Video Games and Virtual Reality as a Relaxation Therapy: An EEG Study

by

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Abstract

Video games are popular as entertainment tools. Yet, they can also be used as tools for other activities, including relaxation and meditation. Virtual reality (VR) games have enhanced player experiences thanks to immersive applications, such as VR cinema, virtual browsing, and virtual spaces that can be used as an extension of the physical area. Among those applications, VR shows promise for relaxing and therapeutic applications. However, most of these applications position users in a passive interaction with their environment. This project explores if relaxation and mindfulness in VR can be achieved through active player engagement, where users directly control their character and provide input. Two versions of a relaxing video game were made: (1) a PC version where the player flies and explores natural landscapes in-game on a classical PC-gaming setup (i.e., a monitor display, keyboard, and gamepad); (2) a VR version, where the game is played via head-mounted display (HMD), specifically the Oculus Quest. I used a brain-computer interface (BCI), specifically the "Emotiv Insight" Electroencephalography (EEG) headband, to record participants' brainwave activities while playing the game. Based on the results of my study, I found a statistically significant difference on both theta and alpha brainwave frequencies (i.e., the brainwaves that express relaxation and engagement) between the PC and VR versions of the game. Furthermore, I collected qualitative impressions of both the PC and VR games, where participants reported their subjective levels of relaxation after each version. The results of the survey show that participants experienced enhanced relaxations states in VR compared to PC. This thesis contributes empirical evidence that VR games can be used to further enhance relaxation states in players and show promise for applications in mindfulness and meditation through active player engagement.

1. Introduction

In this thesis I investigate the potential that gaming technology, in particular virtual reality (VR), can have in inducing meditative and relaxation states in players. Particularly, I explore how active engagement in gameplay, opposed to passive engagement (a player passively observing a relaxing experience without controlling it), can enhance relaxation and meditative states in players. This is partly in contrast, or rather diversified, from prior work who mostly explored the use of games as relaxation and meditation tools in passive gameplay settings (

The objective of this thesis is to craft a game that can be used for therapeutic purposes in eliciting a neurological relaxation response from players that can be observed through using a BCI (brain-computer interface) system. A BCI system is a head mounted device that allows a computer to interpret data from a person's brain by using EEG electrode sensors placed around their head (Emotiv, 2021). The EEG sensors attach to the skin on a person's scalp to measure or record brain activity, that are then interpreted as electrical signals. The frequency and amplitude of these signals can then be displayed through machine learning algorithms as distinct brainwaves to analyze their effects.

I test this relaxing game on both virtual reality (VR) and personal computer (PC) platforms. Using the "Emotiv Insight" BCI, I measure and record the differences in players' brainwave frequencies and relaxation responses between the two platforms. To identify patterns of relaxation, I record the brainwave activity as they play both the PC and VR versions of the game. I particularly focus on observing the two brainwave types that have been shown to correlate with relaxation and meditative states (theta and alpha waves) as well as the brainwave type associated with stress (beta waves) (iMotions, 2019).

By examining the frequencies of the specific brainwave types elicited during play, we can show correlations between the player's relaxation level and the corresponding gameplay condition. By doing this, we can investigate which is the more effective platform in engaging players and eliciting relaxation responses. Additionally, strong relaxation responses recorded through the BCI during this experiment will provide evidence for if games can cause players to relax through active engagement and control, rather than passive interaction.

While games designed for therapeutic purposes are not a new concept, the idea of games as medical interventions has only been touched upon within the past year. One such game titled "EndeavorRx" released earlier this year by Akili Interactive labs. EndeavorRx is an FDA (Food and Drug Administration) approved method for treating childhood ADHD. EndeavorRx is an endless runner game (a game genre where the player runs in a linear fashion while dodging incoming obstacles) played on mobile touch screen devices (Akili Interactive Labs, EndeavorRx, 2020). Several studies have been conducted so far to investigate the efficacy of EndeavorRx as an ADHD (Attention Deficit Hyperactivity disorder) intervention. One study done by Canady et al. (Canady, 2020) found that after four weeks of playing EndeavorRX, one-third of the participating kids showed measurable improvements in their objective attention capabilities. Additionally, 68% of parents reported meaningful improvements in the severity of their child's impairments after two months of continued treatment. EndeavorRx offered actively engaged gameplay and was shown to elicit a staggering improvement in the attention deficit metrics of its target audience in the short term. The success of EndeavorRx warrants further study of other game types and their possible medical or therapeutic applications through player engagement.

The example reported above shows how games can be effective instruments to engage people in self-rehabilitation and therapeutic practices. However, when considering relaxation and meditative games, such therapeutic practices are often leveraged through mechanics that place players in passive interactions (where players do not have agency over themselves or control over events) but rather experience the game as a pre-rendered unfolding sequence of events. By contrast, in this thesis I leverage the immersive nature of VR games and argue that active gameplay (rather than passive interaction) in VR can induce meditation and relaxation states.

I designed a virtual reality game to investigate if the immersive properties of VR can push a significant difference of relaxation effects in comparison to those shown through traditional PC gameplay of the same game. These potential differences were analyzed through brainwave EEG recordings made during VR gameplay and a PC gameplay control group playing the same game, only on a different platform. This thesis contributes evidence that VR games can enhance relaxation and meditative states through active gameplay due to their immersive nature. Based on such evidence, I discuss possible design guidelines for future efforts using VR as a platform to design games for relaxation and mindfulness; in particular, the advantage of engaging players in active gameplay to induce relaxation.

2. Background

For this thesis project, I work from within the intersection of game design and therapeutic methodology. I investigate the prior work in these fields by examining how games have been used for therapeutic purposes in the past by conducting a review of popular relaxation techniques, while seeing how these relaxation effects can relate to BCI and EEG technology. I finish by discussing how virtual reality can be applied to BCI and EEG workflows.

A. Games as Therapeutic Interventions

Games are a very recent addition to the toolset of the medical field, but they are starting to gain recognition for their use. A study done by Kollins Et Al. (Kollins, 2020) earlier this year used a video game as an alternative to medication in treating ADHD in children. This game titled "EndeavorRX" (Akili Interactive Labs, EndeavorRx, 2020) is an on-rails running game (a game where the player's character runs infinitely forward while dodging obstacles). After playing the game for four weeks, kids in the gameplay treatment condition were seeing statistically significant improvements to attention-related measures than those who were assigned to the control group. EndeavorRx can even be medically prescribed. A major benefit of creating games that can treat psychiatric disorders is that they can help build healthier behavioral habits in people that are at a higher risk for drug abuse, dependency, or cannot otherwise obtain pharmacological help (Kollins, 2020).

Figure 1: An EndeavorRx player dodges in-game obstacles

Similarly, exposure therapy using games has helped improve mental health conditions like anxiety, depression, and Post-traumatic stress disorder (PTSD). A recent study conducted by Elliot Et Al. (Elliot, 2015) interviewed several recently retired military veterans who were diagnosed with moderate to severe PTSD symptoms. Each veteran discussed their relationships with first-person shooter games as an exposure therapy and coping mechanism when leaving active duty. Every veteran reported that it was initially difficult for them to play such games after returning home, causing some of the veterans to have panic attacks or recall traumatic events. However, they all eventually learned to mentally distance themselves from the game's events by recognizing that the game was not real and that they were now in a safe space. Playing war games that had close parallels to their experiences in service served as an exposure therapy for them, which helped lessen their subsequent PTSD symptoms (Elliot, 2015).

The above-mentioned work show evidence of games as promising tools for self-rehabilitation therapies by engaging in control of in-game characters and events. In this thesis I consider games that induce relaxation, mindfulness, and meditative states in players to achieve therapeutic results. However as explained below, most common relaxation experiences are based on "passive" interactions as users focus on achieving relaxation, rather than being actively engaged through control of events.

B. Passive Relaxation Methods

A lot of work has already been done regarding research into creating relaxation and mindfulness interventions, but many of these rely on a passive interaction for the participant. There are many applications on the mobile device market intended to combat anxiety and depression by inducing a relaxation response in the participant, but a common methodology used by them are simple guided audio tapes or breathing exercises that the participant listens to. One of the leading applications on the mobile market titled "Headspace" offers such guided meditation audio tapes. A study done by Economides Et Al. (Economides, 2018) found that by following the audio guidance of the app, users showed improved irritability, affect, and stress levels. This study shows that passive consumption of audio-based mindfulness apps is successful at eliciting a form of relaxation response.

Another increasingly popular method for achieving relaxation responses is deep breathing based meditation. Meditation is gaining traction as a clinical practice for treating anxiety and depression disorders. A study conducted by Kabat-Zinn Et Al. (Kabat-Zinn, 1992) enrolled 22 participants with generalized anxiety disorder to take part in an 8-week long training program teaching participants various meditation and deep breathing techniques through weekly 2-hour long sessions. After the eight weeks, 20 of the participants showed significant reductions in anxiety and depression scores when compared to before the study.

A novel relaxation intervention was created by Prpa Et Al. (Prpa, 2016) by creating a VR space that responded to biofeedback. Titled "SOLAR" Prpa's virtual environment was designed to teach users how to relax through practicing mindfulness meditation. SOLAR featured a biofeedback response system that would visually and auditorily reflect the user's affective state. SOLAR used a combination of brain activity and respiratory rate monitoring to accomplish this. The environment is procedurally generated (continuously designed by an algorithm so that each person's experience was slightly different) by responding to the user's brain activity and breathing, giving real-time feedback. Users were instructed to let their minds drift, allowing the biofeedback of the environment to guide them back into a relaxed state. The SOLAR prototype had a statistically significant effect on the participants' subjective relaxation scores when compared to scores recorded before testing. SOLAR was a successful intervention used to passively guide users towards a relaxation response through meditation.

These three studies showed three different methodologies for how technology can help users passively achieve relaxation responses, meaning that the user is only required to follow and respond to guidance. However, I am interested in investigating how similar relaxation responses can be achieved through active engagement instead in a gamified way, meaning that the user will find relaxation from in-game control. To empirically measure the magnitude of the participants' relaxation, I used EEG technology to record and analyze the brainwaves elicited through gameplay.

Figure 2: SOLAR's visuals glow red, giving biofeedback to the anxious user to calm themselves

C. Relaxation and EEG

As a benchmark comparison for my thesis project, I am investigating the neurological effects of the relaxation response and how I can potentially evoke the same effects through active gameplay. A study done by Jacobs Et Al. (Jacobs, 1996) studied the effects of the relaxation response on the brain. Participants in this study were randomly assigned to listen to either a guided deep-breathing audio tape test condition or a control condition where they listened to an audio tape giving information about the relaxation response. It was found that the relaxation response and active mental focus both created significant reductions in beta wave frequencies (the brain wave type associated with stress and anxiety) in anterior brain regions. Jacobs said, "the active ingredient of the relaxation response is the focusing of attention on a repetitive mental stimulus" (Jacobs, 1996, 123). Thus, Jacobs hypothesized that the participants in this study exhibited lower beta wave frequency (lower stress) in the test condition due to their focused engagement and interaction with the stimulus, rather than listening to information in the control condition. Participants in this thesis will be similarly engaged with repetitive active stimulus (gameplay) to achieve relaxation.

In another study done by Jacobs Et Al, (Jacobs, 2004) researchers measured EEG activity of participants in two different conditions; those that listened to a music audio track and those that listened to a guided relaxation method. The guided relaxation audio produced significantly greater theta wave activity in all cortical regions than the music condition. This study gives evidence that theta waves may be more important markers of relaxation responses in the nervous system than alpha waves, but both are important to observe (Jacobs, 2004). The frequency of theta and alpha brainwaves recorded during this experiment will show the degree of relaxation that the participants achieved while playing and if the VR platform elicited stronger responses than the PC platform.

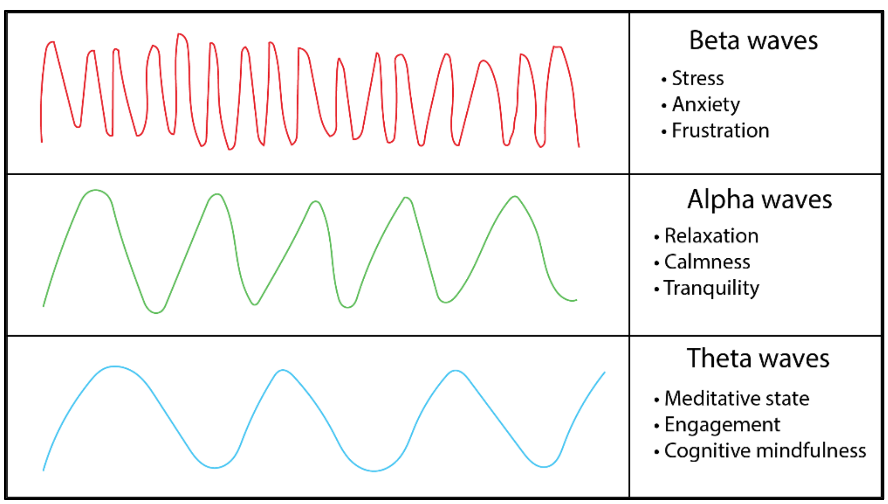

Figure 3: The theta, alpha, and beta brainwaves types that will be examined in this thesis

D. Virtual Reality Applications

One study by Amores Et Al. (Amores, 2018) created a virtual reality experience meant to measure the relaxation scores of the user based on their EEG activity. During this study, participants wore a BCI in combination with a VR headset that placed the participants on a soothing beach. This experience's testing apparatus included an olfactory interface (a mechanism that released a soothing scent as feedback to the user) that made the relaxation method affect the sense of smell in addition to sight and hearing. The participant passively observed the VR visuals and beach setting while listening to soothing to ocean wave audio to relax. Results of the study showed that the user's subjective perception of relaxation and physiological relaxation increased by 26.1% and 25% respectively when compared to the control condition where given no stimulus was given. This study exhibits an application of VR in influencing a person's physiological response using technology to simulate an immersive experience (Amores, 2018).

A second study, by Tarrant Et Al. (Tarrant, 2018), made use of VR in managing anxiety using a nature experience. This experience featured a 5-minute guided mindfulness meditation that directed participants to observe different parts of the visual VR nature environment. Brain activity was recorded during the experiment using a BCI. Compared to a resting control condition, participants that completed the VR nature experience resulted in higher alpha wave (wave type associated with relaxation) frequencies and lower proportions of beta wave (wave type associated with stress and anxiety) frequencies. Tarrant noted that "studies examining EEG changes in response to nature have demonstrated increases in cortical alpha amplitude associated with a relaxation response" (Tarrant, 2018, 2). This study is helpful because it discusses its results more closely in terms of the alpha and beta brainwave frequencies that result in the user's reduction in anxiety, providing evidence of the therapeutic applications of VR (Tarrant, 2018). Like two studies described above, this thesis will leverage nature and wildlife visuals in evoking increased alpha wave frequencies.

The applications of virtual reality have already been documented as successful interventions in treating anxiety, depression, ADHD, and PTSD. Through the lens of the relaxation response and the neurological effects of meditation, this thesis project will create and document a new tool to contribute to this pool of successful therapeutic interventions. However as discussed above, many of these previous studies have relied on a passive engagement with their participants; by either entering a meditative state or relaxing based on virtual feedback to achieve relaxation responses marked by high theta and alpha brainwave frequencies. My thesis will document the same effect as these relaxation responses (strong alpha and theta EEG waves) by creating them through active player engagement. Therefore, this experiment's null hypothesis is: there is no difference exhibited in EEG wave response between the VR and PC conditions. Considering the null hypothesis, this project poses three hypotheses as follows:

- **Hypothesis 1:** The virtual reality test condition will elicit stronger frequency EEG theta wave response than those recorded in the PC test condition.

- **Hypothesis 2:** The virtual reality test condition will elicit stronger frequency EEG alpha wave response than those recorded in the PC test condition

- **Hypothesis 3:** The virtual reality test condition will elicit weaker frequency EEG beta wave response than those recorded in the PC test condition

Hypotheses 1 predicts that alpha brain waves will have higher frequency during the VR test condition. Alpha waves are associated with relaxation, meditation, and mental wellbeing, "You can see increased levels of alpha band power during mental and physical relaxation" (iMotions, 2019, 20). The first hypothesis essentially predicts that players will become more relaxed through engaging with the VR test condition when compared to the PC condition.

Hypotheses 2 predicts that theta brain waves will also have a higher frequency during the VR test condition when compared to the PC condition. Theta waves are associated with engagement, attentiveness, and increase “during focused attention and information uptake, processing and learning or during memory recall” (iMotions, 2019, 19). Thus, the second hypothesis is predicting that the players will feel more engaged and physically present through the VR gameplay condition when compared to the PC condition.

Hypothesis 3 predicts lower beta wave frequency in the VR condition. Beta waves are associated with stress and anxiety, which I am trying to minimize throughout this experiment. “Busy or anxious thinking and active concentration are generally known to correlate with higher beta power” (iMotions 2019, 21). If the participant has a higher level of anxiety during this experiment’s gameplay, their relaxation response is likely not being engaged. The third hypothesis is essentially predicting that the participants will be experiencing minimal stress levels and minimal associated beta wave frequency throughout the experiment.

3. Methodology

Participants played two versions of a relaxing video game on the PC and in VR. This game was designed using principles exhibited in established relaxing games that are known for their soothing properties. Using a BCI and EEG technology, recordings of participants' brainwaves were analyzed to investigate possible differences between the two game platforms.

a. Experimental Design

This study utilized a within-subjects design. This means that each participant completed both experimental tasks to measure the differences in each participants' reactions. The tasks were counterbalanced between participants using the latin-square method. Seventeen participants were randomly assigned to complete either a VR game task or a PC game task while wearing a BCI headband to record brainwave activity. Upon completing their first task, they would then complete the second task (i.e. being assigned to the PC condition first and then completing the VR condition afterwards, or vice-versa). All participants completed both conditions. Both tasks featured an identical game where the only difference was the gaming platform. Thus, the independent variable was the gaming platform (playing on a PC or in VR) and the dependent variable was the resulting brain wave frequency recordings to be compared between conditions.

b. Participants

Participants were asked to report demographic information within a pre-test survey. Twelve male and five female participants were recruited for this study, for a total of seventeen participants. Participants were able to select "male", "female", or specify another gender. Participant ages ranged between fourteen and fifty-two (*M* = 28.33, *SD* = 3.18). All participants gave written and verbal consent to participating in this study. Three participants' data were not included in the analysis due to having consumed caffeine right before participating, resulting in a fourteen-participant sample size.

c. Recruitment Method

The nature of this study and the use of a BCI device required an in-person session. Participants were recruited by word of mouth from family, friends, and the Northeastern University community. Due to the requirements of Northeastern University for on-campus students and faculty to have regularly scheduled Covid-19 tests, the risks both to myself and the participant were minimized by originating from this careful community. All participants verbally communicated to me that they had recently been tested negative for Covid-19 before testing. Due to this experiment relying on recruitment from nearby communities, it may exhibit biases relating to convenience sampling.

d. Test Game: Fly by Night

The relaxing game designed for testing in this experiment was titled "Fly by Night". This game put players in an open-ended role of a bird-like creature flying through an ethereal afterlife setting. Fly by Night was played on the PC using a PlayStation 4 controller. The VR version of the game was hosted on a PC and used a PlayStation 4 controller, but visually cast to an Oculus Quest headset. On loading the game, the player is greeted with a main menu screen where they can (1) select "PLAY" to start the test game, (2) select "Tutorial" to be sent to a short training environment, or (3) select "Quit" to exit the program. The main menu is an animated movie featuring soothing background music that eases the player into their task.

Figure 4: Main menu screen showcasing the simplistic low-poly graphics

Before playing the test game, the participant was instructed to complete the tutorial training course first. They are spawned into a barren and undecorated environment that features signs denoting the control scheme on the PlayStation controller. The left stick moves the player character while the right stick rotates the camera around them. The “X button” is used to jump and flap their wings to gain altitude and speed. The left and right triggers are used to barrel roll the character in the air. The player quickly learns that the spatial freedom of flight is the core mechanic of this game and that their character must flap its wings to stay afloat.

Populating the tutorial area are several large floating rings that the player can fly through to practice their aerial skills. The tutorial is on a time limit of 60-seconds for the participant to experiment with the controls and practice maneuvering their character.

Figure 5: Tutorial spawn point, player walks past signs that instruct them

The tutorial environment is purposefully not aesthetically pleasing so that the player's relaxation response is less likely to activate before playing the test version when the EEG recording begins. If the time limit runs out before the player is comfortable with the controls, they may repeat the training until they are ready to continue. This process eliminates the variable of frustration while learning the controls during the test by making sure that participants that are not very familiar with video game controls are comfortable playing.

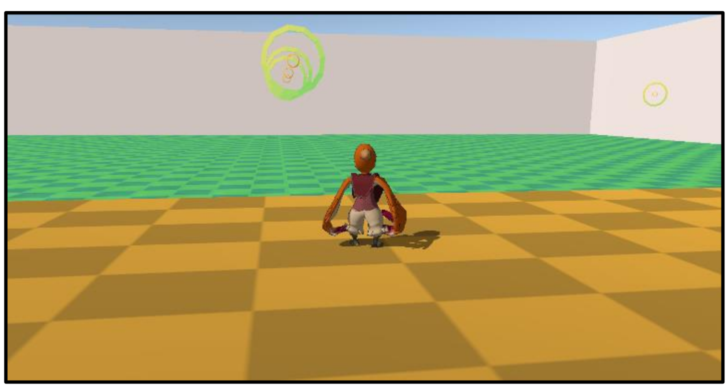

Figure 6: Tutorial environment is plain and only serves to be instructional before the test begins

After the participant completes the tutorial and is comfortable with the controls, they return to the main menu screen. The player presses the “PLAY” button while I simultaneously start the EEG recording. I give the player very little background information about why they are present in the game, except for the control guidance given in the tutorial. Participants are verbally informed that the rings that appeared in the tutorial are also present in the gameplay environment. Players can fly through these rings floating in the environment to create a pleasing light and sound effect that also progresses a score counter present on screen. Participants are told that the rings and score counter are present only if they wish to impose a goal on themselves, and that it is more important for them to relax and pursue aspects in the environment that are intrinsically rewarding for them.

The player spawns into the game as a bird-like creature on a small island in the middle of what seems to be a mystical archipelago. The stars and moons of the cosmos glow in the sky behind ribbons of aurora borealis while fireflies float around through the trees populating the islands. Soothing music plays in the background. At any given moment there are five floating rings spawned randomly around the landscape that rotate towards the player’s position. If a player flies through one of these rings, it pops with a satisfying sound and small light display.

Figure 7: A player in flight aims for one of the glowing rings.

Players spend four minutes exploring the islands before the screen fades to black and loads an animated credits screen that displays a poetic quote about the similarities of a flight and a person's agency over life.

Figure 8: The game ends with a poetic quote, ending the recording session.

Fly by Night was designed with several specific design considerations in mind to maximize the game's relaxation potential. These considerations were inspired by analyzing several well-known relaxation games like "Abzu" by Giant Squid Games and "Flower" by Thatgamecompany. These considerations include being spiritually close to nature, having a visually pleasing aesthetic, and giving players a sense of agency over their actions in a limited setting.

e. Abzu

Abzu (Giant Squid, Abzu, 2016) puts players in control of a deep-sea diver as they explore breathtaking oceanic reef environments in a third-person perspective. The diver is on a mission to restore the ocean's life force and the souls of its inhabitants. The game leverages the spatial mechanics of weightless movement underwater as a puzzle mechanic. There is no breath meter, allowing players to stay submerged in among the ocean life indefinitely to take their time exploring parts of the game that interest them. Players can increase their swimming speed, grab onto large ocean creatures (like dolphins or whales) to hitch a ride, and find spots to sit and meditate amongst the seabed while watching the fish around the area.

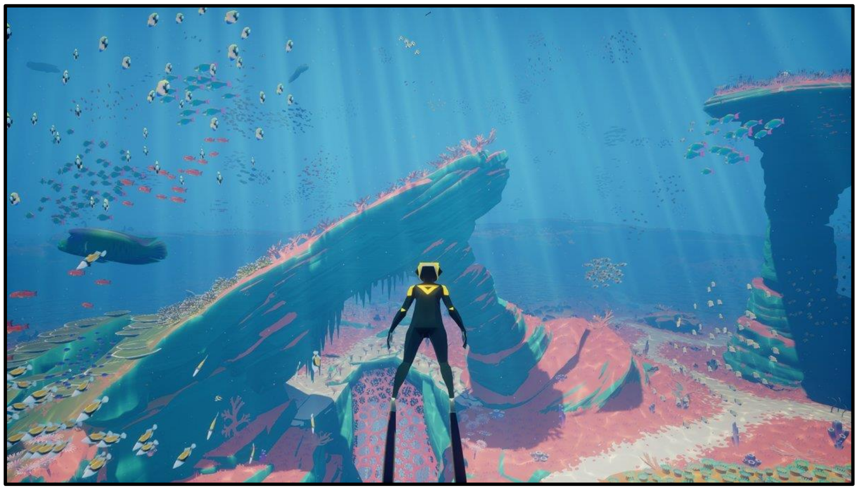

Figure 9: An Abzu player takes a moment to float, appreciating the reef's scenery

While the entirety of Abzu's level design could be boiled down to a series of corridors; the beautiful artwork, movement through large prospect spaces, and a soundtrack that encapsulates the soul of oceanic life imparts the feeling of grand scale and adventure throughout the short game. The story of the game is communicated without a single word, and the player is left to discover the control interactions themselves.

Figure 10: A player merges with nature by riding and controlling an orca whale

Abzu creates a relaxing and mindful experience by encouraging the player to slow down and absorb the environment, while still providing players with the tools to have a more active playstyle. The game fuses a spiritual experience into the aesthetic of the dynamic environments and providing the player with the sense of agency over each area by providing noticeable changes to the area that would otherwise remain lifeless with their intervention. Fly by Night takes many cues from Abzu, providing mindfulness through environments that evoke a spiritual or natural concept and providing players with the tools and movement mechanics that allow them to explore with their own discretion rather than imposed objectives.

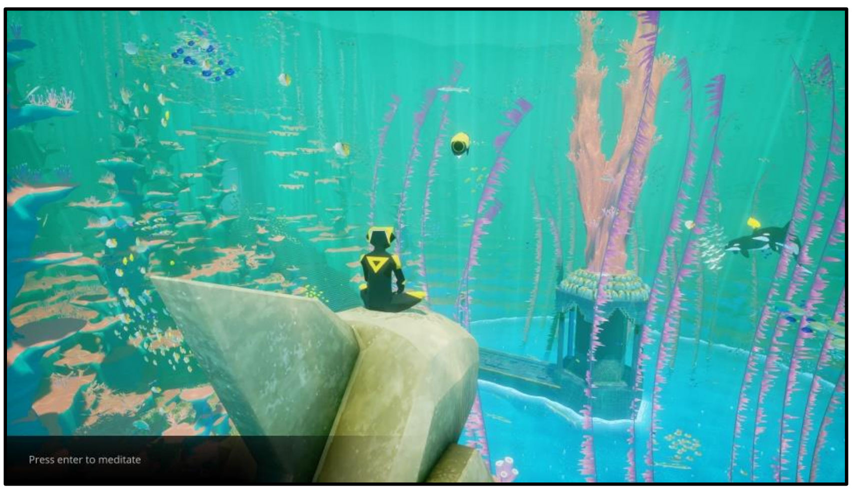

Figure 11: Several statues in the game allow players to sit and meditate with wildlife

f. Flower

Flower (Thatgamecompany, Flower, 2009) puts players in control of the disembodied power of the wind itself. Players move the invisible force of wind through colorless fields to breathe new life into the seeds throughout. These seeds sprout colorful flowers, make a satisfying sound based on their type, and slowly color the surrounding grey fields into a vibrant area.

Figure 12: Players begin in a colorless world, looking for flowers to revive

Figure 13: After reviving enough flower petals, the world becomes vibrantly colored

This relaxing game provides mechanical, auditory, visual, and spiritual satisfaction. Mechanical satisfaction arises from mastering the flight controls of the wind and flying through obstacles successfully. Auditory and visual satisfaction arises from stringing combos of flowers that play different notes, creating music on the wind while coloring the environment. After each flower hit, a petal is added to the player's wind form trailing behind them, signifying their progress and gathering strength as a lifeforce. As quoted from the game's developers "like in the real world, everything you pick up causes the environment to change" (Thatgamecompany 2009). Spiritual satisfaction arises from the unguided agency of the player's mission, breathing life into a dead world.

The game imparts the feeling that their work in the game is meaningful despite the game's simplicity. However, the simplicity of Flower is also its strength. Everything in the game from the soundtrack and visuals to the way the wind handles movement and puzzle obstacles contributes to mindful and spiritual concept of saving the environment through the player's free will and direct intervention.

Fly by Night follows several of the successful design considerations present in both Abzu and Flower to create its relaxing and mindful experience. Rather than impose missions or concrete objectives, Fly by Night opts more for the player to construct their own motivations for being in the game world, which will provide stronger satisfaction when fulfilling what the player perceives is important. However, to successfully encourage behavior like this it is very important to provide the perfect balance of stimulation to hook the player's immersion into the game. Giving player too much agency can result in frustration due to the lack of direction, or even boredom, rather than the feeling of control.

When participants press the play button in Fly by Night to enter the game, they spawn into a low-poly environmental designed to evoke spiritual feelings in a dynamic afterlife setting. The player can walk on the forested islands or fly around the islands gathering rings on their way. The player will be informed of the controls and be able to practice but given no further instruction. This means that they are free to make their own ideal assumptions about the setting and pursue gameplay actions that are inherently meaningful to them. The combination of gameplay flow state of flight, empowered player agency, and environmental aesthetics that promote embodied mindfulness will contribute to a successful relaxation game.

g. Apparatus

This study utilized three primary pieces of equipment: (1) an Oculus Quest (1st generation) VR headset, (2) a PC computer, and (3) an Emotiv Insight BCI headband. The Oculus Quest features a 1400 x 1600 OLED (organic light-emitting diode) display for each eye and a refresh rate of 72 Hz.

Figure 14: The Oculus Quest headset

The Emotiv Insight is a Bluetooth wireless 5-channel (not including two mastoid reference sensors) EEG headband. The Insight records at 128 samples per second per channel at a 14-bit resolution. The greatest benefit of the wireless Insight headband is its small size and non-invasive properties when compared to larger EEG interfaces. The participant simply slides it onto the top of their head and the experimenter will apply a small amount of lubricant to the sensors as necessary to get good conductance readings. Setup for the Insight only takes around five-minutes. Once the Insight headband was on the participant, it connected to the Emotiv Pro EEG recording and analysis software to confirm good sensor conductance with the participant's scalp.

Figure 15: The Emotiv Insight EEG headband

Participants that were assigned to the PC condition were only required to wear the Insight headband before beginning testing. However, participants that were assigned to the VR game condition were required to put on the Oculus Quest headset on top of the Insight headband as shown below. The participant held the goggle portion of the headset firmly to their face while I looped the harness behind the participant's head and tightened until snug. The participant was warned that it might pinch their scalp during the process of putting on the equipment but should be comfortable to wear afterwards.

Figure 16: Testing apparatus combining the Emotiv Insight and the Oculus Quest

h. Procedure

Upon arrival, participants were given an informed consent waiver, confidentiality agreement, and were briefed about the nature of this study. They were assured that I had been vaccinated, recently tested negative for Covid-19, and that they could stop participating in the study at any time without consequence. Participants filled out a pre-test survey asking whether they had caffeine prior to arrival, if they get motion sickness easily, if they are afraid of heights, and to rate how relaxed they felt at the time. See Appendix A for the full pre-survey.

I then helped the participant put on the Emotiv Insight headband and adjusted the sensors until the emotive software signaled that good conductance on all sensors was achieved. If necessary, a small amount of the emotive glycerol gel was applied to each of the sensors to contact with the scalp more easily. The participant was informed that the gel would evaporate without residue. The sensors must read 100% conductance for 15 seconds straight before proceeding. The participant was then randomly assigned to one of the two test conditions to play first: either (1) playing the Oculus VR game test condition or (2) playing the PC game control condition.

Participants spent four minutes engaged with the game task in their assigned condition (see "Tasks" section below). When their time was up, the I ended the EEG recording and repeated this procedure for the second unassigned condition so that every participant played both the VR and PC versions in a counterbalanced order. Once both conditions had been played, I helped the participant remove the Emotiv Insight and the Oculus Quest before handing them a post-test survey asking them to elaborate on their experience. See Appendix B for the full post-test survey. Finally, the participant was debriefed and escorted out. See Appendix C for the full debrief statement. The Emotiv Insight and the Oculus Quest were then disinfected and cleaned in preparation for the next participant.

i. Tasks

This study featured two conditions and a within-subjects design. All participants completed both the PC control and the VR test conditions of the study but were randomly assigned (by counterbalanced order) to which condition was to be completed first. For both conditions, participants were required to play a 1-minute tutorial to become comfortable with the game's controls before playing. Participants were allowed to repeat the tutorial as many times as they wished before proceeding.

After completing the tutorial, the participant began playing a four-minute session in their first randomly assigned condition. See the "Test game: Fly by Night" section above for more details about the test game. The game will fade to black after four-minutes of gameplay, after which I ended the first recording. The participant then played a second four-minute session in the remaining condition, repeating the procedure. After completing both play sessions, the participant filled out a post-test survey about their experience before listening to a short debriefing statement summarizing the project.

j. Data Collection

EEG recordings took place in the Emotiv Pro software while examining the participants' two gameplay sessions. The EEG recordings from the PC and VR conditions were compared to determine if there was a significant difference between their respective relaxation responses by examining the theta, alpha, and beta brainwave frequencies.

EEG recordings began once the participant started the game by pressing the "PLAY" button. The participant played for four minutes and then the recording was stopped. The EEG headset was removed, and the participant was asked to answer a post-test survey. See Appendix A for the full post-test survey. Finally, the participant was debriefed and if they did not have any more questions, they were escorted out.

4. Results

Using EEG technology, significant differences were found between the two gameplay conditions for the frequencies of theta and alpha brainwaves. No significant difference was found for beta wave frequencies.

Data Analysis

Quantitative data analysis was conducted through MATLAB and its EEG analysis toolkit "EEGLAB". Raw EEG recordings were recorded by the Insight headband into the EmotivPRO software (the companion software to the Insight headband) in .EDF file format. The EEG recordings were then imported into EEGLAB according to the instructional workflow proposed by Heunis (Heunis, 2016). An .CED file also created by Heunis was used to label the topographic locations for the five sensors on the Emotive Insight located at the AF3, T7, Pz, T8, and AF4 scalp locations according to the standard 10-20 measurement system. The .CED file is a requirement to enable EEGLAB to correctly analyze the data according to their topographic locations and corresponding brain regions. The raw recording then underwent an ICA decomposition and baseline rejection to observe the individual sensor recordings.

Once the EEG recording was prepped and separated into channels, a basic FIR (finite impulse response) filter was applied to limit the recordings output range to between 4 and 35 HZ. This filter range is common for EEG testing because normal human brain activity occurs between 4 and 35 HZ (Yamada, 2018). This range of filter minimizes the chance that the resulting brainwaves is contaminated by extraneous noise and muscle movement. Next, I manually scrolled through the recording to reject any sections of recordings obscured my eye movement, signal interference, or muscle movement artefacts. Using Makoto's EEGLAB code, the EEG frequencies of the theta, alpha, and beta brainwaves were extracted from the cleaned data recording (Miyakoshi, 2016). The resulting frequencies of each brainwave type from each of the five sensors and a grand average of these frequencies for each brainwave type was recorded in Excel. This process was repeated for both condition recordings per participant for a within-subjects examination.

The two resulting data sets for theta, alpha, and beta waves each (for a total of six data sets per participant) were found to be approximately normal distributions, allowing for parametric testing to proceed. Three two-factor ANOVA's without replication were conducted to examine any statically significant difference in the three types of brainwave frequencies between the two test conditions.

Theta wave frequency

The datasets for theta wave frequencies in the PC and VR condition were found to be approximately normal distributions. The PC condition had kurtosis and skewness values of .87 and .82 respectively. The VR condition had kurtosis and skewness values of -.95 and .48 respectively. With kurtosis and skewness values all falling between -2 and 2, we can assume that the dataset is normally distributed and proceed with parametric testing. For theta wave frequency in the PC condition, mean spectral power was (M = 26.88, SD = 13.13). For the VR condition, mean spectral power for theta was (M = 42.63, SD = 23.47). Using a two-factor ANOVA without replication, there was a significant effect between the VR and PC game conditions for resulting theta wave frequency (F = 8.44, P = .01).

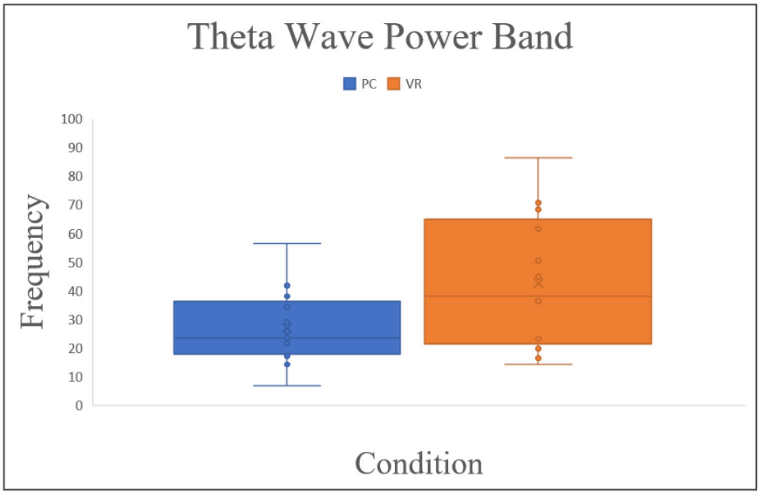

Figure 17: Plot of grand average theta wave frequencies in the PC and VR game conditions

Alpha wave frequency

The datasets for alpha wave frequency in the PC and VR condition were also found to be approximately normal distributions. The PC condition had kurtosis and skewness values of -.41 and .77 respectively. The VR condition had kurtosis and skewness values of -.19 and 1.09 respectively. For alpha wave frequency in the PC condition, mean spectral power was (M = 16.29, SD = 7.70). For the VR condition, mean spectral power for alpha was (M = 28.04, SD = 21.48). Using a two-factor ANOVA without replication, there was a significant effect between the VR and PC game conditions for resulting alpha wave frequency (F = 4.92, P = .04).

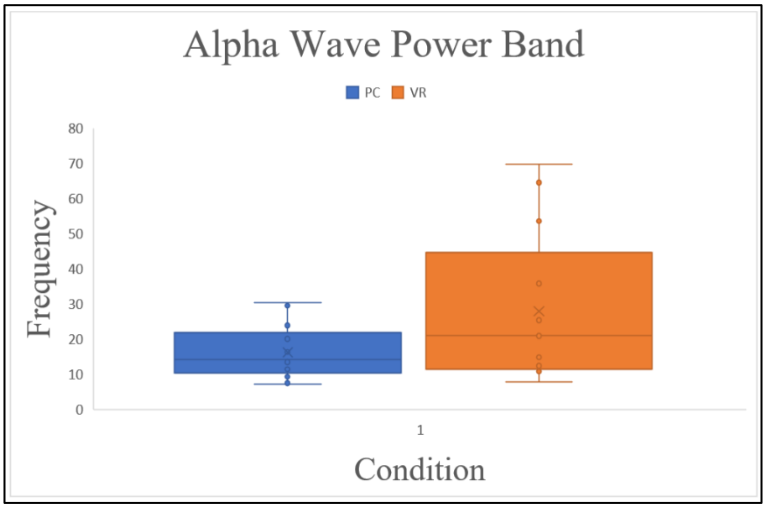

Figure 18: Plot of grand average alpha wave frequencies in the PC and VR game conditions

Beta wave frequency

The dataset for beta wave frequency in the PC condition was found to be an approximately normal distribution, but the VR condition was not. The PC condition had kurtosis and skewness values of .97 and 1.5 respectively. The VR condition had kurtosis and skewness values of 5.94 and 2.35 respectively. For beta wave frequency in the PC condition, mean spectral power was (*M* = 15.56, *SD* = 17.84). For the VR condition, mean spectral power for beta was (*M* = 15.71, *SD* = 17,89). Using a two-factor ANOVA without replication, there was no significant effect found between the VR and PC game conditions for resulting beta wave frequency (F = .002, *P* = .96).

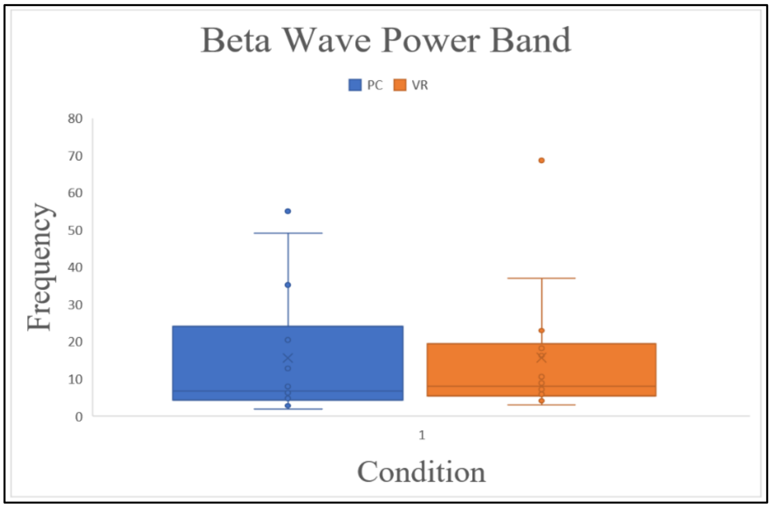

Figure 19: Plot of grand average alpha wave frequencies in the PC and VR game conditions

Qualitative results

Before playing either condition, participants were asked to answer a short pre-test survey. On a scale of 1-10, with 1 being not relaxed at all and 10 being extremely relaxed, participants self-reported their subjective perception of how relaxed they felt before playing (*M* = 6, *SD* =.43). They were asked the same question after playing their first randomly assigned condition and a third time after playing the second condition. For the PC version, players reported relaxation score (*M* = 8.06, *SD* = .32). For the VR version, players reported relaxation score (*M* = 8.13, *SD* = .41). All three datasets (pre-test, PC, and VR relaxation scores) were found to be approximately normal distributions, allowing us to proceed with parametric tests. Significant effects were found for relaxation scores between pretest-PC (F = 37.03, *P* = .000018) and pretest-VR (F = 36.13, *P* = .002). No significant difference was found between the PC and VR conditions for relaxation score (F = .022, *P* = .88).

5. Discussion

The goal of this study was to investigate the effects of active gameplay in VR for eliciting relaxed brainwave responses for use in mindfulness games. I recorded EEG data through an Emotiv Insight BCI while participants played two versions of a relaxing game that I designed, one in VR and one on a PC computer. The brainwave types recorded were theta, alpha, and beta waves. Theta and alpha waves are associated with relaxation and meditative states while beta waves are associated with stress and anxiety.

This experiment featured three hypotheses: (1) The VR test condition will elicit stronger EEG theta wave frequencies than those recorded in the PC test condition, (2) The VR test condition will elicit stronger EEG alpha wave frequencies than those recorded in the PC test condition, and (3) The VR test condition will elicit weaker EEG beta wave frequencies than those recorded in the PC test condition. The conjecture behind these hypotheses is that the inherently increased immersion in the relaxing VR environment combined with the engaged gameplay loop would elicit a higher frequency of the brainwave types associated with relaxation and lower frequencies of the brainwave types associated with stress when compared to the same game on the PC platform.

There were statistically significant differences found for both the alpha waves elicited ($F = 4.92$, $P = .04$) and theta waves elicited ($F = 8.44$, $P = .01$). After looking at the individual theta and alpha wave frequencies for each participant, I identified that this difference was in favor of VR eliciting higher frequencies of theta and alpha waves. In addition, significant differences were found for the participants' subjectively perceived relaxation scores increasing from pre-test to post-test, for pretest to PC ($F = 37.03$, $P = .000018$) and for pretest to VR ($F = 36.13$, $P = .002$). All but three participants reported subjectively perceived increases in relaxation from pre-test to post-test. Therefore, regarding the first and second hypotheses, I successfully reject the null hypothesis because the participants were exhibiting greater frequencies of alpha and theta waves, resulting in relaxed states through VR engagement.

A possible explanation for this result exists in the concept of the “flow state”. The flow state is the “holistic sensation that people feel when they act with total involvement. The state of flow is characterized by a sense of intrinsic reward experienced during immersive engagement” and is what most people mean when they say that they are “in the zone” (Katahira, 2018). The study done by Katahira Et Al. examining the flow state used EEG to record participants’ brain activity during a self-reported flow state. Katahira showed that the flow state was characterized by increased levels of theta and alpha wave frequencies, postulating that the flow state is related to cognitive control and immersion (Katahira, 2018). I postulate that the players in this thesis study may have experienced similar flow states as the participants in Katahira’s study, achieving flow through VR gameplay.

Regarding the third hypothesis, no significant difference was found for beta wave frequency in the EEG recordings between the VR and PC conditions. A possible explanation for this effect is that the participants all had a varying level of familiarity with video games and VR. Despite the significant effects found for the theta waves, alpha waves, and relaxation scores, six of the sixteen participants wrote that they preferred the PC condition because they experienced motion sickness in VR or because still felt unfamiliar with the controls even after practicing in the tutorial. This unfamiliarity with the controls and general uncomfortableness in VR could have caused stress even if the experience would have been otherwise relaxing.

The study done by Tarrant Et Al. that was discussed in the background section reported that their relaxing VR nature experience elicited increased alpha frequency and decreased beta frequency (Tarrant, 2018). A possible explanation for why Tarrant's beta wave result was not the case in this thesis is the way that the user was interacting with the VR stimulus. In Tarrant's study, the player did not move virtually through the nature environment, instead they sat still and could only look around. Player's in Fly by Night had, by design, the freedom of locomotion throughout the game. While it is true that beta wave activity is associated with stress and anxiety, beta frequency increases are also associated with doing strenuous mental tasks (Tarrant, 2018). I postulate that there was no significant difference in beta activity during gameplay could be due to the mental calculations necessary to maneuver in the game, which was equally necessary in both the PC and VR conditions, resulting in no difference in the beta waves exhibited. Therefore, I am unable to reject the null hypothesis regarding the third hypothesis.

Fly by Night successfully elicited relaxation responses through active player engagement, showcasing that VR is a suitable platform for developers to use for creating mindfulness games and experiences. When asked in the post-test survey to identify which game platform they preferred and why, every participant that preferred the VR version wrote pertaining to their level of immersion with the game. One participant wrote "I preferred the VR version more because it made me feel more relaxed and because you can really take in all the scenery". I postulate that the increased theta and alpha wave frequencies seen during the VR condition were achieved by leveraging the immersive properties of VR to create an embodied (a feeling where the user perceives themselves as physically present in their media experience) relaxation game, whereas the PC platform was perceived simply as a relaxing game.

Limitations

This thesis project was limited by a convenience bias and a small sample size due to Covid-19 regulations. Since I was unable to work through Northeastern University's lab and recruit from the larger Boston area, I was limited to recruiting people nearby that were willing to get Covid-19 tests before participating.

My project was also limited by my own game design ability. When working on VR games and experiences, the visuals and game stability are extremely important. Any decrease or drop in a VR game's framerate or response time could result in player nausea, which would ruin even the best crafted relaxing experience. This was the case during sessions with several participants that told me that they would have preferred the VR platform if the framerate was better. I had designed the game on PC where it worked smoothly, and the graphics were suitable, but adapting the game onto a VR platform created optimization issues that resulted in a difference in graphical quality between platforms. Due to time constraints with moving the project forward, I had to make compromises to begin testing which resulted in mechanics being cut and occasional lag during gameplay.

Another limitation this project had was the hardware available to me. The Emotiv Insight is a highly rated BCI that has been used in numerous prior research studies but was not my first choice for EEG recording. The Insight only has five electrode sensor channels (while higher end models have fourteen to 64 channels) that it records from, which results in lower detail recordings. While I chose the Emotiv Insight because it was easy to use and had minimal setup time for participant comfort, it was also chosen for its affordability and availability. While this study focused on strictly theta, alpha, and beta waves, it is possible to identify three sub-levels of beta waves. These three levels are: (1) "lo-beta" waves are those between 12-15 Hz and are associated with alertness, (2) “beta” waves between 15-22 Hz are associated with anxiety and stress, and (3) “hi-beta” waves between 22-38 Hz are associated with complex thoughts, high anxiety, and depression (Ambudkar, 2020). Using a higher fidelity EEG device would allow for closer inspections into these subtypes.

Future work

While this study was successful in documenting that VR can elicit higher frequencies of alpha and theta waves through active gameplay in comparison to PC platforms, there are several revisions to the study that I would recommend if it was repeated. The first revision is to simply repeat the study after the dangers of Covid-19 have passed and the regulations of in-person testing are less strict. The main reason behind this is to lessen the potential for convenience bias by recruiting from a wider area so that the results can be generalized to a larger population.

The second revision is to use stronger BCI equipment for recording participant brainwave activity. While the Emotiv Insight was suitable for this pilot study due to its acceptable detail and ease of use, I would be able to make more generalizations from recordings done with BCI’s that use a larger amount of EEG channel sensors to examine the effects of the relaxation response as well as look at the beta wave sub-levels. These larger BCI’s are more time consuming to setup for a session but result in more robust recordings for analysis as well as being able to filter out more background noise that result in recording artifacts that require removal later on.

The third revision includes modifications to the Fly by Night gameplay and stability. Even though the game was successful, additional content could make the game more robust while having a stronger effect on eliciting relaxation responses from players. I mentioned above in the limitations section that several features I had planned for the game had to be cut due to time constraints. These features included, (1) background music that changed according to the player's current activity (i.e. increasing music tempo and pitch when the player gains speed or slowing the tempo when they opt for slower gameplay) and (2) Additional mechanics and activities that the player could pursue. One intended activity was allowing players to chase spirits through the environment to help "guide them through the afterlife" where success would visually change the environment, making it brighter or more spiritually uplifting. These two features were intended to provide the player with a greater feeling of agency over the environment, showing that their power could directly influence the area. I had to cut these two mechanics from my design due to time constraints but think that the game would benefit from adding them in the future. Also mentioned above in the limitations section, the Fly by Night game would benefit greatly from more aggressive optimization for VR headsets, be it from upgraded hardware or streamlining software stability. This would help minimize the chance that players would experience motion sickness or nausea due to graphical integrity.

Conclusion

I have presented a study that examined the neurological relationship between relaxation and video games in VR. Two versions of a relaxing video game about a bird in flight were created: (1) a PC version using a classical gaming setup including a monitor and gamepad, and (2) a VR version played on an Oculus Quest headset. I used an Emotiv Insight EEG headband to record participants' brain activity during gameplay, to examine potential difference in the brain wave frequencies created between the PC and VR platforms. Significant effects were found for both the theta and alpha waves elicited during gameplay, which after further analysis showed that both types of waves had higher frequencies in the VR condition. Theta and alpha waves are the brainwave types associated with engagement and relaxation, as well as the flow state. The results of a qualitative post-test survey confirmed that participants were experiencing enhanced relaxation states through the VR condition when compared to the PC condition. I postulate that these increase theta and alpha frequencies are in part due to the immersive properties of gameplay in VR environments on entering a flow state through actively engaged gameplay. In conclusion, this thesis contributes empirical evidence supporting the use of VR in enhancing relaxation states and for creating therapeutic experiences through active player engagement.

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Appendix

Appendix A: Surveys

Pre-Test Survey

All data collected is purely for research purposes only. All data given is anonymous, confidential, and will not be shared with any outside source. Please answer as truthfully and completely as possible.

1. What is the participant number assigned to you by the experimenter?
2. What is your age?
3. What is your gender?
4. Have you consumed any caffeine today?
5. Have you ever been diagnosed with an anxiety or depression disorder?
6. If you have been diagnosed with an anxiety or depression disorder, are you actively on medication for said disorder?
7. Do you suffer from vertigo or get nauseous easily?
8. On a scale of 1-10, how familiar are you with playing video games?
9. On a scale of 1-10, how relaxed do you feel right now?

Post-Test Survey

All data collected is purely for research purposes only. All data given is anonymous, confidential, and will not be shared with any outside source. Please answer as truthfully and completely as possible.

1. On a scale of 1-10, how relaxed did you feel after playing the PC version of the game?
2. On a scale of 1-10, how relaxed did you feel after playing the VR version of the game?
3. On a scale of 1-10, how relaxed do you feel NOW after playing both versions?
4. On a scale of 1-10, how easy was the game to learn and interact with?
5. Which version of the game did you prefer? Why?
6. What was your favorite part of the game? Why?
7. What was the worst part of the game? Why?
8. Did you feel nauseous or anxious while playing either version of the game?
9. If you could add or remove something from the game, what would it be? Why?
10. On a scale of 1-10, how likely is it that you would play this game again to relax?
11. How likely is it that you would recommend this game to others to relax?
12. Do you have any additional thoughts to share?

Appendix B: Informed Consent Waiver

Today you will be playing two versions of a video game created with the intention of relaxing the player. You will be randomly assigned to which version you will play first, either on the PC or using the VR headset. We will also be using an EEG headset that will be monitoring your brainwaves while we play so that we can measure how relaxed you become while playing. While it may be tight, it is noninvasive and should not poke or hurt you when it is put on. We will however need to use a drop of solution on the sensors so that it can read correctly, but its does not stain and should evaporate. All the data that we collect in the recordings and in the survey is anonymous and will not be shared with outside sources. You can also refuse or stop participating at any point in the study without consequence. Do have any questions before we begin?

Please sign here if you consent to this experiment: ________________________________

Appendix C: Debrief

During this experiment you played two versions of a relaxing game, one on the PC and one in virtual reality. While you were playing, we were recording your brainwave through an EEG headset to compare the two conditions to investigate a potential significant difference between the relaxing properties of the two modalities. In the past few years video games have begun to be used as medical tools that can help diagnose and treat various psychological disorders through play. This experiment's overall goal was to create a therapeutic experience that can be used as a relaxation tool, supporting the movement of games as valid interventions.