieved with larger samples.

2. **Exposure Duration:** In addition, the exposure times were too short. Although it was done to avoid possible motion sickness, this may have reduced the impact on stress reduction markers. Two brief VR sessions (5 minutes each) may not suffice to induce measurable neurological change.

3. **Equipment Limitations:** Although the EEG system was configured to standards, occasional motion artifacts and environmental drift probably introduced noise into the data set.

4. **Environmental Limitations:** Another limitation was the lack of ventilation and high temperature in the laboratory during data collection that could have introduced sweating or an additional stressor that was not taken into account. The lack of control of the testing site may have impacted the study outcomes.

Chapter 5

Conclusion

By analyzing EEG-based stress markers in students navigating a procedurally produced virtual nature environment, this thesis investigated the relationship between neurophysiology, immersive virtual reality, and affective computing. Several metrics, such as increased theta power and a reduction in frontal alpha asymmetry, trended toward better stress indicators even though the results did not achieve statistical significance.

Despite the results and limitations, these findings point to a prospective role for virtual reality (VR) in the sphere of mental health. Based on existing research, VR has the potential to be a scalable, accessible, and non-invasive mental health intervention, especially for urban populations that have limited access to nature. More generally, this thesis accomplishes its main purpose of adding holistic data to the growing body of research that supports the development of integrative, biofeedback-informed virtual nature environments for therapy.

To expand on this research, future research should include other measures to fully utilize this study. Multiple cohorts and a larger sample size are ideal for investigations. Use repeated longitudinal measures or extend exposure times. Add multimodal biometric information such as heart data reading and sweat production. Examine the surroundings that can be adjusted to the users' EEG signals in real time. The next generation of VR systems has the potential to advance beyond entertainment into the field of individualized mental health platforms by combining immersive media, rigorous neuroscience, and machine learning analytics. This thesis offers a first step in that direction.

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