ENVIROSCAPE: COPING WITH STRESS USING IMPLICIT BIOFEEDBACK APPLICATION

An Undergraduate Research Scholars Thesis

by

YERANIA HERNANDEZ

Submitted to the Undergraduate Research Scholars program at
Texas A&M University
in partial fulfillment of the requirements for the designation as an

UNDERGRADUATE RESEARCH SCHOLAR

Approved by Research Advisor: Dr. Ricardo Gutierrez-Osuna

May 2018

Major: Computer Engineering

TABLE OF CONTENTS

Page

ABSTRACT 1

DEDICATION 2

ACKNOWLEDGMENTS 3

NOMENCLATURE 4

CHAPTER

I. INTRODUCTION 5

Background 5

II. RELATED WORKS 7

Visual and Physical Intervention Games 7
Biofeedback Games 9
Virtual Reality Games 11

III. METHODS 13

Naturalistic Environment 15
Biofeedback Mechanism in Game 22

IV. EXPERIMENTAL DESIGN 24

Protocol 24

V. RESULTS AND DISCUSSION 29

Limitations and Future Work 33

VI. CONCLUSION 35

REFERENCES 36

ABSTRACT

EnviroScape: Coping with Stress Using Implicit Biofeedback Application

Yerania Hernandez
Department of Computer Science and Engineering
Texas A&M University

Research Advisor: Dr. Ricardo Gutierrez-Osuna
Department of Computer Science and Engineering
Texas A&M University

Stress has been identified by the Word Health Organization as an epidemic that has negative impacts on work productivity. It costs the American industry approximately $300 billion/year and is also the leading contributor to obesity and cardiovascular diseases. Current stress remediation tools incorporate techniques such as deep breathing, meditation and biofeedback responses. These type of exercises require a substantial amount of time and resources along with adhering to their strict system in order to see results. Most biofeedback mechanisms are repetitive and mundane and also require complex equipment to participate, in order to receive proper evaluation on stress levels. The purpose of this study is to develop an engaging relaxation technique and analyze the effects of the biofeedback mechanism on the stress levels of a user. An interactive application is developed such that the user receives subtle cues when they are in a "stressed" state, which is determined through the physiological indicator of the user's breathing rate (BR) signal. Unlike previous research, this biofeedback game focuses on providing a soothing natural environment with no specific objectives in order to distract them from their current stressful state. This will help analyze and discuss the effects of a non-competitive video game on a user's stress levels, their awareness to recognize signs of stress and their ability to reduce them.

DEDICATION

For my mentor, my colleague, and most importantly, my friend Kevin J Nguyen who inspired and motivated me throughout all these years, in the best and worst of times.

ACKNOWLEDGEMENTS

I would like to thank Dr. Gutierrez-Osuna and the entire Perception, Sensing, and Instrumentation (PSI) Lab, including Adam Hair, Dennis Silva, Zelun Wang, and Genna Angello, for their guidance and support through the course of this research.

I also want to extend my gratitude to Akanksh Basavaraju for his persistence in believing I could make it this far. His immense support is what helped me push through every step of the way. Thank you for never giving up on me. I would like to also thank Chetrapal Rathore for the inspiration provided and his patience towards me throughout this project. In addition, thanks to Hannah Moore for being there when I needed her the most.

Finally, thanks to my friends, colleagues, and department faculty and staff for supporting me throughout this amazing experience and who were willing to participate in the study.

NOMENCLATURE

BR	Breathing Rate
BPM	Breaths per Minute
CWT	Color Word Test
HRV	Heart Rate Variability
VR	Virtual Reality

CHAPTER I

INTRODUCTION

Background

Stress has been identified by the Word Health Organization as an epidemic that has a negative impact on work productivity [17]. As a matter of fact, it is estimated to cost the American industry approximately $300 billion a year [1], not to mention that mental stress is also a leading contributor to obesity and cardiovascular disease – the leading cause of death in the developed world for the last fifteen years [6]. Due to these problems, many people have turned to techniques that help improve relaxation skills, such as deep breathing exercises, meditation, and biofeedback responses [13]. Within these techniques, biofeedback has been shown to be effective in allowing individuals to become more aware of their stressful state and voluntarily gain control over them [13]. During these biofeedback and deep breathing sessions, an individual will have the opportunity to monitor important psychophysiological measures while they are in the middle of relaxation techniques with a therapist [2]. Although this is beneficial, these type of exercises require a substantial amount of time and resources along with adhering to the strict system in order to see results [11].

To address these issues, we propose a video game application that combines the appeal of biofeedback mechanisms and wearable sensors for individuals to be able to practice relaxation techniques from the comfort of any location and time. Our methods consists of providing implicit biofeedback to the user, compared to explicitly displaying the participant's psychophysiology, through subtle changes in the game's environment based on the participant's breathing rate. By monitoring the participant's physiological signals throughout the game, we are able to adapt the game's environment to reward the participant for showing signs of being in a relaxed internal state. Using implicit biofeedback takes advantage of two aspects. First, it allows participants to focus solely on the gaming experience without being distracted about monitoring their signs and second, it encourages skill learning and transfer [13]. This allows participants to be able to regulate their breathing rate and inadvertently reduce their stress levels. In this paper, we describe prior work that has been done on game-based stress-level interventions, biofeedback implementations, and virtual reality games. We present our prototype implementation of our approach and the biofeedback mechanism that was used in this study. In addition, we describe the different factors that were considered in creating the terrain and selecting the appropriate implicit biofeedback approach. Following this, we discuss the experimental protocol, including the physiological and subjective measures taken to compare the deep breathing technique to that of the biofeedback and non-biofeedback video game. Lastly, we concluded with a thorough discussion of the experimental results, limitations of this study, and the possibilities for future work.

CHAPTER II

RELATED WORKS

Visual and Physical Intervention Games

Although videogames are generally thought of as a form of entertainment, they have shown positive outcomes when strategically used for health-related issues [7]. Various video games have been developed with the purpose of motivating patients in an engaging manner in order to be able to deal with painful or mundane procedures, which are necessary for the improvement of the patient’s health [7]. For example, Vasterling et al. [18] is able to provide a cognitive distraction through the use of video games to cancer chemotherapy patients. These studies reported that patients had lower blood pressures and less nausea after the chemotherapy when provided with such a distraction than those in the control groups who only used relaxation techniques.

Due to the popularity of video games and their engaging nature, more video games began to be tailored specifically to address different health issues [7]. As described, certain games were made with motivational intentions to effectively provide distraction from agonizing and nerve wrecking health procedures. In addition though, other video games made use of the repetitive nature of a video game to begin developing a behavioral model users could follow to practice positive health behaviors. An example of this type of model was a study from Paredes et al. [10], where a smart-phone application was created to provide an intervention when the user self-reported certain levels of stress. The mobile application took advantage of the already existing web applications and organized them into a system that provided relaxing techniques for users to manage their stress. In addition, the study consisted of a machine learning algorithm to provide a recommended intervention to that specific user based on their current situation. The results proved that participants using these recommendations and interventions developed more constructive behaviors to respond to their stress levels. Even though games are being tailored for specific health conditions, application usage on smartphones can also actually be used as indicators of stress levels [9]. Using a subject-centric behavior model, Osmani et al. [9] extracted various features from phone usage along with categorizing the numerous applications that users interacted with throughout the day to investigate the relationship of stress in the workplace through application usage. The study concluded that the behavioral model could indeed predict a user's stress levels with an "accuracy of 75% and a precision of 85.75%" [9].

Stress related health issues have also been addressed through physical game interventions. Maclean et al. [8] presented a physical wearable interface device, MoodWings, with the purpose of alerting the user beforehand if they were going to reach a stressful state level by being able to visually see the wings of a butterfly as indicators of their stress levels. The study was conducted using driving performance as the task and MoodWings demonstrated alleviation of stress levels for short periods of time. However, further investigation on MoodWings is still open considering it acted as a stressor in the specific scenario of driving, despite users reporting to be more aware of their stress level states. Hernandez et al. [5] presents another type of physical interference in a less obtrusive manner through a pressure sensitive keyboard and a capacitive mouse. This study focused on being able to distinguish between a relaxed and stressful state through physiological measurements and analyzing if people handle devices differently depending on their stress levels. The experiments conducted took in consideration two types of stress conditions that could occur: stress associated with high demands and stress associated at a more personal and subjective level due to negative memories that the user recalled. Despite the findings illustrating a lack of intensity in experimental stress compared to that of real-world situations, the results still quantified that approximately 79% of users showed an increase in typing pressure and 75% of users a larger surface contact with the mouse when under such stressful conditions.

Besides specific games being adapted to address an explicit health-concern, studies have also demonstrated the effectiveness of using everyday video games in the improvement of mood and stress conditions. Russoniello et al. [14] focused on this specific aspect by analyzing casual video games (CVG) and determining if such games could improve a participant's mood or decrease their stress levels based on physiological measurements. The authors picked three different popular games for testing: Bejeweled 2, Bookworm Adventures, and Peggle. After evaluating various biosignals to see if there were changes consistent with those of decreased stress and mood improvement, the authors concluded that their hypothesis was supported through the use of CVGs.

Biofeedback Games

Besides motivational games and different interfaces that provide flexibility and engagement with the user, researchers have also explored the area of biofeedback games in order to regulate user's stress and anxiety levels. Parnandi et al. [11] presents Chill-Out, a mobile biofeedback game that focuses on relaxation skills by analyzing a player's breathing rate. The game makes use of positive feedback to the player by penalizing a fast breathing rate by increasing the difficulty of the game and reducing the final score. As a result, the player is rewarded for focusing on slowing their breathing rate even through the stressful task. The authors were able to report that participants that played Chill-Out had indeed been able to reduce their stress levels along with being able to transfer relaxation skills better. This conclusion is indeed an interesting perspective that should be noted considering various studies have also tried examining if relaxation skills could be transferred over to other activities beyond the simple biofeedback exercise training. In a related study, Parnandi et al. [13] uses a biofeedback game to evaluate the effects on a user's physiology, including HRV, electrodermal activity, and breathing rate. Unlike a traditional biofeedback approach where users visually monitor their physiological state, this specific game adapts implicit signals of the user's biosignals forcing the user to become more engaged throughout the training. In addition, this game focuses on teaching relaxation skills while performing a stressful task in order to simulate more of a real-life experience instead of the traditional relaxation trainings where a user must find a quiet environment in order to practice relaxing. The study concluded that participants had a stronger retention rate of their relaxation skills through the use of the biofeedback game.

Similar to how video games provide visual cues for engagement with the user, other motivational methods for users have been developed through visual interfaces. Yu et al. [20] provides a primary example of such a visual interface through a metaphorical visualization that was developed to illustrate HRV. StressTree, as the tree is referred to, was designed to provide a more significant context in order to represent the HRV measurements of a user. This system would portray the HRV of a user in real time and using tree characteristics, it would grow in different directions, branch out, lose and grow leaves, and change different hues to represent growth or decay based on the beat-to-beat (RR) intervals gathered from the HRV data from the user. The evaluation of this visual interface was able to prove that users become driven to grow more healthy-looking tree and therefore, focus on regulating their breathing patterns through relaxation techniques.

Parnandi et al. [12] performed another study to evaluate the effectiveness of relaxation skill transfer when comparing game adaptations versus visual adaptations. In essence, the focus was primarily to explore an additional aspect of biofeedback and whether such feedback in game adaptations should be delivered explicitly through a visual channel or if subtle changes in the game would be more effective. The results show that biofeedback delivery through game adaptations are more effective in acquiring and transferring relaxation skills, which proves the significance of the design we have implemented.

Virtual Reality Games

Recently, researchers have explored a new tool for game adaptations in order to deliver relaxation training techniques: virtual reality (VR). VR games provide a more immersive gaming experience as participants become more active within the situational scenarios. Gromala et al. [4] uses a VR system designed to focus on chronic pain patients. The focus of the study was to provide a learning environment for these patients on the specific meditative technique of mindfulness-based stress reduction (MBSR). With the incorporation of biofeedback sensors, the method of MBSR could help users cope with reducing their stress and in return reducing their pain. The authors evaluate this type of VR intervention with the combination of MBSR and biofeedback adaptation to that of patients only using MBSR as a technique alone and conclude that the VR game adaptation proves to be more effective in reducing the perceived pain of the user. In another study, Soyka et al. [15] also focuses on VR as a relaxation technique by further exploring the visual content and interactivity that is available within the system. Throughout the investigation, it uses an artificially created underwater environment to analyze user's preference over such an immersive and engaging technique compared to that of a traditional relaxation exercise. The study is able to conclude that indeed the VR environment proved to more exciting and likely to engage participants for further use instead of a traditional deep breathing exercise.

As a result, all the research done previously have focused on game applications with difficulty levels in order to analyze the increasing states of stress on a user or provided some type of intervention in the middle of a stressful state. However, the current research we are trying to achieve is creating an ambient game where the user can easily engage in the scenery without any type of difficulties, obstacles, or time constraints while also providing implicit feedback to the user if they are in a stressful state in order to avoid interruptions within the gaming experience. Given that competitive video gaming and biofeedback show to be useful practices to relax, we believe that a non-objective game will prove to create an effective relaxation technique.

CHAPTER III

METHODS

To evaluate the effects of a non-competitive video game as a relaxation technique, we developed environments with nature scenery through the Unity 5.6 game engine platform, named EnviroScape. In this game, shown in Figure 1 to Figure 3, the player will be able to explore the different terrains presented with the only goal being to freely wander through the different environments as long as the player wishes. For this purpose, the player controls the rotation and direction in which they decide to travel. The central mechanism in trying to achieve a relaxation state while playing these video games is a negative contingency between the tool being used and the aversive outcome [12]. In other words, through the biofeedback game, the user is forced to focus on lowering their arousal levels in order to reduce the game penalty and make progress in the game. This type of stress training has been used previously used to teach self-regulation skills [12]. As a result, EnviroScape was adapted to encourage a relaxing behavior through a player's breathing rate in order to prompt the user to modify their behavioral response to stressed conditions and focusing on self-regulating their internal state.

Figure 1. Side perspective of the terrain in the biofeedback video game

Figure 2. Top perspective of the terrain in the biofeedback video game

Figure 3. Top perspective of the terrain in the non-biofeedback video game

Naturalistic Environment

The scenic environment of EnviroScape was implemented with two intentions- to drive attention away from the outside world and to focus a user's attention on their internal state. In order to divert attention from the outside world, the user needs to find the game interactive and entertaining. With competitive video games, this intensive engagement is easily adapted through a sense of accomplishment by unlocking levels, receiving prizes, gaining points, or any other form that provides the user a sense of satisfaction with their progress. However, a non-competitive video game must accomplish the same level of engagement in subtle and indirect ways that the user may not easily perceive as satisfaction. With this in consideration, the terrains developed were extensively detailed with numerous naturalistic characteristics in order to provide an immersive and enticing environment. Considering that users would be requested to compare and explore the game both with and without biofeedback, it was essential to create two similar yet distinct terrains. This would allow us to analyze their level of engagement and study the effect of biofeedback on a user's level of stress.

A variety of components needed to be analyzed in order to develop an engaging virtual environment. One aspect that was taken into consideration was cybersickness, which usually occurs after immersing in a virtual environment and has similar symptoms as motion sickness. Due to this condition, it was necessary to consider what type of movements, perspectives, directions, and rotations the user would be able to control as they wander the environment. The most basic type of movement to replicate is a walking pace, where the camera position of the screen will demonstrate a minimal bounce for every step taken by the virtual user. However, one of the issues that is caused by this type of movement is the abruptness and unstable nature of the steps, increasing cybersickness for the user as they try to wander. As a result, we considered a gliding type of movement instead, attempting to replicate a bird's perspective of motion. This provided stability in the camera's position as the user moves about rocky terrains and hilly grasslands, providing a floating feeling during their exploration. To provide a more immersive virtual environment, a first person perspective was adopted and compared with a third-person perspective. This perspective was intentionally adopted in order for the user to become a part of the game and not be an outside viewer. With the third-person perspective, it was easy for the user to feel as though they are only guiding an object's movement and hence, reduces the amount of engagement throughout the game. With a first-person perspective, we avoid this issue and provide the user a more unique experience of being able to glide through the terrain as if they were actually in it, directing themselves to move and turn as they desire. Drastic rotations or abrupt change in direction also creates a feeling of cybersickness to the videogame user. Taking advantage of the stability provided in the camera's position due to gliding motions and mimicking the movement of a flying bird, the user is able to rotate in all directions, except turn upside down. The rotation speed is set to a low value in order to simulate a gliding effect and avoid causing cybersickness. When these rotations are occurring, the screen displays an arrow key to indicate the direction in which the camera's position is slowly moving towards. These rotations are controlled through mouse movements, where moving the mouse up resembles moving upwards in the game and moving the mouse left resembles moving left in the game, and so forth. In order for the user to continue in the same direction, such as moving in a straight path, the mouse arrow would need to be kept in the center region of the game.

Another aspect that we took into consideration was the height restrictions due to the gliding simulation. Considering the user had the ability to fly at high distances, it was important to consider the implications within the terrain. High altitudes require a larger perspective for the user to visualize the terrain below. This would cause system memory issues considering that the terrain would need to span infinitely. Despite implementing an algorithm that would infinitely expand the terrain as the user wandered around the environment, it did not suffice the flying view of the user. In addition, high altitudes reduce the amount of detail the user is visually capable of seeing. This would eliminate the point of providing features with extensive details and could reduce the amount of engagement the user has with the environment. After careful consideration, a maximum height threshold was selected in order to keep the details of terrain in visible distance while providing the user with some flexibility in moving closer or farther from the ground.

With height being a controlled variable, several examinations on different terrains were made in order to select features that should be implemented throughout the expansively large terrain. Due to the same user playing both biofeedback and non-biofeedback versions of the game, two similar but distinct terrains were created for each scenario. This was necessary in order to analyze the user's engagement level throughout the duration of the game. However, if the user sees the same terrain twice, they are more likely to only spend minimal amount of time in that terrain as they have already explored it before. Hence, the two terrains were created with the idea of providing the user the desire to explore both terrains. Both terrains use similar libraries to display features such as hills, rocky areas, river effects, textures for paths and trails, forest trees, bushes, the perspective of a sunlight flare, and similar grassland flowers, as shown in Figure 4 through Figure 6.

Figure 4. Common rocky area and cave for both game environments

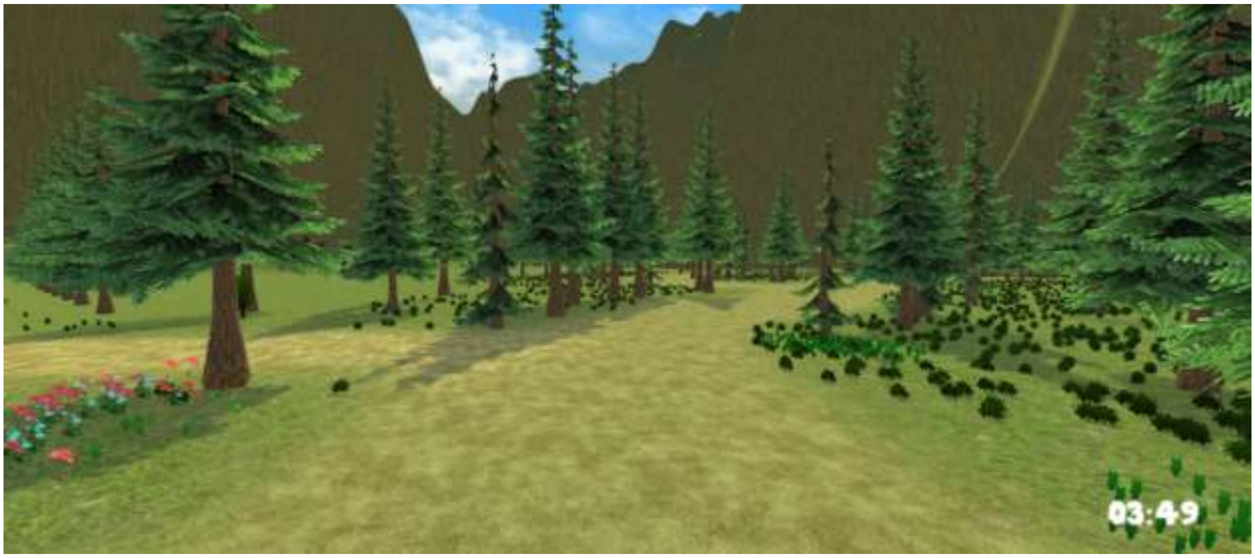

Figure 5. Common forest area and bushes for both game environments

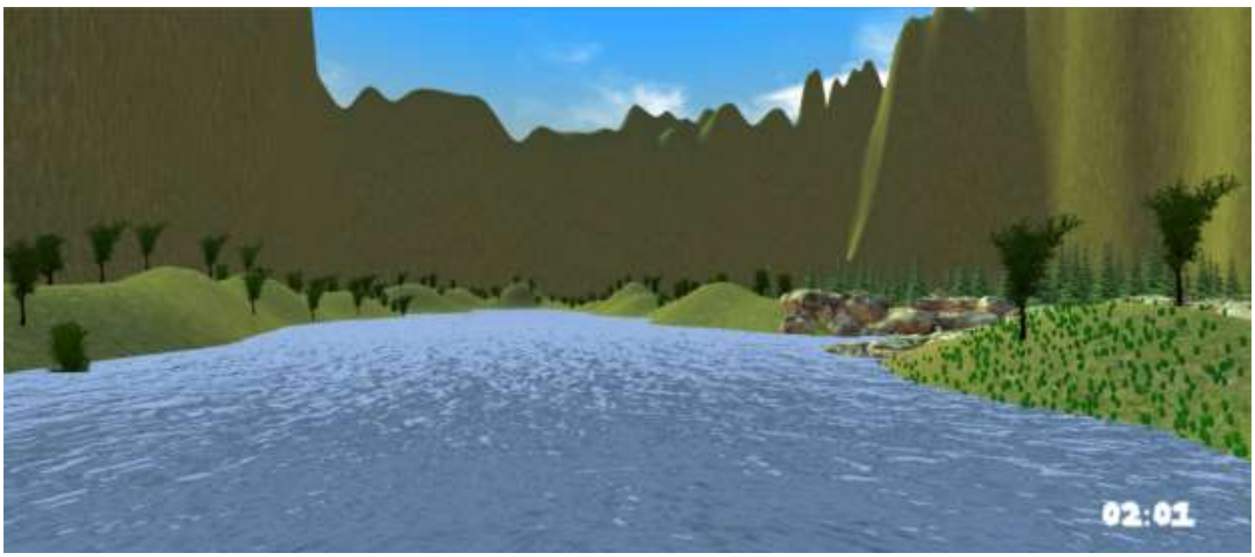

Figure 6. Common lake and river effects for both game environments

However, in addition of having different layouts, these terrains also have certain scenic features that distinguish them from each other. In the biofeedback EnviroScape game, the terrain is composed of five different areas, distinctly containing autumn trees near the main trails, shown in Figure 7, and a river bed with palm trees and canyon rocks, shown in Figure 8. In addition, the river bed has a sand-like texture along its edge and has snow-capped mountains in the background. These mountains lead beyond the river bed to a muddier path with a dense forest of pine trees.

Within the area containing autumn trees, there are various trails that lead to different areas within the terrain, including one that leads directly to a cave within the rocky hill.

Figure 7. Autumn trees in biofeedback video game

Figure 8. River bed with sand-texture and palm trees in biofeedback video game

In the non-biofeedback game, the terrain is also composed of five different areas, with the difference being that this terrain consists of a river stream with a cascade of waterfalls that eventually leads to a lake, shown in Figure 9 and Figure 10. The stream has a bridge across it with a forest path and benches on one side and rocky areas that lead to a cave on the other side.

Figure 9. Cascade of waterfalls in non-biofeedback video game

Figure 10. River stream with bridge in non-biofeedback video game

Biofeedback Mechanism in Game

Based on previous studies, the physiological variable that was decided to be used for the biofeedback in EnviroScape was breathing rate (BR). This variable is distinct in the sense that it can be voluntarily controlled by the user, as compared to other physiological variables such as heart rate variability and electrodermal activity. This provides an intuitive way for the user to reduce their stress levels considering that breathing at a rate of 6 breaths per minute maximizes the heart rate variability, which is a clear psychophysiological indicator of relaxation [12]. After selecting various specific features for the terrains and addressing some of the concerns discovered, the main component of the non-objective video game was the biofeedback mechanism. Although different methodologies could be implemented to achieve biofeedback, this specific game focusses on color contrast. Throughout the development process, aspects such as fog, weather conditions, and other physical sensors were considered, which is further analyzed in the discussion section. The purpose of the color contrast in the game is to take into consideration the user's relaxation state, described by their breathing rate per minute (BRPM). For an adult, the average BRPM ranges from 12 to 20 breaths per minute [13]. However, in a relaxed state of mind, this range drops close to 6 breaths per minute [13]. Taking this into consideration, the contrast of the game is inversely proportional to the BRPM, as shown in Figure 11. A BRPM of 6 breaths per minute allows the user to see the game in full color mode, meaning that the variation of color for the trees, the grasslands and mountains are all visually appealing. However, as the user's BRPM increases between 6 to 10 breaths per minute, the amount of color in the entire game begins to linearly fade into grayscale. As a result, if the BRPM is larger than 10 breaths per minute, the game will be completely displayed in grayscale. With this effect of fading contrast, the user is able to visually see the pace of their breathing. There are no quantitative values that alert the user to relax nor are there any paced breathing signals to follow, causing the user to focus on the change in contrast in the game to perceive awareness of their internal state. The game takes advantage of this implicit feedback in order to avoid any interruptions during the gaming experience and provides an incentive for the user to focus on maintaining a relaxed breathing rate.

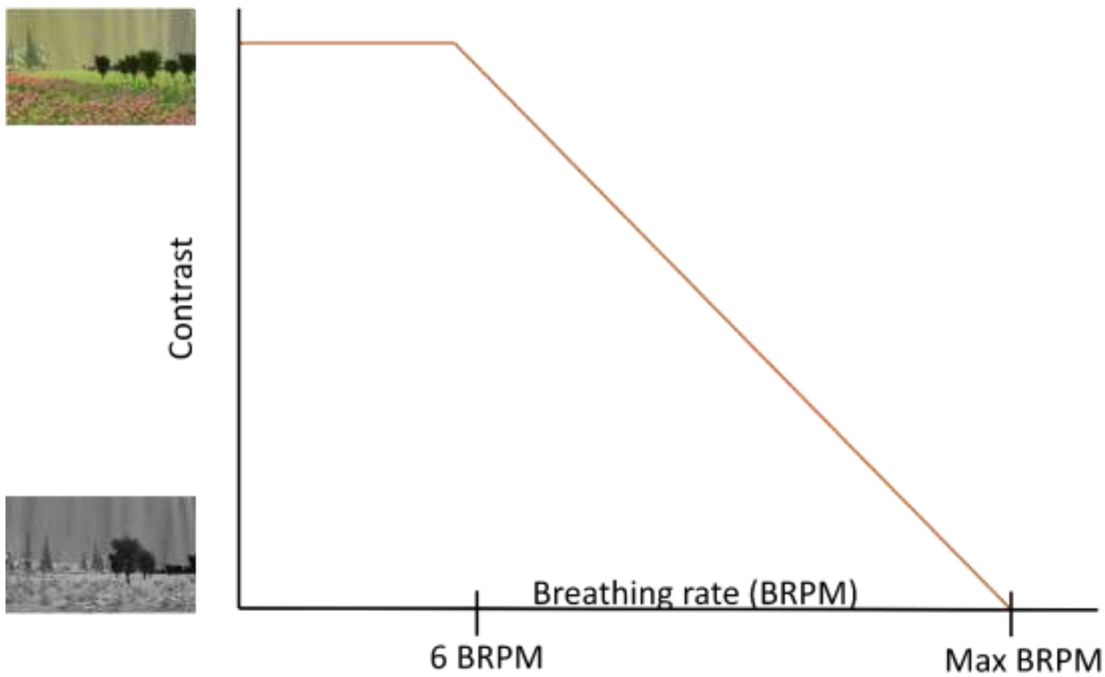

Figure 11. Relationship between contrast and breathing rate per minute

In addition to change in color contrast, the speed at which the user is traversing the game is directed by a sinusoidal equation to resemble the breathing pace signal and to maintain a consistent speed throughout the game. The breathing pace signal represents the exhaling and inhaling pattern of the user, and provides a sensation of moving forward while maintaining the speed within a specific range. The user does not have direct control over their speed, but the game does incorporate an additional increase in speed to the user if they are in a relaxed breathing state, which is less than 6 BRPM. This addition to speed is only provided when the breathing rate signal reaches the exhaling point, allowing the user to feel as they are controlling their movements in the game.

CHAPTER IV

EXPERIMENTAL DESIGN

Our work follows a within-subject study design, with each subject completing both the control and experimental blocks, in which all participants enrolled in the study perform deep breathing techniques and play both versions of the non-competitive video game, one with a biofeedback mechanism and another without biofeedback mechanism. The experiment takes place in a single session with the use of counterbalancing to avoid the introduction of ordering effects when playing the biofeedback and non-biofeedback game. Participant recruitment was done by posting flyers across campus and sending out an email through the university bulk mail system and departmental listserv email communications. The only requirement for participant selection was that they needed to be English speakers since questionnaires and surveys provided during the experiment would only be available in English. Approval from the Institutional Review Board was received prior to conducting the user study and signed consent forms are obtained from each individual participant before the session. Participants would play the video games on a Windows 10 laptop, using the Zephyr BioHarness 3.0 as the chest strap to measure breathing rate. They will use a wireless Logitech mouse instead of the mouse pad in order to avoid any confusion or unfamiliarity to the sensitivity and touch of the mouse.

Protocol

The experimental study session consists of five phases, which are summarized in Figure 12, where the task for the game application will be counterbalanced. After providing consent, the participant would complete a pre-test survey, which contains questions regarding previous experience with biofeedback techniques and meditation, as well as their current valence and arousal levels. The first phase is the baseline, where participants will have the opportunity to learn about deep breathing exercises. In this phase, the participant will follow a paced breathing signal, as shown in Figure 13 that will guide the participant to breathe at 6 breaths per minute for a duration of 5 minutes.

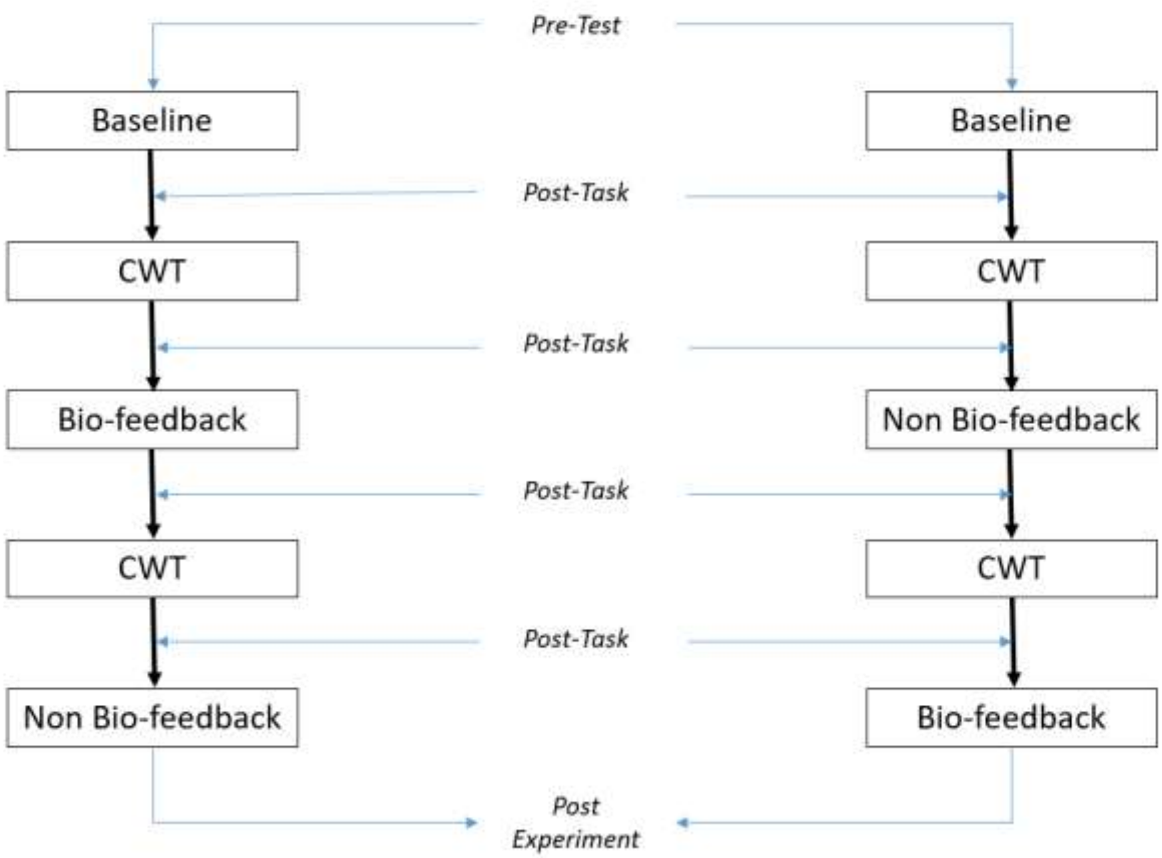

Figure 12. Summarization of experimental phases

Figure 13. Paced Breathing application for deep breathing exercise

In the second phase, the participant will be exposed to a milder stress that will be delivered through a modified Stroop Color Word Test (CWT). This task is widely used as a measure to increase arousal levels [19]. In the original CWT, participants are asked to select the ink color of a word that is displayed. The word is an actual color name printed in a different ink color, such as the one shown in Figure 14. However, in order to increase the effectiveness of the stressor, the modified CWT switches between asking ink color of the word or the text of the word and adds an annoying buzz sound every time the participant answered incorrectly or if the participant does not answer quickly. For our purposes, this phase would provide a measure of the player’s arousal levels after a mild stressor is introduced. Participants are asked to attempt to score as high as possible on the CWT and to try to breathe evenly for the entire three minute duration of the game.

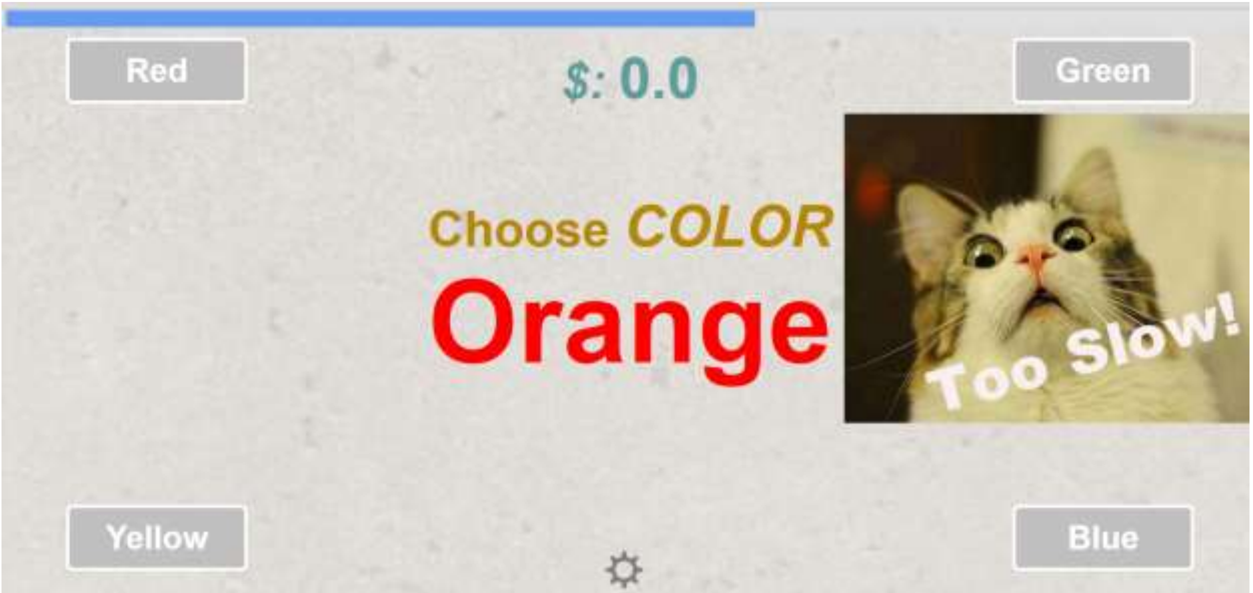

Figure 14. Modified color word test in order to serve as mild stressor

In the third phase, the participant is asked to play either the biofeedback or the non-biofeedback EnviroScape video game, where the order is randomized for each participant. If the participant began with the biofeedback game, the study staff provides an explanation of the game and the mouse controls. The participant is made aware that there are changes in color contrast based on their breathing rate and that they should try to use what they learned from the deep breathing exercise in the game to maintain the same breathing pace. They are also informed that they were required to participate in the game for at least 5 minutes but are free to ask to quit the game after that time when they feel they have finished wandering through the environment. At the end of this phase, the study staff collects the breathing rate data along with the duration of the participant in the game after the minimum five minute duration.

Following the completion of the third phase, the last two phases consists of another five minute CWT and the other treatment that has not been issued, such as the non-biofeedback game considering we counterbalance the order of these two tasks to remove any ordering effects. After the CWT from the fourth phase, the fifth phase will consist of another EnviroScape video game.

Following from the example above, if the participant started with the biofeedback game, then the fifth phase will consist of the non-biofeedback game. The participant will be aware that in this game they are once again allowed to wander as long as they wish with a minimum of 5 minutes, but there will be no color changes. They will be reminded to use what they learned from their deep breathing exercise to maintain the same breathing pace. Following the last phase, the participant will be asked to complete a post-experiment survey to analyze the participant's comparison of techniques used, the design of the biofeedback application, and which relaxation intervention (deep breathing, non-biofeedback video game, or biofeedback video game) the participant felt was most effective. In addition, between each phase a post-task survey is requested from the participant in which they are asked two main questions: their valence state and arousal state. This will help understand the changes in internal states and provide a comparison between phases.

CHAPTER V

RESULTS AND DISCUSSION

To assess the effectiveness of the biofeedback EnviroScape game, we will examine the physiological variables, the engagement levels, the valence and arousal levels self-reported, and the qualitative data from the post-experiment surveys gathered. Due to the project scope and time frame, we are currently in the process of finalizing our user studies and collecting results to provide our final conclusion. However, based on our hypothesis and the preliminary results we have analyzed, we have certain expectations of what our user study analysis would look like. When evaluating the average breathing rate for the participants, we expect that the deep breathing exercise will provide the lowest average breathing rate considering it is an explicit and guided paced signal. However, when comparing both video games, we presume that the biofeedback game will provide a much lower breathing rate average due to the subtle color change serving as a signal for the participant to focus on pacing their respiration rate. When evaluating engagement levels in the video game, we expect to prove that the biofeedback game entertains the participant for a longer amount of time after the minimum five minutes requested. Through the self-reported data, we hope to find qualitative support to these quantitative results in which the participant's level of arousal decreases to a calm state and that their survey responses favor the biofeedback game over the other two types of relaxation techniques.

Based on our preliminary results, we currently have the following data observations for one of our user study cases. As shown in Figure 15, the reported valence levels indicate that the biofeedback game has similar scale values as the deep breathing exercise, however, it shows a higher valence level compared to the non-biofeedback game. In addition, the arousal levels indicate a lower scale value for the biofeedback game as compared to the deep breathing exercise and the non-biofeedback game. In the post-experiment survey where the user describes their experience on how effective the game was and their willingness to participate in similar exercises, the user reported that the biofeedback game was more engaging and relaxing than the deep breathing exercise, as shown in Figure 16. When analyzing the breathing rates recorded during the user's session (Figures 17 to Figures 19), a trend of reduced breathing rate is observed as the game progresses over time. This indicates better awareness and control over their breathing rate. In the baseline recorded for the user's breathing rate, an average of 10 breaths per minute was observed as compared to the biofeedback and non-biofeedback games where the average was closer to 6 breaths per minute. Although these results are promising and are inclined towards our expected results, a larger user study database would be required to provide a generalized conclusion on the effectiveness of using a non-competitive biofeedback-based videogame as a relaxation technique.

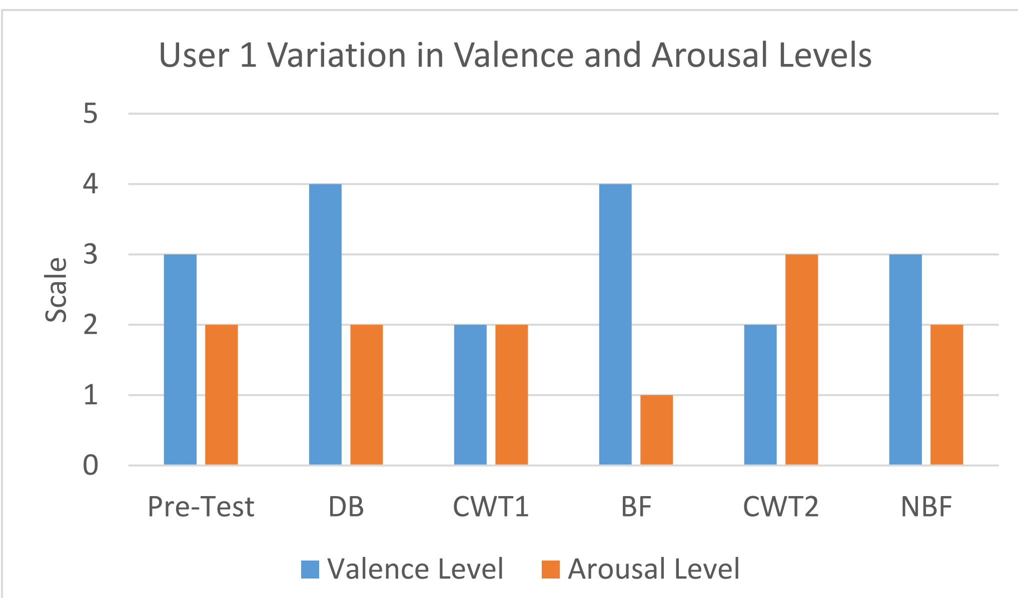

Figure 15. Valence and arousal levels for user 1

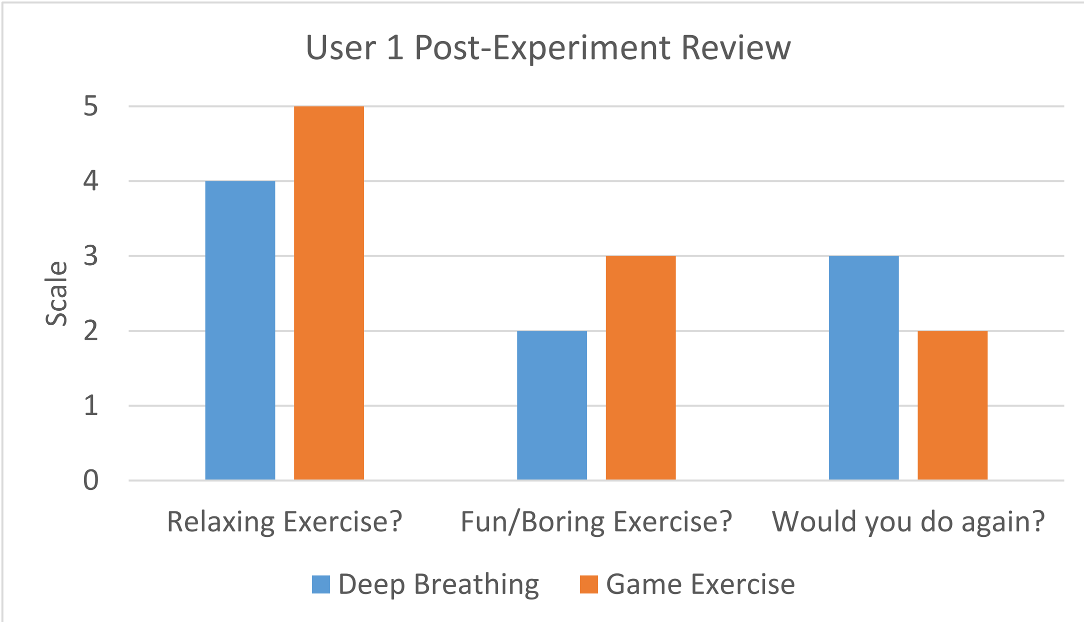

Figure 16. Post-Experiment survey review for user 1

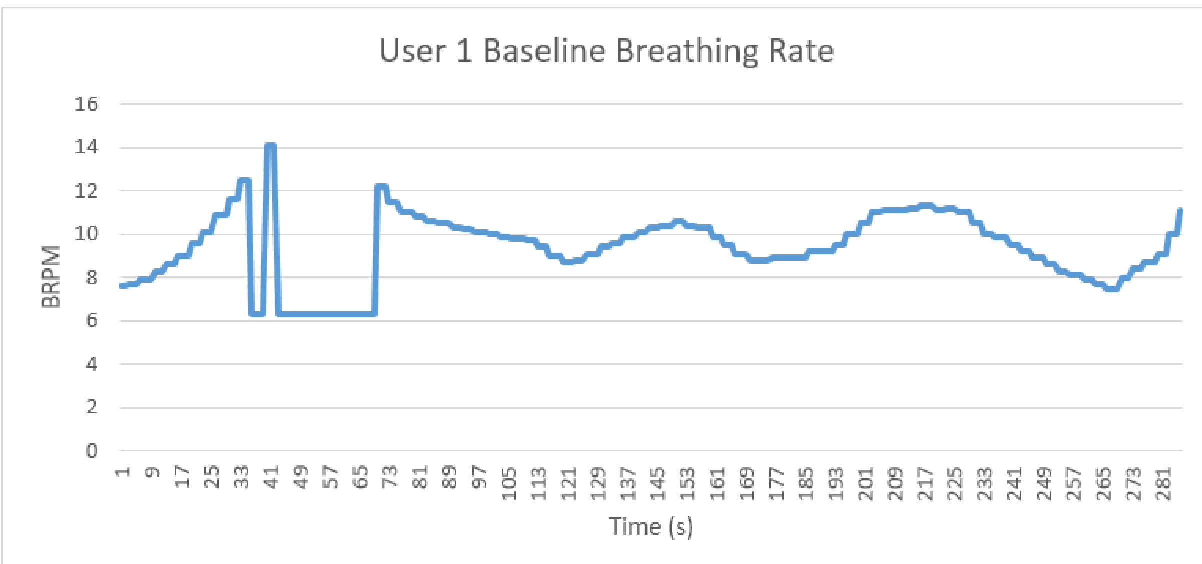

Figure 17. Baseline breathing rate for user 1

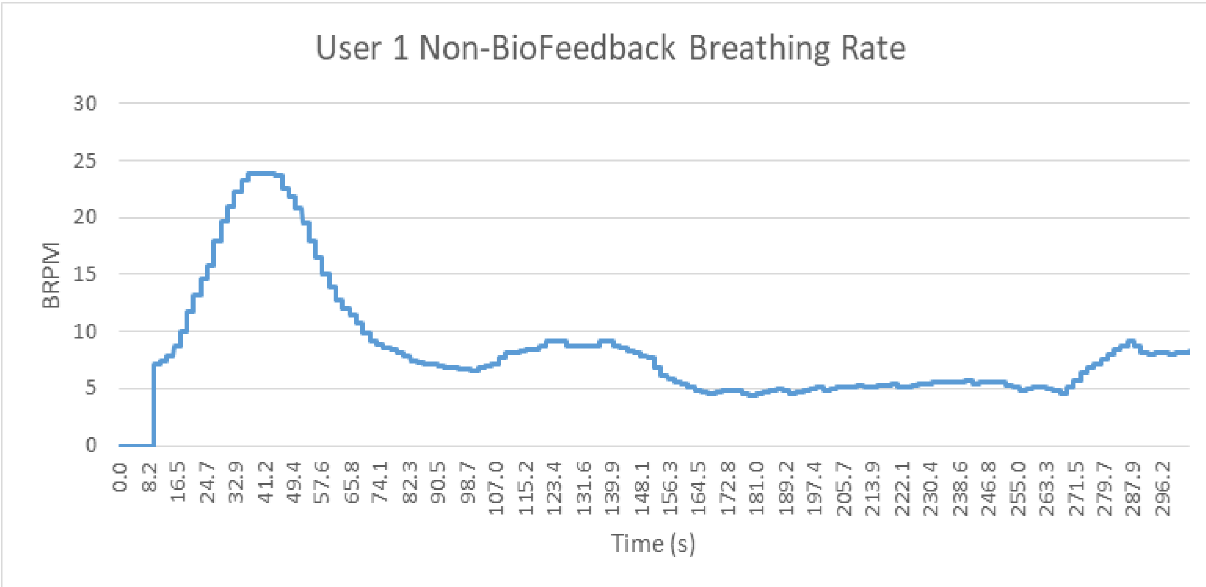

Figure 18. Non-biofeedback breathing for user 1

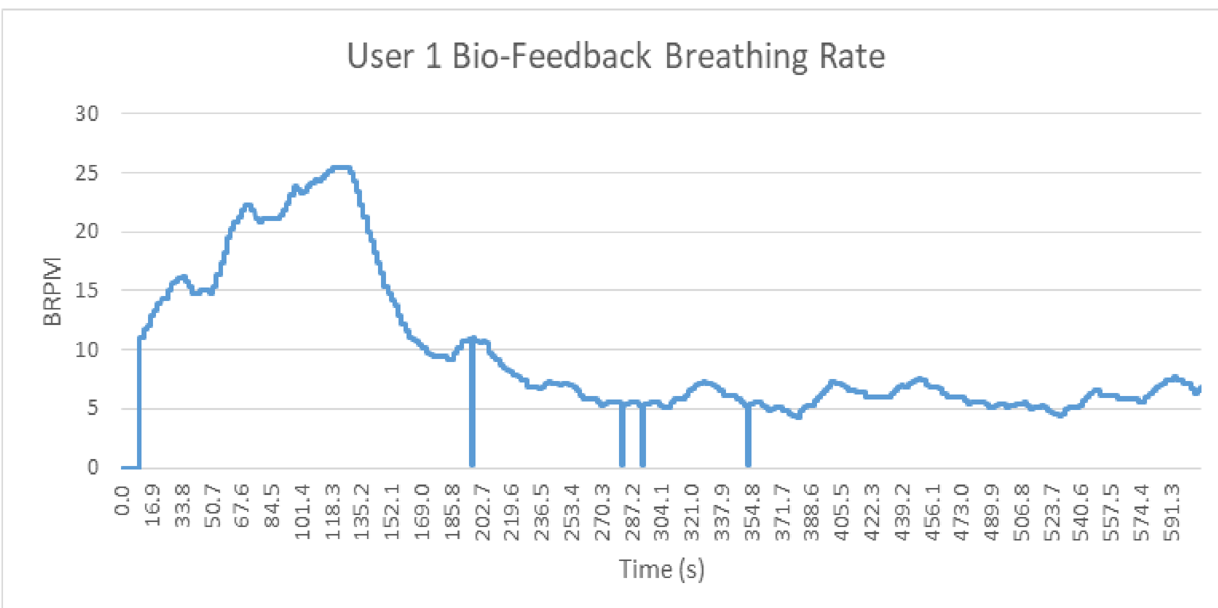

Figure 19. Biofeedback breathing rate for user 1

Limitations and Future Work

Our study has a number of limitations, including sensors that cannot always capture the complexity of real-word stress situations, short-treatment period in a lab setting, and the limited biofeedback techniques provided. Further work is needed in order to provide longer sessions or even multiple sessions over a period of time in order to analyze the effects of long-term skill transfer to recognize stress conditions. Despite investigating the user's experience in the video games developed, additional physiological measures can be taken into consideration to strongly support our claims and demonstrate the actual decrease in stress state levels. Our study was also conducted with a relatively small group of participants and within the specific population of college students. Future work would involve a larger sample size and other demographics in order to verify the results obtained.

Our study consisted of focusing on breathing rate as our physiological measures, but other parameters could have been considered, such as heart rate variability and electrodermal activity. In addition, other respiratory parameters instead of the breathing rate could have been used such as exploring the ratio of exhalation to inhalation and the effects on stress levels. Future work could focus on this ratio in order to train users to increase their ratio of exhalation to inhalation considering certain studies [16] demonstrated that it could lead to an increase in HRV. In addition to considering these measurements as signs of change in stress conditions, these additional parameters could also help in determining the type of changes incorporated in the biofeedback within the video game. Currently, there was only color contrast changes used for biofeedback that was determined through breathing rate. However, the game can be adapted to include fogginess as an indicator of rapid breathing rate or increasing stress level or even weather changes such as it becoming cloudy and stormy compared to sunny and clear skies. In our case, speed was held consistent, simulating the breathing rate as a sinusoidal signal, but it could also be adjusted to change based on the participant's actual breathing rate signal along with increasing the speed when at a relaxed state compared to decreasing the speed when in a stressful state. Our video games presented various types of terrains in one single environment, yet this could also be modified to provide multiple environments with similar terrains instead. This idea is modified from the *Flower* game application in which you can easily travel between different worlds that contain various storylines. However, each world could have a more realistic type of terrain such as an entire desert area and the next world could completely covered in snow to provide a winter environment. These additional terrains that the participant can move from one to the next will provide for that long-term effect of skill transfer that future work could focus on considering the terrains will no longer be constricted by a specific terrain size any longer. As a result, future work can focus on improving the experience within the biofeedback games to include additional measurements and expand in scope in order to study a long-term effect of relaxation skill transfer.

CHAPTER VI

CONCLUSION

The effectiveness in biofeedback games depends on a variety of factors, many of which have already been explored as demonstrated in the Related Works section. This paper explored an additional aspect of game biofeedback: whether implicit feedback is effective in being used as a relaxation technique through a non-competitive video game. Specifically, we analyzed a biofeedback non-competitive game using breathing rate as the psychological variable and its effects on valence and arousal levels and the facilitation of transferring deep-breathing skills in a short-term. After the conclusion of the user study, the results could demonstrate the significance to game developers and researchers as the biofeedback game will be able to prove a new engaging method to deliver relaxation techniques. Despite the method only being tested in a short-term effect, studies have shown that even short relaxation exercises provide a sign of positive impact. Consequently, using this implicit biofeedback method without a competitive purpose would have a long-term positive impact on the health condition of the user through the usage of the game in short periods of time, improving their quality of life overtime.

REFERENCES

[1] Bingham, Peter M., et al. "A Breath Biofeedback Computer Game for Children With Cystic Fibrosis." *Clinical Pediatrics*, vol. 49, no. 4, 2010, pp. 337–342.

[2] Choi, Jongyoon, and Ricardo Gutierrez-Osuna. "Removal of Respiratory Influences From Heart Rate Variability in Stress Monitoring." *IEEE Sensors Journal*, vol. 11, no. 11, 2011, pp. 2649–2656.

[3] Cowley, Benjamin, et al. "The Psychophysiology Primer: A Guide to Methods and a Broad Review with a Focus on Human–Computer Interaction." *Foundations and Trends® in Human–Computer Interaction*, vol. 9, no. 3-4, 2016, pp. 151–308., doi:10.1561/1100000065.

[4] Gromala, Diane, et al. "The Virtual Meditative Walk." *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI 15*, 2015, doi:10.1145/2702123.2702344.

[5] Hernandez, Javier, et al. "Under pressure: Sensing Stress of Computer Users." *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI 14*, 2014, pp. 1–11., doi:10.1145/2556288.2557165.

[6] "How Stress Affects your Health." *American Psychological Association*, American Psychological Association, www.apa.org/helpcenter/stress.aspx.

[7] Kato, Pamela M. "Video games in health care: Closing the gap." *Review of General Psychology*, vol. 14, no. 2, 2010, pp. 113–121., doi:10.1037/a0019441.

[8] Maclean, Diana, et al. "MoodWings: A Wearable Biofeedback Device for Real-Time Stress Intervention." *Proceedings of the 6th International Conference on PErvasive Technologies Related to Assistive Environments - PETRA 13*, 2013, doi:10.1145/2504335.2504406.

[9] Osmani, Venet, et al. "Smartphone app usage as a predictor of perceived stress levels at workplace." *Proceedings of the 9th International Conference on Pervasive Computing Technologies for Healthcare*, 2015, doi:10.4108/icst.pervasivehealth.2015.260192.

[10] Paredes, Pablo, et al. “PopTherapy: Coping with Stress through Pop-Culture.” *Proceedings of the 8th International Conference on Pervasive Computing Technologies for Healthcare*, 2014.

[11] Parnandi, Avinash, et al. “Chill-Out: Relaxation Training through Respiratory Biofeedback in a Mobile Casual Game.” *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering Mobile Computing, Applications, and Services*, 2014, pp. 252–260.

[12] Parnandi, Avinash, and Ricardo Gutierrez-Osuna. “Visual Biofeedback and Game Adaptation in Relaxation Skill Transfer.” *IEEE Transactions on Affective Computing*, 2017, pp. 1–15., doi:10.1109/taffc.2017.2705088. Accessed 1 Sept. 2017.

[13] Parnandi, Avinash, and Ricardo Gutierrez-Osuna. “Physiological Modalities for Relaxation Skill Transfer in Biofeedback Games.” *IEEE Journal of Biomedical and Health Informatics*, vol. 21, no. 2, 2017, pp. 361–371.

[14] Russoniello, Carmen V, et al. “The Effectiveness of Casual Video Games in Improving Mood and Decreasing Stress.” *Journal of CyberTherapy & Rehabilitation*, vol. 2, no. 1, pp. 53–66. Virtual Reality Medical Institute.

[15] Soyka, Florian, et al. “Enhancing stress management techniques using virtual reality.” *Proceedings of the ACM Symposium on Applied Perception - SAP 16*, 2016, doi:10.1145/2931002.2931017.

[16] Strauss-Blasche, G., Moser, M., Voica, M., Mcleod, D., Klammer, N., & Marktl, W. (2000). Relative Timing Of Inspiration And Expiration Affects Respiratory Sinus Arrhythmia. Clinical and Experimental Pharmacology and Physiology, 27(8), 601-606. doi:10.1046/j.1440-1681.2000.03306.x

[17] “Stress: The Health Epidemic of the 21st Century.” *Elsevier SciTechConnect*, scitechconnect.elsevier.com/stress-health-epidemic-21st-century/.

[18] Vasterling, Jennifer, et al. “Cognitive distraction and relaxation training for the control of side effects due to cancer chemotherapy.” *Journal of Behavioral Medicine*, vol. 16, no. 1, 1993, pp. 65–80., doi:10.1007/bf00844755.

[19] Stroop, J. R. (1992). Studies of interference in serial verbal reactions. Journal of Experimental Psychology: General, 121(1), 15-23. doi:10.1037//0096-3445.121.1.15

[20] Yu, Bin, et al. "StressTree:A Metaphorical Visualization for Biofeedback-Assisted Stress Management." *Proceedings of the 2017 Conference on Designing Interactive Systems - DIS 17*, *2017*, doi:10.1145/3064663.3064729.