



Faculty of Computer Science and Information Technology

**Virtual Reality and Artificial Intelligence for Acrophobia Mitigation: An Analysis of
EEG and Heart Rate Physiological Data**

Chan Chiew Mei

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Virtual Reality and Artificial Intelligence for Acrophobia Mitigation: An Analysis of EEG
and Heart Rate Physiological Data

Chan Chiew Mei

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DECLARATION

I declare that the work in this thesis was carried out by the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.



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Signature

Name: CHAN CHIEW MEI

Matric No.: 21020456

Faculty of Computer Science and Information Technology

Universiti Malaysia Sarawak

Date:16.8.2023

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ABSTRACT

The advent and subsequent proliferation of virtual reality (VR) technology have seen its application extended beyond entertainment to the medical field. One such application is in the treatment of acrophobia, a common and costly phobia that often sees patients discouraged by long waiting lists and complex treatment processes. This research evaluated the efficacy of VR and artificial intelligence (AI) in treating acrophobia, focusing specifically on the relative merits of two biophysical measurements: heart rate (HR) and electroencephalogram (EEG). Utilizing graded exposure therapy, acrophobic individuals were gradually exposed to a VR environment commensurate with their acrophobia severity level. In lieu of a traditional therapist, the severity level and corresponding exposure were determined by an AI agent using a Behavioural Avoidance Test (BAT). This AI agent was also programmed to provide tasks and encouragement to the user in the VR environment. This approach not only negates the safety risks typically associated with exposure therapy but also provides an immersive and realistic environment through high-resolution graphics across seven different height environments. Inclusion and exclusion criteria, as well as the severity of acrophobia, were determined using the Visual Height Intolerance Severity Scale (vHISS). Post-therapy fear levels were measured using the Attitudes Towards Heights Questionnaires (ATHQ). Findings were analysed using the Mann-Whitney U test to check for significant differences between the two biophysical measurements. Results showed no significant difference between heart rate (HR) and electroencephalogram (EEG) measurements in gauging fear response during VR therapy. The utilization of VR and AI in treating acrophobia remains promising. The ATHQ score decrease highlights VR and AI's potential for effective acrophobia therapy, offering immersive

experiences to improve outcomes. Future research should aim to replicate these findings in a sample size that exceeds the current one and encompasses greater demographic diversity, thus enhancing the generalizability of these results.

Keywords: Virtual reality, artificial intelligence, acrophobia, biophysical measurement.

***Realiti Maya (VR) dan Kepintaran Buatan (AI) untuk Pengurangan Acrophobia: Analisis
Data Fisiologi EEG dan Kadar Jantung***

ABSTRAK

Kemunculan dan percambahan teknologi realiti maya (VR) yang seterusnya telah menyaksikan aplikasinya melangkaui hiburan kepada bidang perubatan. Satu aplikasi sedemikian adalah dalam rawatan acrophobia, fobia biasa dan mahal yang sering melihat pesakit tidak digalakkan oleh senarai menunggu yang panjang dan proses rawatan yang kompleks. Penyelidikan ini menilai keberkesanan VR dan kecerdasan buatan (AI) dalam merawat acrophobia, memfokuskan secara khusus pada merit relatif dua pengukuran biofizikal: denyutan jantung (HR) dan electroencephalogram (EEG). Dengan menggunakan terapi pendedahan berperingkat, individu acrophobic secara beransur-ansur terdedah kepada persekitaran VR yang sepadan dengan tahap keterukan akrofobia mereka. Sebagai ganti kepada ahli terapi tradisional, tahap keterukan dan pendedahan yang sepadan ditentukan oleh ejen AI menggunakan Ujian Pengelakan Tingkah Laku (BAT). Ejen AI ini juga telah diprogramkan untuk menyediakan tugas dan galakan kepada pengguna dalam persekitaran VR. Pendekatan ini bukan sahaja menafikan risiko keselamatan yang biasanya dikaitkan dengan terapi pendedahan tetapi juga menyediakan persekitaran yang mengasyikkan dan realistik melalui grafik resolusi tinggi merentas tujuh persekitaran ketinggian yang berbeza. Kriteria kemasukan dan pengecualian, serta keterukan akrofobia, ditentukan menggunakan Skala Keterukan Intoleransi Ketinggian Visual (vHISS). Tahap ketakutan selepas terapi diukur menggunakan Soal Selidik Sikap Terhadap Ketinggian (ATHQ). Dapatan dianalisis menggunakan ujian Mann-Whitney U untuk menyemak perbezaan yang ketara antara kedua-dua ukuran biofizikal.

Keputusan menunjukkan tiada perbezaan yang signifikan antara pengukuran kadar denyutan jantung (HR) dan electroencephalogram (EEG) dalam mengukur tindak balas ketakutan semasa terapi VR. Penggunaan VR dan AI dalam merawat acrophobia masih menjanjikan. Penurunan skor ATHQ menyerlahkan potensi VR dan AI untuk terapi akrofobia yang berkesan, menawarkan pengalaman mendalam untuk meningkatkan hasil. Penyelidikan masa depan harus bertujuan untuk meniru penemuan ini dalam saiz sampel yang melebihi saiz semasa dan merangkumi kepelbagaian demografi yang lebih besar, sekali gus meningkatkan kebolehgeneralisasian keputusan ini.

Kata kunci: *Realiti maya, kecerdasan buatan, acrophobia, pengukuran biofizikal.*

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ATHQ	Attitude Toward Height Questionnaire
AVA	Artificial Virtual Agent
BAT	Behavioural Avoidance Task
EEG	Electroencephalogram
HR	Heart Rate
vHISS	Visual Height Intolerance Severity Scale
VR	Virtual Reality

CHAPTER 1

INTRODUCTION

1.1 Study Background

Virtual reality (VR) and artificial intelligence (AI) have evolved into an undeniable and integral part of contemporary existence. The combination of VR and AI has also been utilized in various therapies (Maples-Keller et al., 2017). Nearly 5% of people worldwide suffer from acrophobia, or a fear of heights, as it is a natural environmental phobia (Misiewicz et al., 2016). Acrophobia would bring different levels of anxiety and symptoms to individuals. A case study done by Juan and Pérez (2009) on a comparison of the levels of anxiety in the acrophobic environment via the head-mounted display (HMD) and Cave Automatic Virtual Environment (CAVE) showed that both visualization systems would provoke anxiety. The case study had proven that the use of a VR environment would provoke acrophobia as in a real environment. Numerous anxiety symptoms exist, encompassing perspiration, rapid heartbeat, panic, and more. Different types of methods are used to measure the anxiety level of acrophobia. The Acrophobia Questionnaire-Anxiety Subscale (AQ-Anxiety) (Cohen, 1977), a self-report questionnaire comprising 20 items is the most widely used in various studies. This questionnaire prompts participants to evaluate their anxiety levels in situations involving heights. This extensively employed tool effectively gauges height-related fears and demonstrates commendable psychometric attributes (Baker et al., 1973). VR provides a safe environment for those who want to treat their fear. In this research, the graded exposure virtual therapy approach was used. The immersive VR environment enables users to experience a sense of complete involvement, making them feel integrated into the environment. In the virtual world, the implementation of

an artificial virtual agent (AVA) would present to inform and guide patients through the therapy. Tielman et al. (2017) successfully built a virtual agent for offering a novel type of home therapy to assist post-traumatic stress disorder (PTSD) patients. An AVA in this graded exposure therapy environment is a type of task-giving agent which guides the user in the virtual world and gives encouragement to the user while the user reaches some point of the task. On the other hand, human biophysical data have been used in virtual therapy to detect an individual's fear level (Bălan et al., 2020a). While virtual therapy, through tools like AVAs, has shown promise in treating various phobias and disorders, the combination of biophysical data provides a novel avenue for a more personalized therapeutic approach (Bălan et al., 2020b). The potential of integrating biophysical measurements with AVAs in a VR environment offers a unique opportunity to enhance the effectiveness of therapy sessions, especially for individuals suffering from acrophobia. Therefore, the focus should be on creating a VR environment with an AI core AVA for evaluating the most suitable choice of biophysical measurement to combat acrophobia.

1.2 Problem Statement

Acrophobia, characterized by a fear of heights in one's surroundings, poses a significant challenge for individuals. Exposure therapy stands out as the primary treatment method for acrophobia, with various severity levels often categorized through questionnaires. Utilizing VR to simulate exposure therapy of reality-like environments offers a promising avenue for safely addressing acrophobia. The field of Artificial Intelligence (AI) was formally founded in the year 1956 (McCarthy et al., 1956) and has already been around for over six decades years. AI systems, akin to the human mind, can learn from data and make predictions, presenting an opportunity to provide real-time coping strategies for acrophobic individuals.

Fear can interrupt processes in the human brain's decision-making abilities (Louise, 2016). In the case of individuals with acrophobia, their ability to cope diminishes when they experience a state of fear. The loss of coping ability may cause a lack of balance and a loss of the ability to deal with difficult situations. The utilization of biophysical measurements can effectively detect the user's fear, while the artificial intelligence virtual agent (AVA) in the VR environment can suggest an appropriate height for the user to experience through the behavioural avoidance task (BAT) (Steketee et al., 1996). The artificial virtual agent (AVA) would provide suggestions such as "take a deep breath", "look up to the sky", "stand still", and more in the system to make decisions based on data input. Therefore, the assistance of an (AVA) would have the ability to provide suggestions while the participants are in a fear state.

The integration of virtual reality (VR) environments with artificial intelligence virtual agents (AVA) presents a promising approach to address acrophobia. The AVA's ability to offer instant, calming suggestions during moments of heightened fear could be revolutionary in therapeutic contexts. Previous researchers have employed various biophysical measurements, including heart rate and electroencephalogram (EEG), among others. However, the optimal choice of biophysical measurements to effectively combat acrophobia in such environments remains unclear.

While biophysical data such as heart rate and EEG are commonly used, it was essential to ascertain whether one measurement is more suitable than the other, or if both are equally effective in aiding acrophobia therapy.

Given the challenges in determining the optimal choice of biophysical measurements, the following research questions are proposed:

- What are the differences between heart rate and EEG measurements in combating acrophobia within a VR environment with an artificial intelligence virtual agent (AVA)?
- Which biophysical measurement—heart rate or EEG—is more suitable for effectively combating acrophobia in a VR environment with an artificial intelligence virtual agent (AVA)?

1.3 Aim and Objectives

The study aims to evaluate a suitable choice of biophysical measurement for combating acrophobia in a VR environment with an artificial intelligence virtual agent (AVA).

The specific objectives of the study are as follows:

- i. To investigate and evaluate different biophysical measurements, specifically HR and EEG, in detecting the fear level of the individuals.
- ii. To design and implement the VR environment with artificial agents and assess participants' fear levels using biophysical data (HR and EEG).
- iii. To evaluate the effectiveness of the developed VR exposure therapy in mitigating acrophobia.

1.4 Hypothesis

Null Hypothesis (H_0): There is no significant difference in the participants' attitude toward height as measured by the Attitude Toward Height Questionnaire (ATHQ) result when comparing HR measurement with EEG measurement.

Alternative Hypothesis (H₁): There is a significant difference in the participants' attitude toward height as measured by the Attitude Toward Height Questionnaire (ATHQ) result when comparing HR measurement with EEG measurement.

1.5 Study Methodologies

Figure 1.1 shows the methodologies phase for this study.

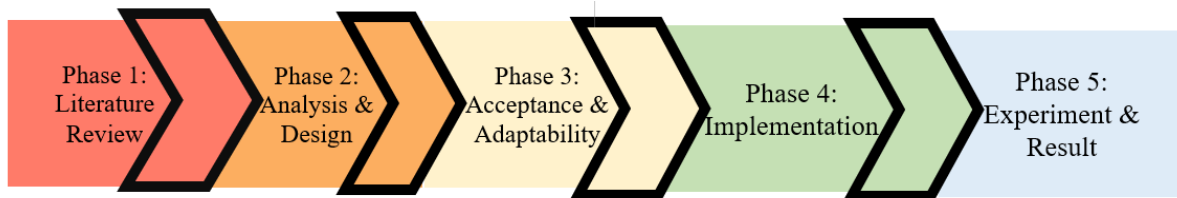


Figure 1.1: Methodologies Phase for this Study

From Figure 1.1 there are five phases for this study methodology which are literature review, analysis and design, acceptance and adaptability, implementation and lastly the experiment and result. Each phase is constructed continuously throughout this study as outlined below:

(A)Literature review:

- Review various methods for detecting individuals' fear levels.
- Consult research papers and articles for background information.
- Gather valuable information and methods for assessing fear levels.
- Explore biophysical and perceived methods for detecting fear.
- Review the utilization of self-report questionnaires to subjectively assess fear levels.

- Examine commonly used questionnaires to determine their effectiveness in measuring perceived fear.

(B) Analysis and design:

- Utilize validated scales to quantify the severity of acrophobia symptoms.
- Administer the acrophobia Questionnaire to assess anxiety levels specific to heights.
- Randomly select participants with diverse acrophobia severity levels and ensure demographic diversity to enhance result generalizability.
- Develop a VR environment with varied height scenarios.
- Develop the AVA (artificial virtual agent) to provide real-time guidance and support.

(C) Acceptance and adaptability

- Design AVA to predict suitable height levels.
- Ensure a friendly AVA model.
- Ensure accurate height level prediction and high-resolution graphics.
- Address safety concerns for example absence of falling scenarios.
- Design user-friendly VR environment controls.
- Develop therapy as an Android application compatible with various versions.
- Use high-quality VR equipment for a realistic experience.

(D) Implementation:

- Successfully implement a virtual reality environment.
- Ensure individuals with acrophobia experience suitable height levels.
- Verify the correct functioning of AVA for level prediction, task assignment, and encouragement.

(E) Experiment and result

- Obtain informed consent from all participants before participation in the study.
- Ensure confidentiality and anonymity of participant data.
- Adhere to ethical guidelines for research involving human subjects, including protection from harm and voluntary participation.
- Collect biophysical data and perceived fear data.
- Utilize appropriate statistical tests to compare differences in fear responses between biophysical measurements and self-report questionnaires.

1.6 Scope of the Study

This research is confined to a VR environment with an AI-powered AVA application and the collection of various biophysical data from individuals with acrophobia. The study is delimited by age, excluding participants under 18 years old and those older than 55 years old. A consent form is provided to inform participants, ensuring they carefully consider their decision to participate, understand the research information, and confirm their understanding and agreement by signing the consent form. Participant information remains confidential. The research excludes individuals with no history of fear of heights, regular medication use, sudden illness, and claustrophobia. Additionally, the investigation does not include the assessment of acrophobia recurrence.

The scope of this research focuses on evaluating a suitable choice of biophysical measurement for combating acrophobia in a VR environment with an artificial intelligence virtual agent (AVA). The study aims to develop different levels of a VR environment with an AVA for participants to use in exposure treatment. Participants with acrophobia are divided into

3 groups (low, medium, and high) based on their acrophobia level using the Visual Height Intolerance Severity Scale (vHISS) by Huppert et al. (2017). Each group and each type of biophysical measurement (heart rate (HR) and electroencephalogram (EEG)) include at least two participants. Thus, this study targeted twelve males or females who suffered from acrophobia.

To evaluate a suitable choice of biophysical measurement for combating acrophobia and the therapy's performance, the experiment results, including questionnaire sessions and each level of height exposure experienced by the participants, are recorded. The experiment results are analyzed using the Mann-Whitney U test to check for significant differences between the biophysical measurements. This analysis aims to evaluate a suitable choice of biophysical measurement for combating acrophobia. Additionally, the results are assessed using the Attitudes Towards Height Questionnaires (ATHQ) by Abelson and Curtis (1989) after participants experience virtual therapy. The ATHQ questionnaires gauge the present fear of the participant after each experiment, evaluating the therapy's dependability on different levels of acrophobia.

Figure 1.2 illustrates the research structure through a flowchart. It begins with participant recruitment, followed by data collection using the Visual Height Intolerance Severity Scale (vHISS) to confirm acrophobia and categorize participants into severity groups. Participants are then randomly assigned to different biophysical measurement types for Graded Exposure Virtual Reality Therapy. Finally, Attitude toward Height Questionnaire (ATHQ) scores are collected for Mann-Whitney U test analysis.

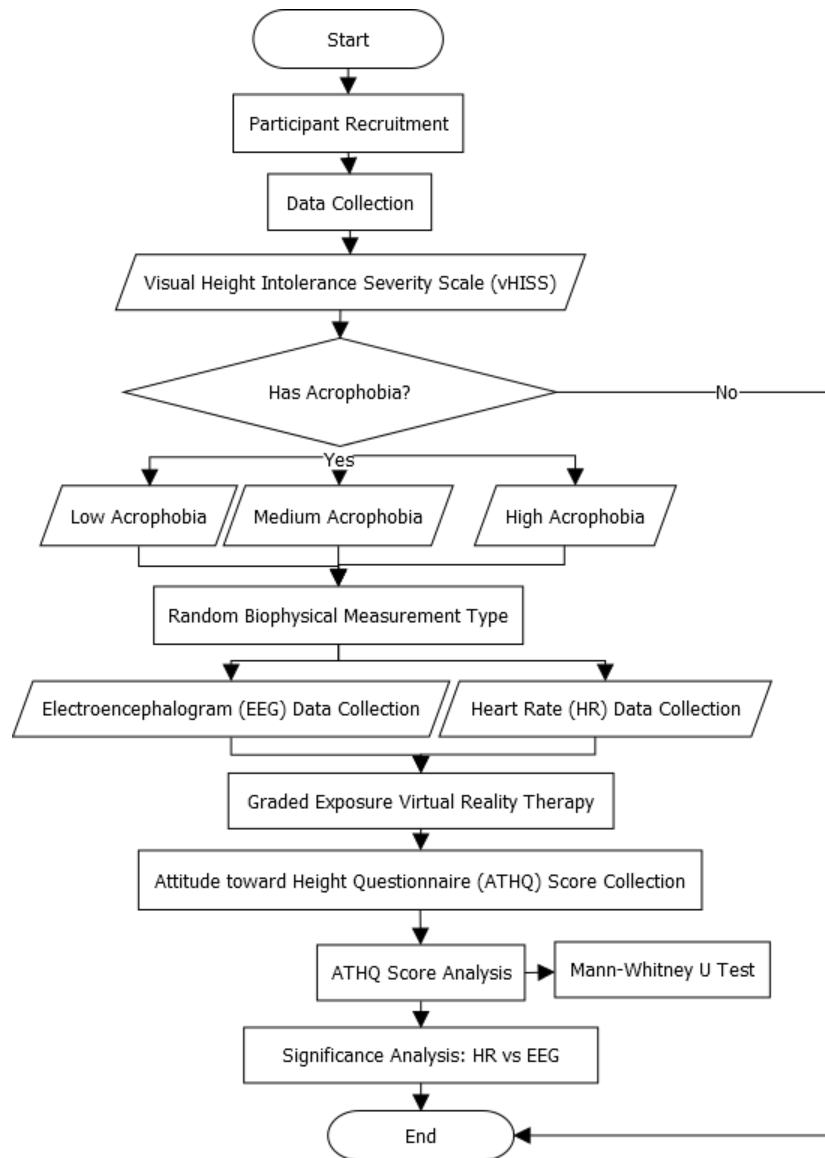


Figure 1.2: Flowchart of the Research Structure

1.7 Significance of Study

VR environment therapy with different modelling height levels can combat acrophobic individuals' fear. Instead of attending exposure therapy in real life, the use of virtual reality would not cause any safety issues for the individuals. The use of biophysical measurement can accurately detect the user's fear and AVA in the VR environment can suggest the user a suitable

height to experience through the behavioural avoidance task (BAT) (Steketee et al., 1996). This is more efficient instead of waiting for a suggestion from the therapist. Throughout the experience of the virtual reality environment, acrophobic individuals will adapt to the situation inside the virtual reality environment. The conclusion of study by Gallagher et al. (2013) highlights the potential for adaptation from virtual reality (VR) environments to real-world tasks. To investigate whether there is a potentially significant difference arising from diverse biophysical measurements during acrophobia therapy, the study employs the Mann-Whitney U test. This test aims to investigate significant distinctions in ATHQ results among various biophysical measurements and determine the most appropriate choice for acrophobia treatment.

1.8 Summary

In Chapter 1, the study's scope is defined, and the anticipated outcome is established. Utilizing this study scope, the expected result is to identify the most suitable choice of biophysical measurement using AI to combat acrophobia in a VR environment.

CHAPTER 2

BACKGROUND STUDY

2.1 Introduction

This chapter provides an in-depth exploration of the background and fundamental terminologies of the utilization of a virtual reality environment and artificial intelligence in combating acrophobia. All the information presented in this chapter is derived from published research. Additionally, this chapter examines the model method and classification related to the intersection of virtual reality, artificial intelligence, and acrophobia. Furthermore, the necessary tools required to successfully conduct this study are identified.

2.2 Virtual Reality and Acrophobia with Biophysical Measurement

A preliminary search was done to identify the research related to the keywords: virtual reality, acrophobia, biophysical measurement and artificial intelligence. A simple search was done through Google Scholar, Elsevier and Scopus, and 55 pieces of research were found related to acrophobia and virtual reality. The inclusion criteria for this study were (1) research study related to acrophobia, virtual reality, biophysical measurement and artificial intelligence; (2) type of acrophobia treatment and biophysical instrument; (3) no restriction to date. The exclusion criteria were (1) a study of acrophobia virtual reality treatment with no data extracted; (2) No biophysical instrument and artificial intelligence included. After the inclusion and exclusion criteria, among the 55 pieces of research, 9 of them are relevant to virtual reality, acrophobia, biophysical measurement and artificial intelligence. Sections 2.3.1 to 2.3.9 will briefly explain the objective, virtual reality, method, biophysical measurements used and the key findings of thesis research studies.

2.2.1 An Investigation of Various Machine and Deep Learning Techniques Applied in Automatic Fear Level Detection and Acrophobia Virtual Therapy.

The research by researchers Bălan et al. in the year 2020a aimed to develop a VR game with machine learning-based decision support to adapt the levels of exposure to the patient's physiological characteristics. The virtual reality (VR) environment used was a cityscape with tall buildings. The researchers utilized real-time recording of Heart Rate (HR), Galvanic Skin Response (GSR), and Electroencephalogram (EEG) data and analysed it by comparing the data before and during the test. Various machine learning and deep learning classifiers were used, including Support Vector Machine (SVM), k-Nearest Neighbours (kNN), Linear Discriminant Analysis (LDA), Random Forest (RF), and four deep neural network architectural models. The performance of each machine learning type was evaluated based on classification accuracy, referring to a review of emotion recognition techniques using physiological signals. As a result, the deep learning model achieved the highest accuracy for player-independent modality, while the support vector machine performed best for player-dependent modality in fear detection.

2.2.2 eTher – An Assistive Virtual Agent for Acrophobia Therapy in Virtual Reality.

This was another research conducted by researchers Bălan et al. in the year 2020b to implement and validate eTher, which is an assistive virtual agent for acrophobia therapy in a virtual reality environment. The virtual reality (VR) environment used featured a mountain landscape with cable car rides as the sole mode of transportation. Ten subjects were included, each with their user profile (name, age, level of acrophobia), and baseline HR and GSR measurements were taken before the game started. Photoplethysmography signals were also recorded. Biophysical signals, including Galvanic Skin Response (GSR) and Heart Rate (HR),

were continuously recorded during each game level. A virtual agent with a female voice was provided to keep the user in a comfort zone. The user's anxiety level was detected using GSR and HR, referencing a therapy plan library. Situations 1 through 4 were conditions where the GSR colour was either green and the HR colour was either green or yellow. In situation 1 the GSR colour was green and the HR colour was green, the GSR colour was green and the HR colour was yellow, the GSR colour was yellow and the HR colour was green and in situation 4 GSR colour was yellow and the HR colour was yellow. In all these situations, both GSR colour and HR colour indicated that the user was relaxed or rather relaxed, allowing them to proceed to the next game level. As a result, the most frequent situation was situation 1 (44%), denoted by green, indicating the user's relaxed state. This was followed by situation 2 (21%) and situation 3 (17%), as well as situations 1 to 4 in the green to yellow-zone, indicating that the user was relaxed and could proceed to the next game level. Paired sample T-tests were conducted, revealing a reduction in GSR and HR after therapy. The designed model, eTher, successfully comforted the acrophobia subjects, and the VR agent therapist is expected to be a cost-effective solution for combating acrophobia compared to traditional therapy.

2.2.3 Classifying the Levels of Fear by Means of Machine Learning Techniques and VR in a Holonic-Based System for Treating Phobias.

The research conducted by researchers Bălan et al. in the year 2020c aimed to implement and evaluate a VR-based system for treating phobias, simulating stress-provoking real-world situations while monitoring physiological signals. The virtual reality (VR) environment used featured a cityscape with buildings of varying heights. Four subjects were included in the study. Biophysical data (EEG, GSR, and HR) were recorded alongside the Subjective Unit of Distress

(SUD) value, representing the current level of fear perceived by the patients. The experiment consisted of four stages: baseline, pre-treatment, treatment, and post-treatment, conducted over six consecutive days. Users were instructed to play the Virtual Reality game three times, with the task of collecting virtual coins within the VR environment. Each time a user collected a coin, a virtual panel appeared, prompting them to report their perceived level of fear (SUD). The system was developed using the Unity game engine, employing a holonic-based architecture. Biophysical data was also recorded during the exposure. The level of fear decreased after the VR-based treatment sessions. The research demonstrates the feasibility of a holonic-based system for diagnosing and treating phobias.

2.2.4 Using Machine Learning to Regulate Intensity of Immersion Therapy Treatment of Phobias Through Vital Feedback.

This research was conducted by the sole author, researcher Beauchamp, in the year 2020. It aimed to investigate whether machine learning, when combined with exposure therapy, has a strong synergistic effect that enhances the efficiency and effectiveness of treatment. Biophysical data, such as heart rate, blood pressure, and galvanic skin response, were collected. The research consisted of two main parts: a test course (a simple course with gradually more acrophobia-triggering scenarios) and a training course (which utilized the machine learning model trained earlier to generate a dynamic virtual reality scene). The training course featured similar scenarios to the testing course, but the height of those scenarios was adjusted dynamically by the machine learning model. The trained model generated the buildings on which participants would stand. This was achieved by generating buildings with random x, y, and z dimensions and recording the subjects' average fear levels over 30 seconds. The buildings were generated

based on a subject's ECG. The machine learning model's performance with the ECG input yielded a fear level validation accuracy of 85.27%, with a training accuracy of 85.93%. As a result, a strong correlation was found between ECG and heart rate with fear levels, sufficient to create a dynamic environment for immersion therapy for acrophobia. This novel VR approach for acrophobia therapy, where building dimensions adapt to the patient's fear levels, holds promise. It suggests that combining machine learning and exposure therapy can significantly enhance treatment effectiveness for acrophobia.

2.2.5 A Serious VR Game for Acrophobia Therapy in an Urban Environment

This research was conducted by researchers Anton et al. in 2020 to prototype a method that allows exposure therapy to be conducted in a controlled environment, in a more comfortable, quick, and cost-effective manner. The virtual reality (VR) environment used featured a city landscape. Participants completed the Heights Interpretation Questionnaire, Visual Height Intolerance Severity Scale, and Acrophobia Questionnaire, and were divided into three groups (low, medium, and high). Subjects rated their perceived level of fear during the trial using the acrophobia questionnaire. User biophysical data of Galvanic Skin Response (GSR) and Heart Rate (HR) in a resting baseline position and during gameplay were collected. Each subject played the VR game twice. The therapy VR game aims to expose people to heights in an urban environment with the player's goal to reach the top of a building. The player is required to answer a short questionnaire and a mathematical quiz before heading towards the stairs and beginning their trip. The mathematical quiz aims to distract the user from the game by activating his/her logical thinking and deactivating the emotional hemisphere. In conclusion, all users agreed that the game is intuitive and helpful for relieving anxiety.

2.2.6 A Machine Learning Approach to Automatic Phobia Therapy with Virtual Reality.

This research was conducted by researchers Bălan et al. in the year 2021 to introduce a novel approach to using an intelligent virtual therapist that recognizes human emotions based on biophysical signals. The virtual reality (VR) environment used featured a mountain landscape. Participants completed the Heights Interpretation Questionnaire, Visual Height Intolerance Severity Scale, and Acrophobia Questionnaire, and were divided into three groups (low, medium, and high). The system was evaluated through a comparison of several machine learning and deep learning techniques using data from the DEAP database. These techniques were used to classify the six basic emotions (sadness, happiness, disgust, anger, fear, and surprise) into two groups (positive and negative) using four classical machine learning techniques (Support Vector Machine, Linear Discriminant Analysis, Random Forest and k-Nearest Neighbours). Both machine learning and deep learning models were trained and cross-validated. Fear was classified in two ways: a binary 2-level paradigm (0-no fear, 1-fear) and a 4-level paradigm (0-no fear, 1-low fear, 2-medium fear, 3-high fear). An unsupervised K-means clustering algorithm was applied to the data, achieving an accuracy of 87%. The system incorporated two classifiers, C1 (to determine the patient's current fear level) and C2 (to estimate the next exposure scenario). Biophysical data, including Galvanic Skin Response (GSR), Heart Rate (HR), and Electroencephalogram (EEG), were collected from subjects who were exposed to heights at different levels (1, 4, and 6 floors of a building). Subjects rated their perceived level of fear during the trial. The system automatically adapted exposure scenarios according to the user's fear level. Each subject played the VR game twice, with each session consisting of 10 trials. Two models were used to assess classifier accuracy: user-dependent and user-independent. In the user-dependent modality, the classifier was trained and tested on the same subject's

recordings, while in the user-independent modality, it was trained on data from all participants and tested on the current subject's recordings. As a result, high cross-validation accuracy was achieved on the training set, with good test accuracies ranging from 42.5% to 89.5%. The C2 classifier, with the parameter called target fear level, played a crucial role and had a high importance index. It was selected for all three fear estimation scales, both in the user-dependent and user-independent modalities. This VR-based therapy adapts to users' fear levels with an artificial intelligence method. It holds the potential for personalized and effective acrophobia treatment.

2.2.7 Application of Big Data and VR Technology in the Treatment of Acrophobia

This research was conducted by researchers Wang et al. in the year 2022 and aimed to explore the application status of big data and virtual reality technology in the treatment of acrophobia. The virtual reality (VR) environments used included a single wooden bridge in the air, a cliff, and a tall building. Experimenter electroencephalogram (EEG) and heart rate data were collected during and before the test. The experimenter was required to fill in the high-response questionnaire before the therapy. The experimenter used a brain wave instrument and a VR helmet to experiment with Scene 1 for 3 minutes. Then, the experimental group underwent training in Scene 2 and Scene 3: twice a day, every three days, with each training session lasting 3 minutes and a 5-minute interval between experiments. Once the experimenter was stable in Scene 2, they transitioned to Scene 3 to repeat the experiment. After achieving stability in Scene 3, the experimenter returned to Scene 1 for another 3-minute session. In conclusion, the research shows that virtual reality exposure therapy (VRET) has strong safety.

2.2.8 Electroencephalography Correlates of Fear of Heights in a Virtual Reality Environment

This research is conducted by researcher Apicella et al. in the year 2023. They utilized an electroencephalography (EEG)--based classification system to evaluate three levels of fear of heights. Subjects underwent exposure to fear-inducing stimuli within a virtual reality (VR) environment representing a canyon, with intensity gradually escalating. Using an elevating platform, participants accessed three different height levels. Initial assessments of fear severity were conducted using the Acrophobia Questionnaire (AQ) and the Subjective Unit of Distress (SUD) scores. Eight subjects took part in three experimental sessions, during which EEG signals were recorded using a 32-channel headset. The analysis primarily focused on identifying the EEG bands and scalp regions most affected. The gamma and high-beta bands, particularly in the frontal scalp area, emerged as the most significant. For the three-class fear classification task, an average accuracy of $(68.20 \pm 11.60) \%$ was achieved using absolute powers across five EEG bands. In conclusion, the fear of heights was successfully detected using the EEG-based classification system.

2.3 Current Limitations

The current limitation faced in investigating the use of VR therapy is the prediction of the patient's fear level in the exposure environment. The literature review did not indicate a specific biophysical measurement that is most suitable for predicting the patient's fear level. Selecting an appropriate method for predicting fear can reduce development costs and simplify the treatment process. An accurate prediction by the therapist plays a crucial role in alleviating the patient's anxiety when they face a fearful situation. In virtual therapy, the therapist cannot

physically assist patients in the VR environment by providing encouragement or guidance. Boeldt et al. (2019) mentioned that when therapists cannot control exposure therapy, it may pose a risk of sensitizing the patient and worsening anxiety. Therefore, the implementation of a virtual therapist or AI virtual agent (AVA) to control exposure therapy becomes essential. A promising approach to simplify therapy involves combining VR with AVA to predict suitable exposure levels for patients. Thus, there is a need for a VR environment with an AI virtual agent that can assist in evaluating the most suitable choice of biophysical measurements for combating acrophobia.

2.4 Acrophobia Anxiety

Acrophobia, a common and extreme fear of heights, falls under the category of natural environment phobias as defined by the Guze (1995). Natural environment phobias encompass specific fears related to particular situations such as heights, storms, or darkness. Studies have shown that the prevalence of natural environment phobias is higher in females, with a prevalence rate of 17.4%, compared to 8.5% in males (Fredrikson et al., 1996). Kapfhammer et al. (2014) found that Visual height intolerance (vHI), related to acrophobia, has a lifetime prevalence of 28.5% (32.4% in women, 24.5% in men), while general acrophobia prevalence ranges from 3% to 5%. Acrophobia affects a significant portion of the population, with at least one individual out of every 20 adults experiencing this fear. This highlights the common nature of acrophobia and emphasizes the need for serious attention and effective treatment. Furthermore, the prevalence of this fear tends to increase with age (Fredrikson et al., 1996).

Acrophobia can manifest in individuals with varying levels of anxiety and associated symptoms, including panic attacks, anxiety, and a compromised ability to make decisions. It

significantly distresses and interferes with a person's life (Antony and Rowa, 2007). Acrophobia is characterized by a range of symptoms, including sweating, abdominal discomfort, loss of balance or light-headedness, heart palpitations, restlessness or pacing, tremors or shakiness, nervousness, feeling scared, weakness in the knees, tightness in the chest, and overall feelings of tension (Hodges et al., 1995). These symptoms can provoke emotional distress, significantly impacting an individual's daily life. The emotional distress experienced by individuals with acrophobia not only affects their own lives but also has an impact on their friends and family. For example, a study by Andrews (2007) reported cases where a father's fear of his son falling led to him grabbing his son to prevent him from going to high places. Additionally, emotional distress, such as self-imagination of danger in high places, can consume an individual's attention and cause concern among bystanders. Acrophobia is closely linked to higher rates of coexisting anxiety and depressive disorders (Huppert et al., 2020).

Acrophobia is not only a psychological issue but also a perceptual one. Individuals with acrophobia who confront their fear in public settings may experience emotions of awkwardness, and prolonged suffering can affect their psychological and emotional management abilities. Acrophobia is a treatable condition, and professional therapists recommend suitable therapies for its management. In severe cases, a combination of cognitive-behavioural therapy and psychopharmacological treatment has shown substantial symptom improvement and increased ability to engage in activities involving heights (Kapfhammer et al., 2014). However, most individuals with acrophobia struggle to overcome their fear without external assistance (Andrews, 2007).

VR has emerged as a promising tool for treating acrophobia, and its potential has been further enhanced through the integration of AI in various therapeutic applications (Maples-Keller et al., 2017). A case study conducted by Juan and Pérez in 2009 compared anxiety levels in acrophobic environments using a head-mounted display (HMD) and Cave Automatic Virtual Environment (CAVE). The study revealed that both visualization systems provoked anxiety. It demonstrated that virtual reality environments could induce acrophobia just like real-world settings, leading to various anxiety symptoms, including sweating, rapid heartbeat, and panic. These symptoms can greatly hinder a person's capacity to participate in everyday activities, like going on high balconies for scenic views, flying on aeroplanes, or even looking out from tall buildings.

Taking a comprehensive approach to mitigating acrophobia is crucial. Before the therapy starts, categorizing acrophobia individuals' severity level is important. Understanding individual differences helps us understand some of the most basic differences within humans (Jackson, 2009). Several methods exist for measuring the anxiety levels of individuals with acrophobia. The most widely used is the Acrophobia Questionnaire-Anxiety Subscale (AQ-Anxiety), introduced by Cohen in 1977. This 20-item self-report questionnaire assesses participants' anxiety related to height-relevant situations and has shown good psychometric properties (Baker et al., 1973). Another method for measuring anxiety in acrophobia is the Visual Height Intolerance Severity Scale (vHISS), introduced by Huppert et al. in 2017. This questionnaire provides a concise way to quantify the severity of individuals' acrophobia on a metric interval scale ranging from 0 to 13. Researchers like Bălan et al. (2020a), Beauchamp (2020), and Hu et al. (2020) have used this method in their studies, helping categorize individuals into different

levels of acrophobia (low, medium, or high). Visual Height Intolerance Severity Scale (vHISS) by Huppert et al. in 2017 was selected due to its ability to provide a continuous quantification of acrophobia severity on an interval scale from 0 to 13. Above mention questionnaire categorised acrophobic individuals into variations of high, medium, and low levels of acrophobia. The granularity of vHISS could capture variations in acrophobia making it a preferred choice in the study for categorizing acrophobia severity.

To assess the impact of various biophysical measurements on acrophobic individuals' attitudes toward height environments and determine the most suitable measurement for acrophobia treatment, both subjective fear and physiological arousal of heights must be considered. The research conducted by Hang et al. (2022) indicates significant alterations in brain regions such as the orbitofrontal cortex, medial prefrontal cortex, and visual areas in individuals with acrophobia. Researcher Wang et al. (2021) evaluated the effectiveness of using EEG on acrophobia and concluded that the community structures of certain cerebral cortex regions could be used to identify the degree of acrophobia. These findings suggest that biophysical signals, including those measured by EEG, play a crucial role in reflecting fear in acrophobia. Identifying these regions may lead to the development of targeted interventions and preventive strategies for acrophobia. To gauge an individual's current fear of heights more directly, the Attitudes Toward Heights Questionnaire (ATHQ) by Abelson and Curtis (1989) is employed. ATHQ consists of six items that assess feelings toward height, including 'Good/Bad,' 'Comfort/Terrible,' 'Pleasant/Unpleasant,' 'Safe/Dangerous,' 'Non-threatening/Threatening,' and 'Harmless/Harmful.' It provides a score to gauge an individual's emotional response to height experiences.

Furthermore, to assess acrophobic individuals' instant anxiety level for the AVA to suggest exposure levels to various severity level users, the Behavioural Avoidance Test (BAT) (Steketee et al., 1996) is built in the VR environment. The BAT allows observers to assess an individual's fear by observing how far they can approach a feared situation. A BAT test observes an individual approach to a feared situation until he or she is unable to go further with their physical symptoms like heart rate and other variables measured (Sam, 2013).

2.5 Type of Biophysical Measurement of Fear

The details of the biophysical measurements utilized in the research discussed in sections 2.2.1 to 2.2.8 are outlined in Table 2.1. This table systematically lists each specific type of biophysical measurement, alongside the relevant year and the frequency of its usage.

Table 2.1: Biophysical Measurement Included in Research with Year and Used Frequency

Type of measurement Year	Heart Rate (HR)	Skin Conductance Response (SCR)	Electroencephalogram (EEG)	Electrocardiogram (ECG)
2017	1	1		
2018	1	1	2	
2019	1	1		
2020	2	2	3	1
2021	1	1		
2022	1			
2023			3	
Total	7	6	9	1

As documented in Table 2.1, the frequency of each type of biophysical measurement used from the year 2017 to 2023 in the intersecting fields of artificial intelligence, acrophobia, and virtual reality is recorded. Amongst the biophysical measurements employed for assessing acrophobia, electroencephalogram (EEG) and heart rate (HR) were most frequently utilized, followed by skin conductance response (SCR) and Electrocardiogram (ECG).

The aforementioned biophysical measurements reveal that the two most frequently used are the electroencephalogram (EEG) and heart rate (HR). Specifically, the EEG has found substantial application in research related to acrophobia AND virtual reality AND artificial intelligence. It has been employed nine times between the years 2018 and 2023. The EEG works by attaching sensor electrodes to the scalp, enabling the recording of the brain's electrical activity. These EEG signals are crucial for identifying various emotions such as fear, disgust, and happiness (Wioleta, 2013). Utilizing EEG recordings in a VR environment has proven beneficial for patients dealing with fear. This approach allows therapists to understand and analyse patients' reactions and emotions in the virtual world, where direct control or assistance is not feasible.

The heart rate (HR) stands as a pivotal biophysical data point for objectively assessing human fear. Between the years 2017 and 2023, HR analysis was employed seven times in research studies aimed at detecting the fear of heights. This consistent use underscores its reliability and effectiveness in assessing fear responses. The effect of the heart rate on the perception of fear was correlated with individual differences in anxiety levels (Garfinkel et al., 2014). The research done by Bălan et.al in the year 2021 used the blood volume pulse (BVP) as the method of measuring the heart rate for detecting the subject's fear of their phobia therapy.

Thus, as a more convenient way of combating acrophobia, the use of heart rate would simplify the way of combating it. The heartbeat detection accuracy is generally taken to be a stable constitutional trait of the individual.

These two types of biophysical measurements were included in this research and compared on their effectiveness in detecting the fear of the test subject.

2.6 Artificial Virtual Agent (AVA)

The integration of AI in mental health treatment holds the potential to improve the efficiency and effectiveness of therapies. Artificial Intelligence (AI) encompasses various techniques, including machine learning, neural networks, and expert systems, that enable computer systems or algorithms to perform tasks that traditionally require human intelligence, such as learning, problem-solving, perception, and decision-making. Deep learning techniques, for instance, employ multiple layers to extract higher-level features from raw data input (Galván and Mooney, 2021). AI has been applied to decision-making processes in numerous studies, with researcher Silver et al. (2016) using deep neural networks and tree search algorithms for decision-making in the game of Go. AI is particularly adept at analysing data, recognizing patterns, facilitating decision-making, and interacting with human intelligence. In the field of mental health treatment, AI is employed for data analysis from various sources, self-report questionnaires, and electronic health records, and aiding in personal assessment and diagnosis of mental health conditions. Predictive analytics and risk assessment are areas where AI excels. For example, natural language processing and machine learning techniques have been utilized to identify mental health signals in Twitter data, which can be especially beneficial for capturing data on rarer disorders (Coppersmith et al., 2014). AI has also been utilized as chatbots and

virtual therapists, with a study by Fitzpatrick et al. (2017) demonstrating that a fully automated conversational agent, Woebot, resulted in 4 significant reductions in symptoms of anxiety and depression among participants. Multiple studies have highlighted the effectiveness, engagement, and acceptance of AI as a virtual therapist.

In acrophobia therapy, incorporating AI can overcome the limitations of traditional therapy. Machine learning can automate the task of building analytical models and performing cognitive tasks (Janiesch et al., 2021). By utilizing AI, the system can automatically detect fear levels and recommend an appropriate level of exposure for the subject. Artificial virtual agents (AVA) can be employed to motivate and assign tasks to individuals. In acrophobia therapy, the role of the therapist's encouragement and supervision is crucial. Therefore, the inclusion of AI in the VR environment plays a significant role as a therapist in therapy. The benefits of the inclusion of AVA can be concluded as below:

- i. Assists individuals by providing real-time feedback on their progress in the virtual reality (VR) environment, indicating how high or far they have travelled.
- ii. Accompanies users throughout therapy sessions, offering encouragement and interactive support within the VR world.
- iii. Assigns tasks to users during exposure sessions, allowing them to complete therapy independently without the need for constant therapist supervision.
- iv. Adjusts the therapy level based on individuals' fear levels, using interactive communication to personalize the experience for each user.

By utilizing AI as a core of an artificial virtual agent (AVA) the system can automatically detect fear levels and recommend an appropriate level of exposure for the subject. AVA can be

employed as a therapist to motivate and assign tasks to individuals. In summary, the integration of AI in mental health treatment holds the potential to improve the efficiency and effectiveness of therapies.

2.7 Current Treatment Approaches

Acrophobia varies in severity, and therapists must assess the level of severity in each individual to determine the most suitable therapeutic approach. Acrophobia primarily arises from sensory experiences, causing significant levels of discomfort and fear, even in individuals who are typically calm (Coelho and Wallis, 2010). There are several treatment approaches used to address acrophobia, including Virtual Reality Therapy (VRT), Desensitization Therapy, In Vivo Exposure Therapy, Graded Exposure Therapy and more. All therapy involves gradually exposing individuals to real-life situations or environments that trigger their fear. Traditional therapies involving real-life height exposure can be risky for acrophobic individuals. Acrophobia therapy provides repeated and controlled exposure, allowing individuals to learn that their fear response is not justified and that they can cope with the situation without significant harm.

The limitations of the traditional approach include limited access to appropriate settings in real life, safety concerns when exposing individuals to heights, and the time-consuming and challenging nature of generalizing fear reduction in a limited environment. Firstly, finding suitable real-life situations or environments that trigger the fear of heights can be challenging. To provoke fear in different individuals, various environments such as tall buildings, bridges, or other elevated structures may be needed. However, not all of these environments are readily available or easily replicable for different height-related situations. Next, safety is a significant

concern for acrophobic individuals during exposure sessions. Some phobia individuals may be unwilling to voluntarily expose themselves to the stimuli they fear (Öst, 1989), or they may drop out of exposure treatment due to low acceptance of in vivo exposure (Choy et al, 2007). Ensuring the safety of individuals is crucial, as different individuals may experience symptoms of acrophobia differently, including anxiety, dizziness, and a feeling of weakness in the knees (Hodges et al., 1995). These symptoms can pose significant risks to individuals, so proper precautions and supervision are necessary. Additionally, the traditional approach is time-consuming and requires the availability of specific locations or scheduling therapy sessions, making it less flexible for individuals. Research indicates that there is often a gap of over ten years between the onset of symptoms and the first therapy session attended by individuals (Dingemans et al., 2001). It may also be challenging to generalize fear reduction achieved in one specific environment to other height-related situations.

Despite these limitations, traditional therapy remains a valuable and widely used treatment. These limitations can be addressed by combining new therapies, like Virtual Reality Therapy, to improve safety and tailor treatment. The research conducted by Bentz et al. (2021), which utilizes a smartphone-based, stand-alone virtual reality exposure app, demonstrates significant improvements in acrophobia. With its low costs and accessibility, they have shown that the combination of VR does help in enhancing traditional therapy, serving as a valuable adjunct to existing mental health care services. Integrating new therapies and tailoring treatments can overcome traditional therapy limitations, providing more effective interventions for acrophobia.

2.8 Virtual Reality (VR) Exposure Therapy

The virtual reality (VR) approach has gained popularity in treating various phobias, including acrophobia, agoraphobia, and fear of public speaking environments. Research has demonstrated the effectiveness of virtual reality exposure therapy in addressing the fear of heights (LeBeau et al., 2010). Virtual reality offers a safe and controlled environment for individuals seeking treatment for their fears. Wearing a head-mounted display can enhance immersion in the virtual world and trigger anxiety symptoms similar to those experienced in real-life situations. Importantly, the VR environment allows users to exit the virtual world if they cannot handle the anxiety or if unexpected situations arise, ensuring that the therapy remains under control. Furthermore, virtual reality therapy is not limited to solitary experiences. In the virtual world, virtual agents can be implemented to inform and guide users through the therapy process. In 2017, Tielman et al. successfully created a virtual agent for a novel type of home therapy for post-traumatic stress disorder (PTSD). Additionally, researchers such as Bălan et al. (2020b) have developed virtual agents, such as the female avatar named eTher, for acrophobia therapy in virtual reality.

In vivo, exposure therapy involves real-life exposure to height-related situations, while graded exposure therapy enables individuals to gradually confront their fear at their own pace. All these therapy approaches focus on addressing the fear of heights through exposure to suitable environments. Studies have shown that VRT is equally effective as in vivo exposure therapy in reducing fear and avoidance behaviours, as demonstrated by an analysis conducted by Powers and Emmelkamp in 2008. Additionally, a study by Botella et al. (2017) compared VRT, in vivo therapy, and a combined approach (VRT followed by in vivo exposure), revealing that the

combined approach yielded the most significant improvements in fear reduction. In several treatment approaches, graded exposure virtual reality therapy is utilized. Graded exposure virtual reality therapy uses VR to simulate height-related situations with customized exposure levels, while Graded Exposure Therapy helps individuals confront their fear gradually.

The presence of a virtual reality environment with a VR therapist can indeed provide valuable encouragement and personalized guidance to patients during their treatment. This enhancement significantly contributes to the overall effectiveness of combating acrophobia when utilizing virtual reality therapy.

2.9 Scenarios Modelled

There were different types of scenarios being used in various research for AI-assisted acrophobia therapy. These scenarios are shown in Table 2.2. The environment built in the virtual therapy was mostly a city view and a mountain landscape. The city view is an environment that people are used to in daily life, thus the selection of city landscapes in virtual reality was developed. The selection of mountain landscapes is to provide a relaxing environment for users. Nature views can lower stress hormones and reduce feelings of depression (Edward-Elmhurst Health, 2020). Thus, both scenarios were developed in this study.

Table 2.2: Type of Scenarios Being Used in Various Research

Scene	Source
Mountain landscape with cable car rides	Bălan.O, Cristea.S, Moise.G, Petrescu.L, Ivaşcu.S, Moldoveanu.A, Moldoveanu.F., & Leordeanu.M. (2020).
A cityscape and a tall building with terraces and balconies.	Bălan, O., Moise, G., Moldoveanu, A., Moldoveanu, F., & Leordeanu, M. (2018).
A mountain landscape	Bălan, O., Moldoveanu, A., Alin.M & Leordeanu, M. (2021).
City buildings with different heights (the first, fourth and sixth floors of a building)	Bălan, O., Moise, G., Moldoveanu, A., Moldoveanu, F., & Leordeanu. (2020).
City view with high buildings	Bălan, O., Moise, G., Moldoveanu, A., Leordeanu, M., & Moldoveanu, F. (2020).
The atrium of a large ten-story office complex.	Freeman, D., Haselton, P., Freeman, J., Spanlang, B., Kishore, S., Albery, E., ... Nickless, A. (2018).
Cable car, ski lift and walking route	Bălan O., Cristea.S, Moldoveanu.A, Moise.G, Leordeanu.M, Moldoveanu.F. (2019).
City view on a wood plank on high buildings.	Hu, F., Wang, H., Chen, J., & Gong, J. (2018).
A busy city surrounded by tall buildings	Beauchamp, M. (2020).
A snow mountain landscape with elevator taking, cliff diving, heli-skiing, and rooftop walking.	Hong, Y.-J., Kim, H. E., Jung, Y. H., Kyeong, S., & Kim, J.-J. (2017).

2.10 Mann-Whitney U test

The Mann-Whitney U test, introduced by Mann and Whitney in 1947, is a nonparametric statistical test used to assess whether there is a statistically significant difference between two independent groups based on their ordinal or continuous data. In this study, the Mann-Whitney U test is employed to examine the differences between two independent groups of biophysical instruments with their Attitude Toward Height Questionnaire (ATHQ) results. The test involves

ranking all data points from both groups and comparing these ranks to determine if a significant difference exists in the distributions of the two groups. In the Mann-Whitney U test, the expected sum of ranks under the null hypothesis is used to calculate the U statistic. This U statistic is then compared to critical values from the Mann-Whitney U distribution or used to calculate a p-value. If the U statistic is greater than or equal to the critical value (or if the p-value is greater than the chosen significance level, e.g., 0.05), then the null hypothesis is not rejected, suggesting no significant difference between the two groups. On the other hand, if the U statistic is less than the critical value (or if the p-value is less than the chosen significance level), then the null hypothesis is rejected, indicating a significant difference between the groups. Mann-Whitney U test is a non-parametric test and does not assume any specific distribution of the data, allowing it to accommodate unequal sample sizes in the research. Below is the formula for calculating the U value of the Mann-Whitney U test. The smaller U_1 and U_2 is the test statistic for the Mann-Whitney U Test, which is indicated by U.

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \quad \text{Equation 2.1}$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2 \quad \text{Equation 2.2}$$

n_1 = Number of individuals in group 1

n_2 = Number of individuals in group 2

R_1 = Sum of Ranks of Group 1

R_2 = Sum of Ranks of Group 2

U_1 = U value of group 1

U_2 = U value of group 2

This analysis will help to determine the most suitable choice of biophysical measurements for addressing acrophobia and evaluating the effectiveness of the therapy.

2.11 Summary

In summary, traditional approaches to acrophobia treatment face several critical challenges, including limited accessibility to real-life exposure settings, safety concerns during exposure sessions, time constraints, and difficulties in generalizing fear reduction across different environments. By leveraging virtual environments, VR approaches provide a safe, accessible, and flexible platform for exposure therapy, allowing for personalized and adaptive treatment tailored to individual fear levels and responses. These challenges can be addressed through virtual reality therapy, which enables patients to automate therapy sessions themselves. Although biophysical measurements are commonly used to assess fear in research, none have conclusively determined which measurement is the most suitable. To address this gap, a virtual reality-based approach integrating biophysical measurements and AVA offers a promising solution for identifying suitable biophysical measurements for mitigating acrophobia. The proposed solution utilises the Mann-Whitney U test to analyse the ATHQ results alongside biophysical measurements, aiming to determine the most suitable biophysical measurement for acrophobia.

CHAPTER 3

DESIGN AND DEVELOPMENT OF VR SOLUTION

3.1 Introduction

This chapter will present the workflow pipeline and its various stages. In the previous chapter, the study's direction was outlined, which is to assess the most appropriate biophysical measurement for addressing acrophobia through the use of virtual reality and artificial intelligence. The virtual reality environment will be designed to accommodate individuals with varying levels of acrophobia by providing different height levels to experience. An AVA will recommend specific levels based on the user's fear level. This chapter will provide an overview of the virtual reality environment system, the input data pipeline within the workflow, and the methodology for evaluating the research results.

3.2 Design and Development

The VR environment was designed using the Unity game engine. It included seven different height levels: 1, 10, 20, 40, 60, 100, and 220 meters. It contained both city and mountain views. An AVA was developed within the VR environment. The AVA supported test subjects by assigning tasks and providing encouragement. It predicted the appropriate height level for individuals based on their BAT results automatically. Individuals' heart rate (HR) and Electroencephalogram (EEG) were monitored to confirm their fear state. The severity of acrophobia in individuals was measured using the Visual Height Intolerance Severity Scale (vHISS) developed by Huppert et al. (2017) and categorized the individuals into different categories (low, medium, high). Subjective fear levels were assessed using the Attitudes Towards Height Questionnaires (ATHQ) by Abelson and Curtis (1989). Based on the findings

of a study conducted by Hong et al. (2017), the results indicated a discordance between subjective fear and physiological arousal. Therefore, it was essential to consider both results in investigating their relationships. Figure 3.1 illustrates the use case diagram of the exposure therapy virtual reality system with an artificial intelligence agent.

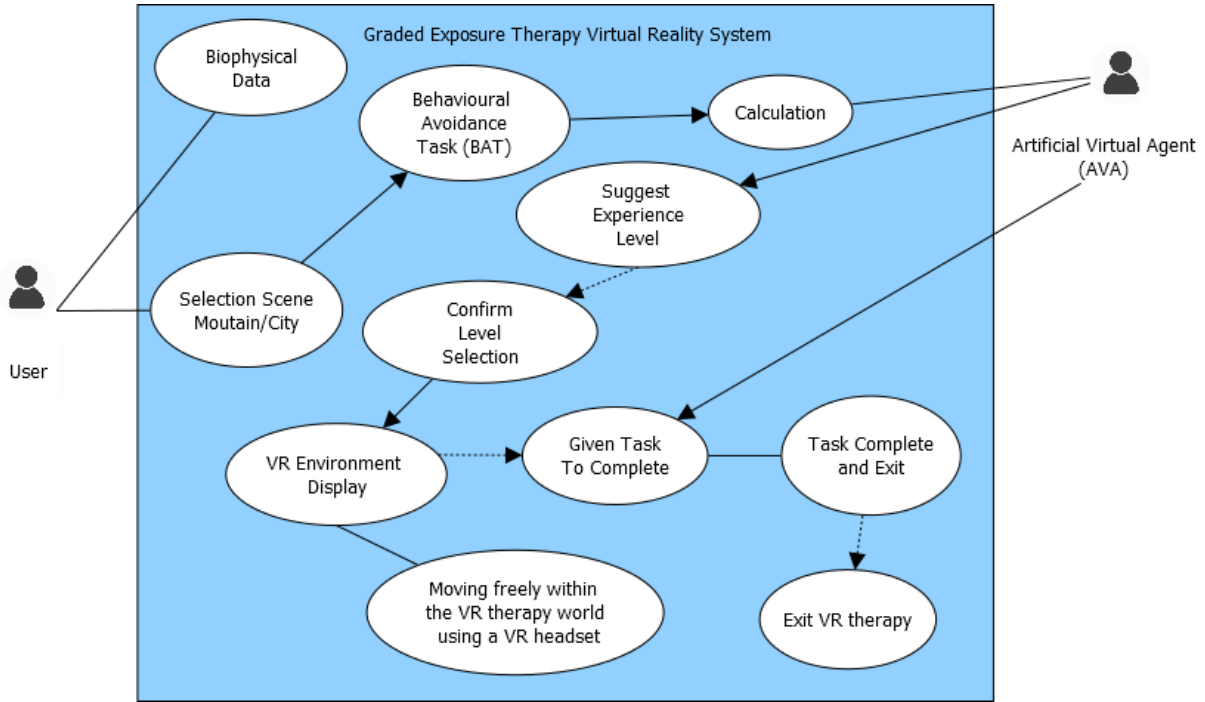


Figure 3.1: Use Case Diagram

Experimental Process

In the inclusion and exclusion stage, individuals completed a vHISS questionnaire to determine their level of acrophobia (low, medium, or high). Following this, acrophobic individuals needed to sign an agreement to participate in the therapy and were categorized based on their fear levels, a classification method also employed by researchers like Hu et al. (2018), who divided acrophobic individuals into low-fear and high-fear groups. This categorization of fear levels relied on the questionnaire method using the Visual Height Intolerance Severity Scale (vHISS) introduced by Huppert et al. (2017). Subsequently, individuals proceeded to the

experiment phase, where they were randomly assigned to one of the biophysical measurements for the graded exposure therapy. After each session of graded exposure therapy, participants were required to complete the ATHQ questionnaire to record their present perceived level of fear. Each individual underwent the VR therapy sessions at their own pace, twice a week for two weeks, totalling four sessions. The experiment results, including the questionnaire responses and the levels of height exposure experienced by each participant, were recorded. Finally, the test results were analysed using quantitative analysis methods. This study included the Mann-Whitney U Test to compare the U-value, with a degree of freedom of 2 and a significance level of 0.05, between the two biophysical instruments and their ATHQ results. The analysis results demonstrated the system's efficiency with artificial intelligence and identified the best choice or combination of physiological characteristics.

UI/UX design of the VR environment

The design of this study encompassed the creation of a graded exposure therapy VR environment using the Unity game engine, complete with various height levels, including city and mountain landscape views, and an artificial virtual agent (AVA) with an AI core. The Unity version used in the development was 2019.4.20f1. Build player settings included XR-Plugin management with XR-Setting VR SDK 'None' and 'Cardboard-16-bit depth' of multi-pass stereo rendering mode set to switch between VR and touch screen mode. The graphic quality was set to Ultra for a realistic view. The application included a touch-screen mode for 'view selection' and 'level suggestion' screen display and interacted with the user without a VR controller. The VR equipment used was Google Daydream View. The measured total field of view of Google Daydream View was 75.9 degrees, and the stereoscopic field of view was 75.9 degrees. The application was applied to Android versions 4.4 to 11.0 with graphics API level 19 - 30.

Different height levels were designed (1, 10, 20, 40, 60, 100, and 220 meters). Soundtracks for the views were added for a realistic feel. The VR world included an AVA for encouragement and task assignments. VR 3D models were built using Blender 3D computer graphics software and Unity-free assets. The city views included components such as office buildings, traffic lights, street lights, industrial areas, etc. The mountain views included snow mountains, trees, rivers, waterfalls, fog, etc. Figure 3.2 illustrates an example of the city view and mountain view for the VR application. In the VR environment, walking was initiated by tilting the player's VR camera down by 30 degrees, as illustrated in Figure 3.3.



Figure 3.2: City view and Mountain View for the VR Application

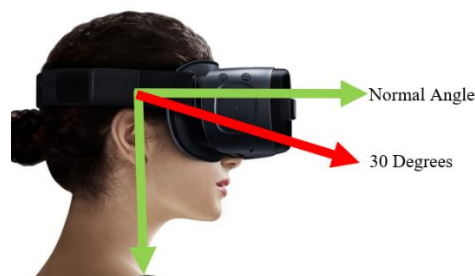


Figure 3.3: Walking Initiation View

In the user interface, simplicity is prioritized, with all elements consolidated into artboards for export and testing. The acrophobia therapy is designed as an application where users first access the environment selection page before proceeding to the BAT session. Following this, users are directed to a VR scene to conduct a Behavioural Avoidance Task (BAT), during which their biophysical data are collected. The BAT, originally developed by

Steketee et al. (1996), aims to observe avoidance behaviour and assess the effects of behavioural treatment for anxiety disorders. For instance, researchers like Coelho et al. (2006) included BAT in their research to measure the anxiety levels of individuals. In their study, subjects were asked to climb a staircase with a total of 40 steps, allowing for an accurate investigation of the anxiety experienced by acrophobic individuals. In this study, the AVA calculates the user's fear level based on the BAT test results and suggests an appropriate level for the user to experience. Table 3.1 illustrates the BAT Result (Height of user stopped) with the AVA-suggested VR height level.

Table 3.1: BAT Result (Height of User Stopped) with the AVA Suggested VR Height Level

BAT Result (Height of user stopped)	Suggested VR Height Level
0 to 1 meter	Level 1
2 to 10 meters	Level 2
11 to 20 meters	Level 3
21 to 40 meters	Level 4
41 to 60 meters	Level 5
61 to 100 meters	Level 6
101 to 220 meters	Level 7

In the research conducted by Baylor et al. (2004), it was concluded that agents with more realistic images and expert roles facilitated greater transfer of learning for individuals. Transfer of learning refers to the application of knowledge, skills, or strategies learned in one context to another context or situation. It involves the ability to generalize learning from one task or domain to another, thereby enhancing adaptability and problem-solving capabilities. Thus, to enhance immersion and realism, the AVA is equipped with state machines to define different behaviours for AVA actions such as blinking, looking around, looking up and down, and flying. These actions are implemented using a state machine approach, which organizes

animations in a structured and modular way, making it easy to manage and maintain the agent's logic. The AVA recognizes the user via the player tag and follows them. Real-time distance processing is employed by the AVA to calculate the distance between itself and the player, enabling it to make decisions and adapt its behaviour accordingly. The AVA is equipped with foundational principles of AI, such as goal-directed behaviour, decision-making based on rules and constraints, and control of an agent's motion and orientation. AVA's decision-making process is based on the C# code. The C# code pseudocode below illustrates the use of these AI principles on the AVA in this study:

Procedure FollowPlayer()

playerPosition = GetPlayerPosition()

targetPosition = CalculateTargetPosition(playerPosition)

ClampTargetPosition(targetPosition)

MoveTowardsTargetPosition(targetPosition)

RotateTowardsPlayer()

End Procedure

Procedure GetPlayerPosition()

Return position of player object

End Procedure

Procedure CalculateTargetPosition(playerPosition)

targetPosition = playerPosition + (forward * followDistance) - (right * followOffset) + (up * followHeight)

Return targetPosition

End Procedure

Procedure ClampTargetPosition(targetPosition)

```

    Clamp targetPosition.x between minPosition.x and maxPosition.x
    Clamp targetPosition.y between minPosition.y and maxPosition.y
    Clamp targetPosition.z between minPosition.z and maxPosition.z
End Procedure

Procedure MoveTowardsTargetPosition(targetPosition)
    Move towards targetPosition at speed * Time.deltaTime
End Procedure

Procedure RotateTowardsPlayer()
    Calculate lookPos as playerPosition - transform.position
    Set lookPos.y to 0
    Rotate lookPos around y-axis by -90 degrees
    Set rotation of object to look at lookPos
End Procedure

Procedure DrawGizmos()
    Draw wire cube representing allowed movement area using minPosition and
maxPosition
    Draw line from player position to player position + forward * followDistance
End Procedure

```

The pseudocode demonstrates that the AVA incorporates principles of AI, including:

- Target Following: The code calculates a target position for the AVA to follow the player, akin to basic pathfinding or motion planning.
- Constraint Enforcement: It imposes movement constraints on the AVA to keep it within defined boundaries, representing rule-based decision-making.
- Smooth Movement: The script achieves smooth movement toward the target position using interpolation (Vector3.MoveTowards), facilitating fluid motion.

- Orientation Control: The AVA consistently faces the player, demonstrating simple direction control.

This C# code ensures that the AVA maintains a constant speed of 3 floating-point numbers and a distance of 2 floating-point numbers while following and facing the player.

For example, in 2020, researcher Bălan et al. designed a 3D model named eTher that interacted with subjects through sound, successfully comforting individuals with acrophobia. Their research demonstrated the model's effectiveness in providing comfort to acrophobic subjects. Figure 3.4 depicts the BAT test view with an AVA in the VR application, while Figure 3.5 illustrates the level suggestion page of the VR application.

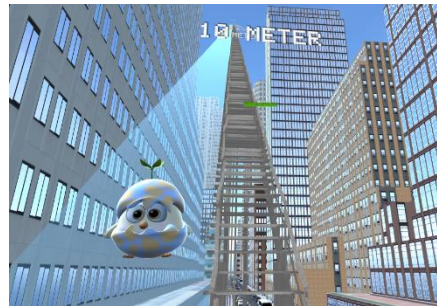


Figure 3.4: BAT Test View with an AVA of the VR Application



Figure 3.5: Level Suggestion Page of the VR Application

In the VR environment, an Artificial Virtual Assistant (AVA) has been integrated with a core AI system to enrich user interaction. Constructed using Blender 3D, the AVA model utilizes Unity's rule-based systems for decision-making, enhancing user experience through

predefined rules and conditions. Unity's platform provides flexibility for implementing and experimenting with reinforcement learning algorithms, enabling effective training of intelligent agents within the VR environment (Sam et al., 2013).

AVA's decision-making process is based on the C# code. The pseudocode below outlines the logic and structure of the algorithm used, providing a high-level description of the decision-making process.

Procedure ChangeSceneWithTag()

player = FindGameObjectWithTag("Player")
playerCollider = GetColliderComponentFromPlayer(player)
colliders = FindCollidersOverlappingPlayer(player, playerCollider)

For each collider in colliders

If collider has tag "lvl0"

Set currentLevel to 0

LoadScene("slvl")

Else if collider has tag "lvl1"

Set currentLevel to 1

LoadScene("slvl")

// Repeat similar code for other levels

End For

End Procedure

This code enables the AVA to evaluate the user's context and suggest tasks or provide encouragement based on their current height level, identified by associated tags. For example,

if the user's height corresponds to 'lvl0,' the AVA adjusts the level to 0 and loads the 'slvl' scene accordingly. This decision-making process ensures a personalized and adaptive experience for users within the VR environment. Overall, these AI algorithms enhance interactivity and immersion by tailoring interactions and tasks to users' context and preferences.

Additionally, the AVA includes an encouragement function that displays height progress to users via a text view and triggers encouragement based on the achieved height. Encouraging words such as 'Great Job!', 'Keep Going!', 'You've got this!', 'Onward and Upward!', 'No fear can hold you back!', and more are provided. Figure 3.6 illustrates the encouragement provided by the AVA in the VR environment.



Figure 3.6: Encouragement Given by the AVA in the VR Environment

The user is presented with the option to either accept or reject the height suggestion. If the suggestion is rejected, the system prompts the user to repeat the BAT test. Conversely, if the suggestion is accepted, the user progresses to the demonstration scene where the AVA showcases the task. Subsequently, they move on to the corresponding height scene to carry out the assigned task. In the mountain view, users are tasked with collecting flowers along the wooden corridor, while in the city view, they collect coins from the building's edge and glass areas. Figure 3.7 illustrates the demonstration section in the VR application, while Figure 3.8 depicts scenes from the mountain and city views with their respective tasks.



Figure 3.7: Demonstration Section in VR Application

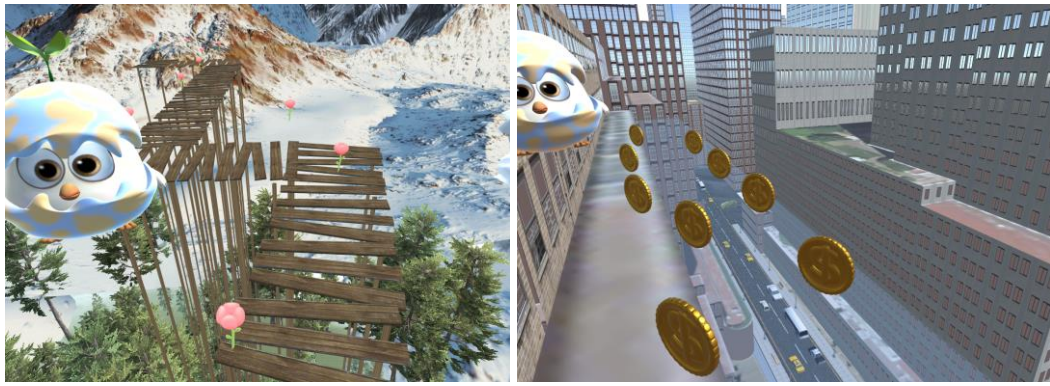


Figure 3.8: Mountain View Task Scene and City View Task Scene

The duration of each therapy session varies based on the user's pace in completing the task. Upon task completion, the system guides the user to the ending scene. Biophysical data is collected and recorded throughout the therapy session. Following each therapy session, users are required to fill out the ATHQ questionnaire.

3.3 Acceptance and Adaptability

The research aimed to assess the most suitable biophysical data, aided by VR and AI, for successfully mitigating acrophobia in individuals. Firstly, the acrophobic individuals experienced varying levels of the VR environment with the assistance of an AVA, and ATHQ data were recorded. The Visual Height Intolerance Severity Scale (vHISS) by Huppert et al. (2017) was included to confirm the presence of acrophobia. The level of fear exhibited by the

individuals was crucial for categorizing them into different acrophobia groups (low, medium, and high), using the vHISS questionnaire. The vHISS severity scores ranged from 1 to 13. Scores from 1 to 5 categorized participants into the low acrophobia group, scores from 6 to 9 placed them in the medium acrophobia group, and scores from 10 to 13 categorized them as part of the high acrophobia group. Additionally, individuals had to consent to the treatment and agree to participate in a treatment study by signing a consent form. Inclusion criteria, as specified in the vHISS form, required individuals to meet at least one acrophobia symptom (a. - d. List A), exhibit visual height intolerance (vHI) for longer than six months, experience intense or extremely strong fear when exposed to heights, and make efforts to avoid heights. Participants falling outside the 18 - 55 years age range, those with limited English language proficiency, regular medication users, individuals with claustrophobia, or those who had recently experienced sudden illness were excluded. Participants had the right to continue or discontinue their participation in the experiment. An example of the vHISS questionnaire used in this study is presented in Table 3.2 (the complete questionnaire is provided in the appendix section). Table 3.2 presents an example of the vHISS questionnaire that acrophobic individuals completed in this study. The scoring instructions for the vHISS were computed following the guidelines provided by Huppert et al. (2017). The vHISS is a questionnaire designed to assess the severity of visual height intolerance, which is characterized by discomfort or anxiety related to heights and visual stimuli. The study primarily focuses on assessing intolerance; additional questions also inquire about the individual's desire for treatment, willingness to participate in a treatment study, and the presence of claustrophobia if relevant to the research or clinical context.

Table 3.2: Example of Visual Height Intolerance Severity Scale (vHISS)

Visual Height Intolerance Severity Scale (vHISS)		
Question	Yes ☐	No ☐
Have you already experienced Visual Height Intolerance (vHI) while looking from a height? (distressing instability when standing or moving) Continue to fill out the rest of the questionnaire only if you answered “yes.”	 Continue	 Finished
1. Because of your vHI, how much difficulty did you recently have doing sports?	0 ☐ 1 ☐	No difficulty Any difficulty (a little/moderately/quite a lot/very much).

Additionally, the ATHQ is presented in Table 3.3. The Attitude Toward Height Questionnaire (ATHQ), designed by Abelson and Curtis (1989), is included to assess the individual's current fear of height. The ATHQ consists of a six-item measure that evaluates the individual's feelings about the height they are experiencing, using dimensions such as 'Good/Bad', 'Comfort/Terrible', 'Pleasant/Unpleasant', 'Safe/Dangerous', 'non-threatening/threatening', and 'harmless/harmful'.

Table 3.3: Attitude Towards Heights Questionnaire

Question: How do you feel about the height experienced? (✓ on the selected score)

Item	Scoring										
	0	1	2	3	4	5	6	7	8	9	10
Good (0) – Bad (10)											
Comfort (0) – Terrible (10)											
Pleasant (0) – Unpleasant (10)											
Safe (0) – Dangerous (10)											
Non-threatening (0) – Threatening (10)											
Harmless (0) – Harmful (10)											
Total:											
Total Score:											

3.4 Implementation

In this phase, the virtual graded exposure therapy application with artificial intelligence was developed. The system was designed and implemented as an Android mobile application. Figure 3.9 depicts the storyboard of the VR-graded exposure therapy system with an artificial virtual agent (AVA).

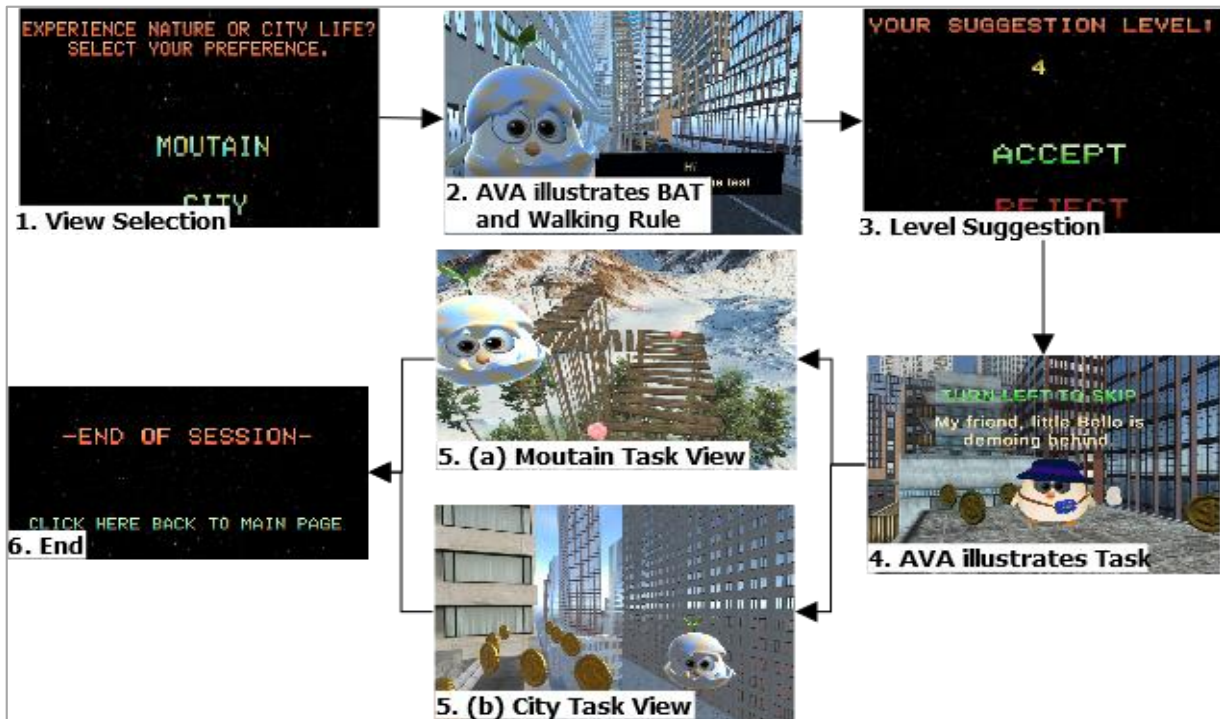


Figure 3.9: Storyboard of the VR-Graded Exposure Therapy System with an Artificial Virtual Agent (AVA)

In Graded Exposure Therapy in VR, users start by choosing a view in the "View Selection" interface, which then directs them to the BAT section. Upon the user's entry into the VR world, the AVA initiates by providing instructions on the rules for walking in the VR environment. Following this, the user begins the BAT test by ascending the stairs. If the user is unable to handle the height anymore, they have to forward to a 10-second pause at the glass area which allows the AVA to suggest alternative levels. The rule-based decision-making algorithms, NavMesh system, behaviour designer algorithms, and state machines equipped by the AVA in the Unity engine are used to build the AVA's ability to navigate to the user's location and trigger level suggestions. By analysing the user's condition through triggers and tags, the AVA can make informed decisions and provide appropriate suggestions to the user. Once the suggestion

is accepted, the user follows AVA's instructions for collecting items in the VR environment. In this task, the user is required to collect coins/flowers within the VR scene, with each collected item contributing to their score. The score is tracked and added to the player's total, ensuring progress is accurately recorded. Once all the items have been collected, the user is automatically taken to the end scene. Throughout the task scene, the AVA continues to follow the user and provide encouragement based on the score they have achieved. Each therapy session depends on the user's tempo.

3.5 Summary

Chapter 3 provides an in-depth exploration of the study's analysis and design, presenting the workflow pipeline. The iterative development approach aims for the rapid creation of functional software early in the development phase. By showcasing the system's development methodology and user interface design, this chapter enables readers to grasp the development process and visualize the system's functionality before its completion.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter delves into the results of the Attitude Toward Heights Questionnaire (ATHQ) and biophysical measurements obtained from the graded exposure therapy system utilizing a virtual reality environment with artificial intelligence. The data includes assessments using both the Visual Height Intolerance Severity Scale (vHISS) and ATHQ to capture participants' perceived fear levels. In total, twelve participants took part in this project. The ATHQ generates total scores ranging from 0 to 60, where a score of 0 reflects an acrophobic individual feeling comfortable at the selected height, while a score of 60 indicates the individual feeling extreme danger at the chosen height. As for the vHISS questionnaire, the severity scores range from 1 to 13. Scores from 1 to 5 categorize participants into the low acrophobia group, scores from 6 to 9 place them in the medium acrophobia group, and scores from 10 to 13 categorize them as part of the high acrophobia group. To assess differences between the two types of biophysical instruments, the ATHQ results for each acrophobic participant in each group are analysed using the Mann-Whitney U test. This analysis aims to determine which biophysical measurement is more effective in evaluating the participants' fear levels during therapy.

4.2 Participant Background

This section provides an overview of the participant characteristics and demographics in the study. The study comprised 12 participants, consisting of 2 males and 10 females, all falling within the age range of 19 to 26 years old. The participants represented various racial

backgrounds, including Malay, Iban, Chinese, Indian, and others. Only two of the participants had sought help for acrophobia before they participated in this study. Three participants had previous experience with virtual reality (VR). All participants had experienced a fear of heights before and possessed at least a post-secondary education level (pre-university). These participants were all students from Universiti Malaysia Sarawak in Malaysia and had no history of sudden illnesses. In terms of the fear provoked at various heights, 33.33% (4/12) of participants reported feeling greater fear at heights greater than 40 meters, 50% (6/12) at 12 meters height, and 16.67% (2/12) at 2 meters height. Table 4.1 displays the vHISS scores categorized by the severity of acrophobia for each participant.

Table 4.1: vHISS Score with Category of Acrophobia for Each Participant

Number of Participants	vHISS score	Category of acrophobia
1	4	Low
2	3	Low
3	7	Medium
4	6	Medium
5	10	High
6	12	High
7	3	Low
8	5	Low
9	7	Medium
10	8	Medium
11	11	High
12	10	High

In conclusion, there were an average of two participants with each category: Low, Medium, and High groups of acrophobias and each biophysical measurement type with each category included 2 individuals.

4.3 Analysis of Biophysical Data (EEG and Heart Rate) and Statistical Methods

Employed

Arduino KY-039 5V Finger Detection Heartbeat Sensor Module Detector was utilized to detect and record the participants' heartbeats. The heartbeat sensor is connected to an Arduino Uno microcontroller board, which is based on the microchip ATmega328 microcontroller. The Arduino Uno microcontroller was attached to the player's finger and linked to Microsoft Excel. The recorded heartbeat data was directly saved to an Excel file. Figure 4.1 illustrates the image of the participant with the biophysical measurement of the HR.



Figure 4.1: Participant with the Biophysical Measurement of the HR

Table 4.2 illustrates the average heartbeat of each participant in both normal and task states. Since all participants were under the age of 30, the maximum HR recorded was set to 170 beats per minute (bpm), based on the target HR chart provided by the American Heart Association (2021). The data reveal that the average heart rate of each participant increased when they were engaged in the assigned tasks at each level, ensuring the effectiveness of the VR in provoking the fear of heights.

Table 4.2: Average Heartbeat of Participants in Normal and Task States

No. of participant	Average Heartbeat (BPM)							
	Number of times							
	1		2		3		4	
	N	IT	N	IT	N	IT	N	IT
1	82.99174	100.1099	82.83854	99.13343	82.92168	98.61356	83.19474	99.37713
2	85.4687	96.34372	85.4799	96.70454	85.53912	96.87878	85.56696	94.9647
3	82.49948	95.22172	82.46156	95.97598	82.59	96.24022	82.43396	96.15366
4	93.45744	103.2778	93.04502	106.2397	94.68544	105.9007	92.88542	110.0124
5	96.47364	107.6534	96.51038	106.0781	96.46526	106.5415	96.45132	104.1395
6	93.11602	112.2666	93.07996	112.7815	93.09238	107.1065	92.95126	113.0185

*Note: The values are in beats per minute (bpm).

*N= Normal IT = In Task

Based on Table 4.2, participants 1 to 6 were assigned to the heart rate group, while participants 7 to 12 were assigned to the EEG group. In the study conducted by Choong et al. (2021), the researchers employed the 14-channel wireless Emotiv Epoc+ device. Each channel was paired and subjected to a one-way analysis of variance to assess the variability among different emotions, including anger, disgust, fear, happiness, sadness, and surprise. Their results revealed that the FC6_F4 channel pair exhibited the highest correlation in the beta band for the emotions of anger, fear, and surprise. This channel pair demonstrated a stronger functional relationship between the two brain regions and the corresponding emotional states. The primary focus of this research was to elicit fear responses associated with acrophobia (fear of heights) from participants while they engaged in specific tasks within a VR environment. As a result, the analysis primarily concentrates on the beta band channel pairs FC6_F4. Figure 4.2 illustrates the image of the participant with the biophysical measurement of the EEG.



Figure 4.2: Participant with the Biophysical Measurement of the EEG

Table 4.3, displays the EEG band power frequency for the FC6 - F4 channel pair for each participant on each test, highlighting the high values observed in the beta band for each participant during the task sessions.

Table 4.3: EEG Band Power Frequency for the FC6 - F4 Channel Pair for Each Participant on Each Test

No. of test	No. of participant	EEG band power FC6-F4																		
1	7	<table border="1"> <caption>Estimated EEG Band Power Data for Test 1</caption> <thead> <tr> <th>Band</th> <th>FC6</th> <th>F4</th> </tr> </thead> <tbody> <tr> <td>Theta (4-8Hz)</td> <td>~0.8</td> <td>~1.5</td> </tr> <tr> <td>Alpha (8-12Hz)</td> <td>~1.5</td> <td>~2.2</td> </tr> <tr> <td>Low Beta (12-16Hz)</td> <td>~6.2</td> <td>~6.5</td> </tr> <tr> <td>High Beta (16-25Hz)</td> <td>~0.5</td> <td>~0.8</td> </tr> <tr> <td>Gamma (25-45Hz)</td> <td>~0.2</td> <td>~0.3</td> </tr> </tbody> </table>	Band	FC6	F4	Theta (4-8Hz)	~0.8	~1.5	Alpha (8-12Hz)	~1.5	~2.2	Low Beta (12-16Hz)	~6.2	~6.5	High Beta (16-25Hz)	~0.5	~0.8	Gamma (25-45Hz)	~0.2	~0.3
Band	FC6	F4																		
Theta (4-8Hz)	~0.8	~1.5																		
Alpha (8-12Hz)	~1.5	~2.2																		
Low Beta (12-16Hz)	~6.2	~6.5																		
High Beta (16-25Hz)	~0.5	~0.8																		
Gamma (25-45Hz)	~0.2	~0.3																		
2	7	<table border="1"> <caption>Estimated EEG Band Power Data for Test 2</caption> <thead> <tr> <th>Band</th> <th>FC6</th> <th>F4</th> </tr> </thead> <tbody> <tr> <td>Theta (4-8Hz)</td> <td>~0.8</td> <td>~3.0</td> </tr> <tr> <td>Alpha (8-12Hz)</td> <td>~1.5</td> <td>~2.2</td> </tr> <tr> <td>Low Beta (12-16Hz)</td> <td>~7.0</td> <td>~7.5</td> </tr> <tr> <td>High Beta (16-25Hz)</td> <td>~0.5</td> <td>~0.8</td> </tr> <tr> <td>Gamma (25-45Hz)</td> <td>~0.2</td> <td>~0.3</td> </tr> </tbody> </table>	Band	FC6	F4	Theta (4-8Hz)	~0.8	~3.0	Alpha (8-12Hz)	~1.5	~2.2	Low Beta (12-16Hz)	~7.0	~7.5	High Beta (16-25Hz)	~0.5	~0.8	Gamma (25-45Hz)	~0.2	~0.3
Band	FC6	F4																		
Theta (4-8Hz)	~0.8	~3.0																		
Alpha (8-12Hz)	~1.5	~2.2																		
Low Beta (12-16Hz)	~7.0	~7.5																		
High Beta (16-25Hz)	~0.5	~0.8																		
Gamma (25-45Hz)	~0.2	~0.3																		

Table 4.3 continued



Table 4.3 continued



Table 4.3 continued

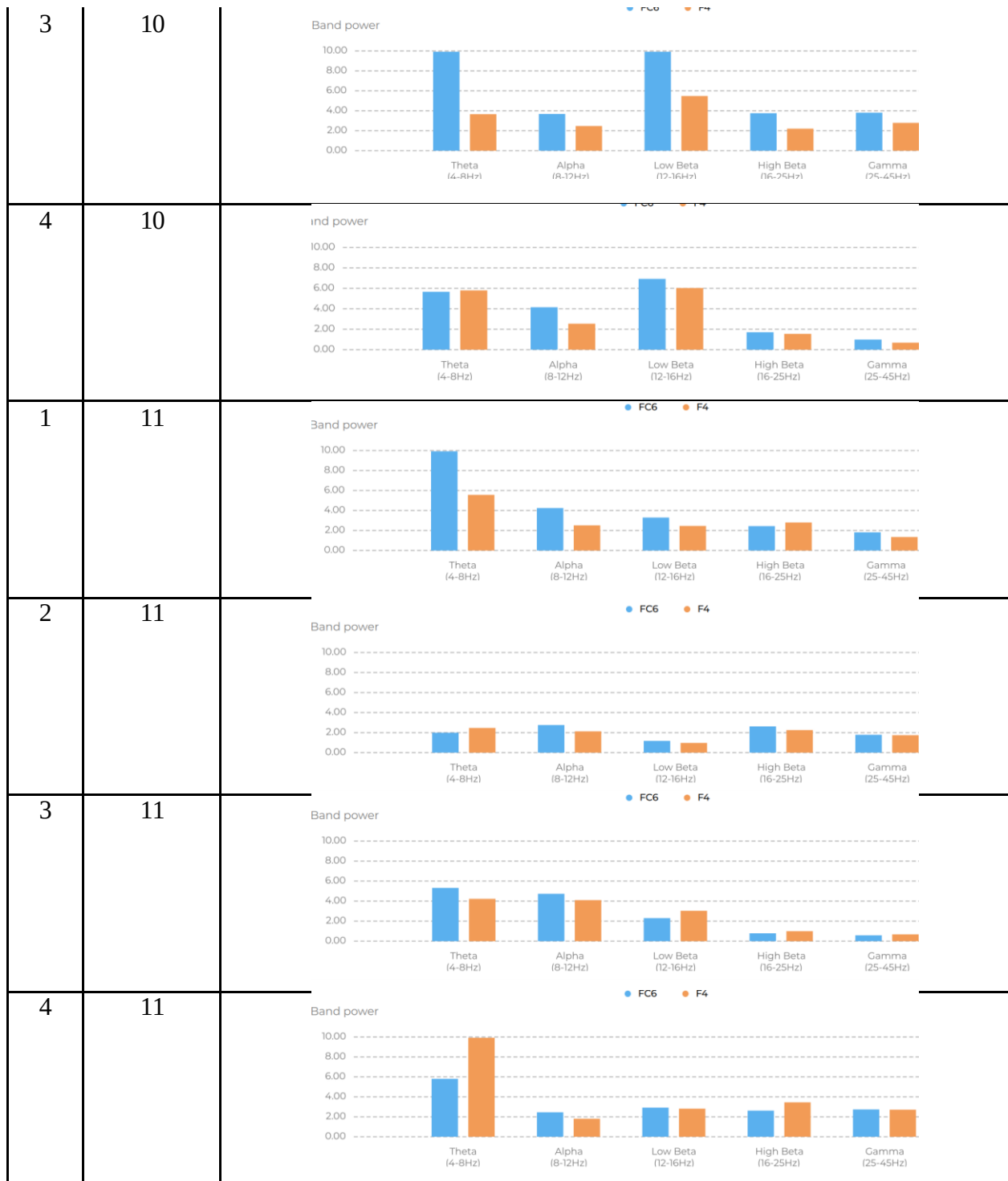
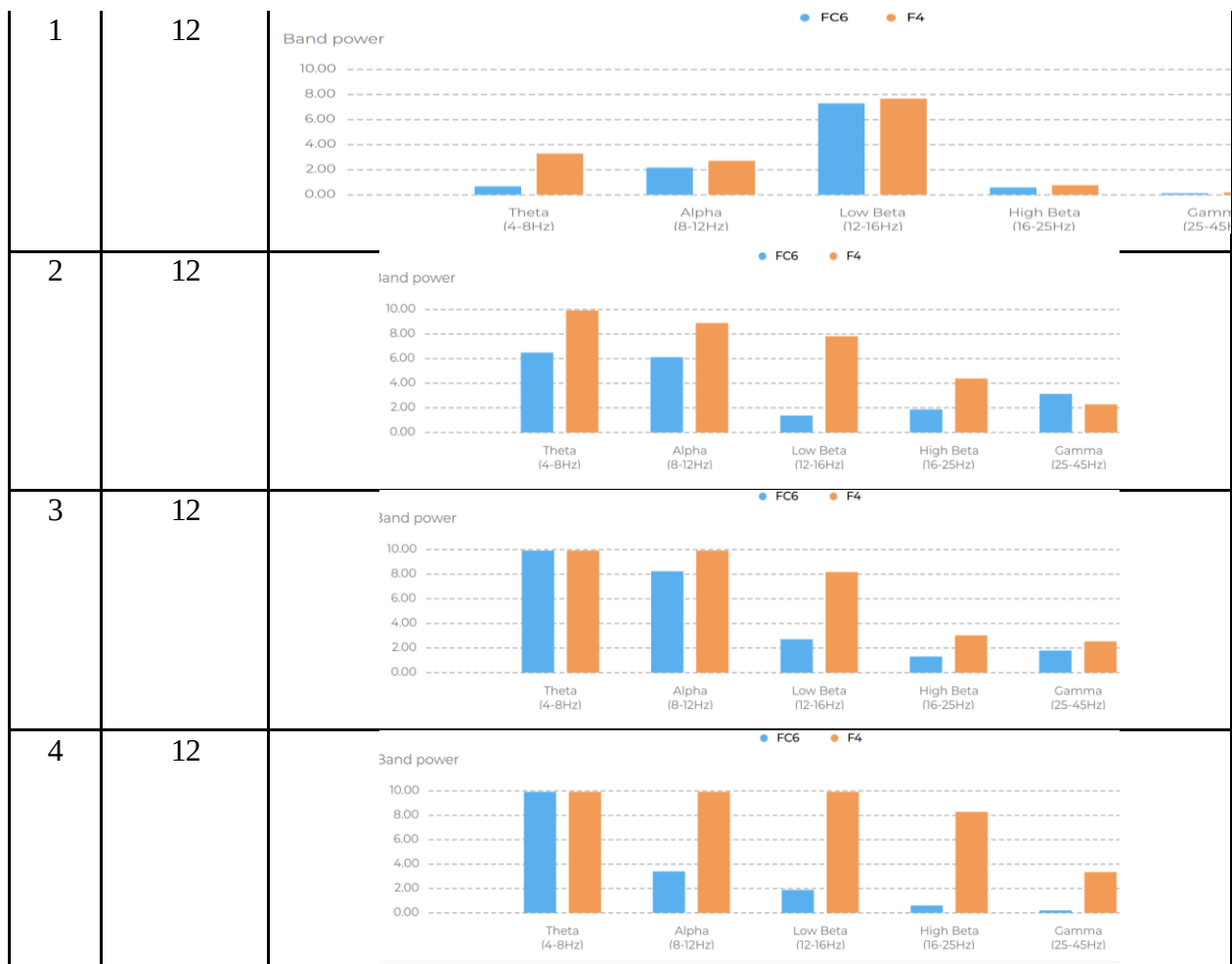


Table 4.3 continued



The ATHQ scores are collected through the ATHQ questionnaire, as shown in Figure 4.3 below, which first calculates the scoring for each item and then totals up to get the total score.

Attitude Towards Heights Questionnaire (ATHQ)											
Question: How do you feel about the height experienced? (✓ on the selected score)											
Item	Scoring										
	0	1	2	3	4	5	6	7	8	9	10
Good (0) – Bad (10)									✓		
Comfort (0) – Terrible (10)				✓							
Pleasant (0) – Unpleasant (10)					✓						
Safe (0) – Dangerous (10)									✓		
Non-threatening (0) – Threatening (10)							✓				
Harmless (0) – Harmful (10)				✓							
Total:				6	4		6		16		
											6 + 4 + 6 + 16 =
											Total Score: 32
Biophysical Measurement Type: HR/EEG											
Number of test: 1/2/3/4											

Figure 4.3: The ATHQ Scores Collection

Table 4.4 presents the ATHQ scores of each participant at four different tests. The results were recorded after the participants underwent graded exposure to virtual reality therapy using the application. In table 4.4, HR depicts the group using heart rate, and EEG is for the group using an electroencephalogram.

Table 4.4: Attitude Toward Height Questionnaire (ATHQ) Score of Each Participant

No. of participant	Attitude Toward Height Questionnaire (ATHQ) Score			
	Number of times			
	1	2	3	4
HR				
1	20	35	33	30
2	30	27	33	33
3	13	16	15	10
4	38	38	38	37
5	49	28	24	23
6	41	22	22	21
EEG				
7	30	33	33	32
8	24	23	22	22
9	44	49	43	42
10	35	31	31	30
11	34	38	38	29
12	43	48	42	42

The Mann-Whitney U test is utilized for the ATHQ results, with a sample size of 6 ($n_1=6$) in the HR group and 6 in the EEG group ($n_2=6$). The test statistic is determined by the smaller U_1 and U_2 values. Initially, the ATHQ results from both the HR and EEG groups are averaged over the four trials. These average scores are then ranked and ordered, resulting in combined ranks ranging from 1 to 12, as illustrated in Table 4.5.

Table 4.5: Average ATHQ Results with Orders and Ranks

Average ATHQ result					
Group		Total Sample (Ordered Smallest to Largest)		Ranks	
Heart Rate	Electroencephalogram (EEG)	Heart Rate	Electroencephalogram (EEG)	Heart Rate	Electroencephalogram (EEG)
29.5	32	13.5		1	
30.75	22.75		22.75		2
13.5	44.5	26.5		3	
37.75	31.75	29.5		4	
31	34.75	30.75		5	
26.5	43.75	31		6	
			31.75		7
			32		8
			34.75		9
		37.75		10	
			43.75		11
			44.5		12

The sum of ranks for the HR group is $R_1 = 29$, and for the EEG group is $R_2 = 49$. The total sum of ranks can be calculated using the formula $\frac{n_1(n_1+1)}{2}$, where n is the number of instances. With $n = 12$, the total sum of ranks is 78, which is equal to $R_1 + R_2 = 29 + 49 = 78$. The total sum of ranks is equal to the expected total sum of ranks which reassures that the calculation has been performed correctly and the validity of the statistical test is ensured. Next, compute U_1 and U_2 as follows:

$$U_1 = 6(6) + \frac{6(7)}{2} - 29 \quad U_2 = 6(6) + \frac{6(7)}{2} - 49$$

$$U_1 = 28$$

$$U_2 = 8$$

4.4 Mann-Whitney U test Result Discussion

Eighteen participants were initially involved in this research. However, six of them discontinued treatment for autonomous reasons. Consequently, the final sample size totalled 12 participants. Previous research studies related to biophysical measurements, virtual reality, and artificial intelligence commonly utilized small sample sizes ranging from 4 to 25 participants. The decision to have a sample size of 12 was influenced by practical considerations such as feasibility and resource constraints. Conducting research involving biophysical measurements, virtual reality environments, and artificial intelligence technologies was time-consuming, requiring coordination between participants and researchers for each data collection session. Consequently, this study balanced the desire for a larger sample size with the practical limitations of available resources, including time, funding, and participant access. Moreover, the Mann-Whitney U test, as a nonparametric test, does not require as large a sample size as parametric tests. Nonparametric tests are robust and suitable for analysing data from relatively small samples. Therefore, the sample size of 12 participants (6 in each group) was deemed appropriate for conducting the statistical analysis required to compare the ranks of ATHQ results between the HR and EEG measurement groups. To compare the ranks of ATHQ results between HR and EEG measurements, a Mann-Whitney U test was conducted at a 5% significance level. With 6 participants in the HR group ($n_1 = 6$) and 6 participants in the EEG group ($n_2 = 6$), a nonparametric test is appropriate. Using the critical values table for the Mann-Whitney U test, the critical value for accepting the null hypothesis (H_0) is 6. The U value for the Mann-Whitney U test, $U_1 = 28$ and $U_2 = 8$, the U value is higher than the critical value. This indicates support

for the null hypothesis, suggesting that there is no significant difference in ATHQ results between HR and EEG measurements. Based on the Mann-Whitney U test results and the U values, there is statistical evidence to accept the null hypothesis(H_0) and reject the alternative hypothesis (H_1). In conclusion, there is no significant difference in the ATHQ results when comparing HR measurement with EEG measurement.

4.5 Relation of ATHQ Results with HR and EEG Biophysical Measurements

The Mann-Whitney U test revealed no significant difference in ATHQ outcomes between the two biophysical measurement sets. ATHQ score reflects individuals' subjective fear. Differences in biophysical measurements stem from participants' responses to acrophobia levels in VR therapy. Figure 4.4 below illustrates the ATHQ score of each acrophobia participant of low, medium and high levels for biophysical measurements HR and EEG.

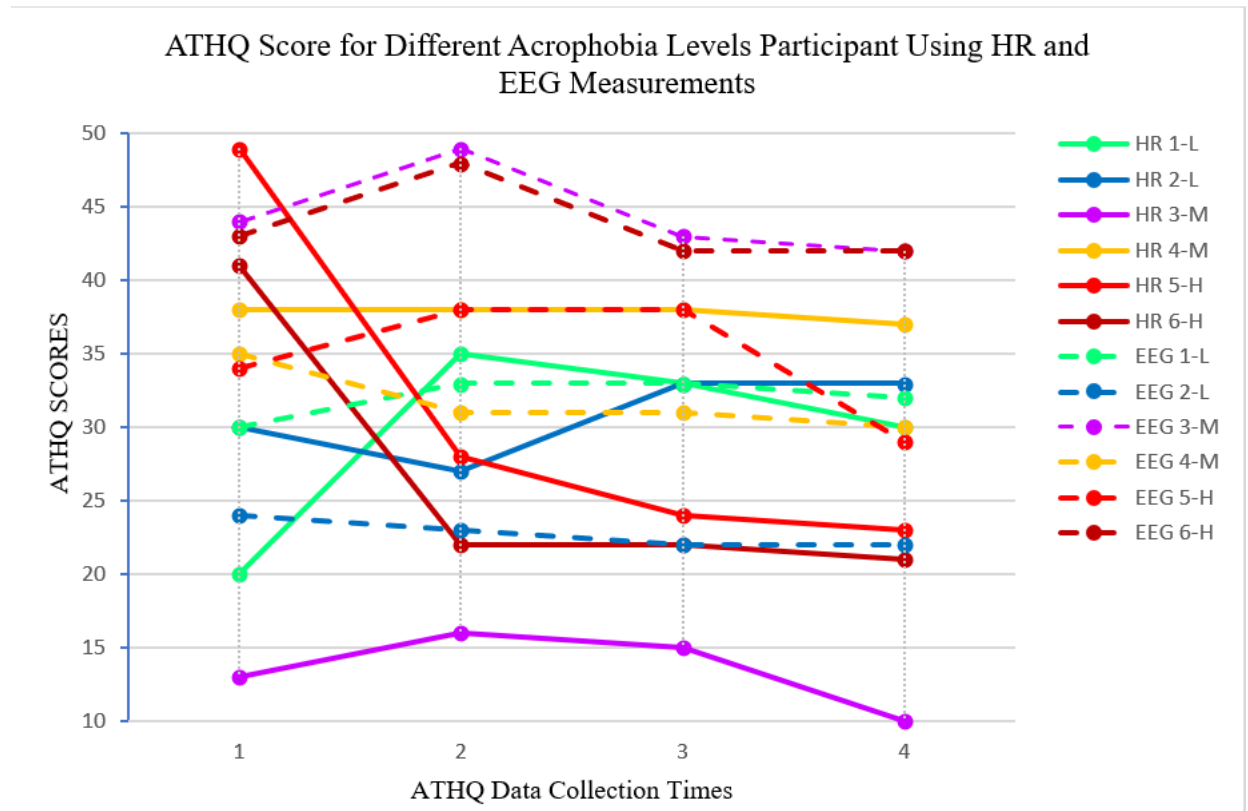


Figure 4.4: The ATHQ Scores of the Acrophobia Participants at Low (L), Medium (M) And High (H) Levels for the HR and EEG Measurements

Firstly, in the HR and EEG group, individuals with low acrophobia showed a medium-low ATHQ score. Observed the result by comparing the ATHQ scores of participants in group HR and group EEG on their third and fourth sessions at the same experience levels and found that three participants showed a decrease in ATHQ score, suggesting reduced fear, while one participant did not experience a significant change.

Furthermore, participants with medium acrophobia in both the HR and EEG groups exhibited a similar decrement in ATHQ scores during the therapy session. This suggests that individuals with moderate acrophobia also benefited from the therapy and experienced an improvement in their acrophobia levels.

However, the differences in the ATHQ score for both participants in group HR had a slight decrement during therapy. In the EEG group, there is only one participant who had a slight decrement in the ATHQ score. Additionally, another participant showed an increment in ATHQ score during the second therapy, but the subsequent therapy sessions maintained the same score. Both HR and EEG show a decrement in ATHQ changes for low, medium and high acrophobia groups, indicating the effectiveness of therapy among individuals. The differing levels of fear resulted in observed slight differences between the two measurement sets. Each category of the acrophobia group indicates a slight decrement in their ATHQ score. It appears that differences in biophysical measurements may not significantly influence the individuals' subjective fear levels, as evidenced by the observed differences between the measurement sets.

4.6 User Engagement and Feedback

During the study, some individuals spontaneously provided feedback on their experiences with the Graded Exposure VR therapy application. While feedback collection was not originally planned as part of the methodology, these unsolicited comments offer valuable insights into the user experience for the Graded Exposure VR therapy application. Feedback from individuals in different categories of acrophobia is as follows:

Low Acrophobia Group Feedback:

- "It was entertaining to see the agent looking around."
- "The agent has a cute appearance."
- "I hope I can feel the wind blowing while experiencing the therapy."
- "The environment feels quite open."

Medium Acrophobia Group Feedback:

- "Experiencing different environments brought a sense of novelty."
- "The agent helped in diverting my attention."
- "I suggest including some people walking around the building to attract attention."
- "I hope I can experience this therapy with a friend."

High Acrophobia Group Feedback:

- "I suggest having a more secure height environment, like a fence surrounding the high areas."
- "I hope there are handrails available during the therapy."

These feedback comments provide valuable insights into the user experience and can be used for future improvements or modifications to the Graded Exposure VR therapy.

4.7 Summary

The experiment process and questionnaire session provided insights into the condition of each participant with acrophobia. The virtual reality environment that was developed aimed to recreate a realistic setting, incorporating elements such as brightness, shadows, and sound effects, and matching the player's height to that of a real environment. This heightened the sense of realism for individuals with acrophobia. Artificial intelligence played a role in suggesting appropriate levels of exposure and providing encouragement within the VR environment. During the investigation using heart rate and EEG measurements, all participants exhibited symptoms of acrophobia and fear when experiencing the virtual reality environment. The results of the Mann-Whitney U test revealed no significant differences between the two types of biophysical measurements. Based on the results of the Mann-Whitney U test, it appears that either the EEG or the heart rate sensor can be used effectively. The absence of significant

differences between these two biophysical measurements suggests that both modalities are suitable for assessing acrophobia individuals' physical and mental states during therapy sessions. This flexibility allows us to choose either measurement based on practical considerations and user preferences. While there were no significant differences observed among the two biophysical measurements, the utilization of these measurements remains crucial for direct data analysis and assessment of acrophobia individuals' current physical and mental state during therapy sessions. These biophysical measurements play a vital role in understanding and addressing the participants' well-being, facilitating more effective interventions tailored to their specific needs. The graded VR therapy has demonstrated its effectiveness through the reduction in subjective fear levels, as indicated by the decrease in ATHQ scores.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Implications of the Findings for the Use of VR and AI in Combating Acrophobia

The use of VR with AI to utilize an adaptive approach helped individuals gradually overcome their acrophobia. This research provides personalized level selection of different heights based on individuals' subjective fear which exhibited a decrement in ATHQ score resulting in different acrophobia groups.

Individuals with acrophobia may show varying responses, necessitating the selection of different height levels to observe improvement during therapy. The inclusion of seven different levels may fulfil most of the individual's situation. However, some of the high-category acrophobia individuals suggest having a more secure height environment such as a fence surrounding a high environment. The combination of Virtual Reality (VR) and Artificial Intelligence (AI) has been found to increase engagement and motivation in therapy sessions. Participant engagement and motivation were enhanced through the use of different environments and coin placements in the therapy. The immersive experience provided by the VR environment resulted in acrophobic individuals becoming more focused on the task in the heightened environment.

Furthermore, therapist guidance provided through the AVA offered clear instructions and provided comfort to users, addressing potential feelings of loneliness in the VR environment. One participant with medium acrophobia mentioned that experiencing different environments brought a sense of novelty and helped in diverting attention and also suggested the inclusion of

modelling some people walking around the building to attract attention. Another participant with low acrophobia found it entertaining to see the agent looking around.

Participant feedback and testimonials reflect the beneficial role of the virtual agent in supporting the progress. Additionally, incremental level progression and the ATHQ results showed a slight decrease, indicating an improvement in participants' fear levels. Overall, incorporating personalized level selection, task-based engagement, therapist guidance through the virtual agent, and incremental level progression significantly enhanced individuals' ability to combat acrophobia.

5.2 Achievements of Research Objectives

I. Investigation and Evaluation of Biophysical Measurements

The investigation and evaluation of biophysical measurements utilized in previous research were undertaken to assess their effectiveness in detecting fear levels, particularly in individuals with acrophobia. Amongst the biophysical measurements employed, electroencephalogram (EEG) and heart rate (HR) were found to be the most frequently utilized. Previous studies, such as Garfinkel et al. (2014), have shown that heart rate correlates with individual differences in anxiety levels, influencing the perception of fear. Additionally, EEG signals, as highlighted by Wioleta (2013), play a crucial role in identifying various emotions, including fear. Utilizing the Arduino KY-039 and Emotiv Epoc+ devices, this study successfully collected participants' fear data, enabling detailed analysis and enhancing the understanding of fear responses in acrophobia. Overall, the successful utilization of these biophysical measurements allowed for

the collection of comprehensive fear data from participants, facilitating detailed analysis and furthering the understanding of fear responses in acrophobia.

II. Design and Implementation of VR Environment with Artificial Agents

In this study, a tailored VR environment for graded exposure therapy was successfully designed and implemented, featuring integrated artificial intelligent virtual agents (AVA) for user assistance. The VR environment offers diverse settings, including city and mountain views, with varying height levels. Each setting offers a spectrum of height levels, to evoke varying degrees of acrophobia response, ensuring a comprehensive therapeutic experience. The AVA enhances user interaction, providing support and guidance for self-therapy. Moreover, the integration of the Behavioural Avoidance Task (BAT) within the VR environment represents a pivotal innovation in enhancing therapy effectiveness. Utilizing the Behavioural Avoidance Task (BAT) within the VR environment, the AVA analyzes user fear levels and recommends suitable levels for virtual exposure. Previous research by Bălan et al. (2020b) underscores the effectiveness of agent-based assistance in VR environments. Therapy session durations are flexible, accommodating users' pacing and problem-solving abilities. Overall, this research successfully utilized VR technology and artificial intelligence to mitigate acrophobia.

III. Evaluation of Effectiveness of VR Exposure Therapy

In this study, a comprehensive assessment of the efficacy of graded exposure therapy in mitigating acrophobia within a virtual reality (VR) environment had conducted. The results unequivocally demonstrate the effectiveness of this therapeutic approach in alleviating the symptoms of acrophobia. The utilization of the Attitude Toward Height Questionnaire (ATHQ)

revealed a significant reduction in fear levels among participants following the graded exposure therapy sessions. This tangible improvement underscores the efficacy of the therapy in addressing the underlying manifestations of acrophobia. Furthermore, the biophysical measurements, including Electroencephalogram (EEG) and Heart Rate (HR), provided corroborating evidence of the therapy's impact on physiological arousal levels. The observed changes in EEG patterns and heart rate fluctuations during exposure to height stimuli corroborate the therapeutic efficacy in eliciting fear responses and subsequently facilitating their reduction.

It is concluded that sustained exposure and engagement are crucial for reducing fear and enhancing adaptability over time, as highlighted by Jones (1996). Therefore, the findings underscore the importance of long-term therapy interventions tailored to individual adaptability levels for sustained efficacy in mitigating acrophobia. Looking ahead, the integration of graded exposure therapy with VR technology, augmented by artificial intelligent virtual agents (AVA), holds immense promise as a convenient and self-directed treatment modality. By empowering individuals to engage in therapy sessions at their own pace and convenience, this approach represents a paradigm shift in the delivery of acrophobia treatment, offering newfound flexibility and accessibility to individuals seeking relief from their symptoms.

5.3 Strengths and Limitations of the Study

The strength of this study lies in its utilization of multiple assessment tools, specifically the vHISS questionnaire and ATHQ score, which allows for a comprehensive evaluation of acrophobia levels and fear responses. Below is the strength of the study:

- **Utilization of Multiple Assessment Tools**

Various assessment tools employed, such as the vHISS questionnaire and ATHQ score, provide a comprehensive evaluation of acrophobia levels and fear responses.

- **Personalized Level Suggestions**

The inclusion of an AI virtual agent and a Behavioural Avoidance Test (BAT) allowed for personalized level suggestions tailored to individuals' fear levels, enhancing the effectiveness of the therapy.

- **Tailored and Effective Therapy Experience**

The personalized level suggestions based on fear levels resulted in a more tailored and effective therapy experience, improving the chances of successful treatment outcomes.

- **Task-Oriented Approach**

The adoption of a task-oriented approach in the VR environment fostered higher participant engagement and interaction during therapy sessions.

- **Integration of AI Technology**

Integration of AI technology through the artificial virtual agent (AVA) added an innovative dimension to the therapy, potentially improving treatment efficacy and participant experience.

- **Promotion of Participant Engagement**

The task-oriented VR environment and personalized level suggestions promoted higher participant engagement, making the therapy more appealing and encouraging active participation.

- **Consistency in Biophysical Measurements**

The absence of a significant difference between the two biophysical measurements, as revealed by the Mann-Whitney U test, underscores the reliability and consistency of both modalities in assessing acrophobia individuals' physical and mental states during therapy sessions. This finding suggests that both biophysical measurement methods, despite their differences, are suitable and complementary tools for evaluating therapy outcomes, enhancing the robustness of the assessment approach.

Next, the limitation of the study is stated below:

- **Lack of Long-Term Follow-up**

The absence of long-term follow-up data prevents the assessment of the sustainability of the observed improvements over an extended period, leaving uncertainties about the lasting effects of the therapy.

- **Potential Bias Problem**

The study may be susceptible to bias issues, such as response bias or subjectivity in participant assessments, which could impact the accuracy and reliability of the results.

- **Limited Diversity in the Participant Pool**

The lack of diversity in terms of age, gender, or other demographic factors among the participants may limit the external validity of the findings, as they might not fully represent a more diverse population with varying characteristics and experiences.

5.4 Recommendations

Future studies may include larger and more diverse samples to enhance the generalizability of findings. Some recommendations for further research:

- **Larger and More Diverse Samples**

Future studies should include larger and more diverse samples to enhance the generalizability of findings and ensure that the results can apply to a broader population.

- **Longitudinal Studies**

Conduct longitudinal studies that collect data from the same participants over an extended period to observe and analyse changes or developments that occur within individuals or groups over time, providing valuable insights into the long-term effects of the therapy.

- **Randomized Controlled Trials**

Implement randomized controlled trials to compare the relationships between VR therapy and its effects on acrophobia symptoms with control conditions or alternative interventions, helping establish the therapy's efficacy in comparison to other treatments.

- **Self-Report Measures**

Utilize self-report measures to provide an alternative method of assessment, enabling participants to express their experiences and perceptions more openly, which can complement objective measurements.

- **Multi-Modal Approach**

Consider a multi-modal approach that combines multiple biophysical measurements, such as EEG, heartbeat, and skin conductance response, to enhance the accuracy and usefulness of real-time fear detection during therapy sessions.

5.5 Conclusion

The study aimed to investigate whether the choice of biophysical measurement method would have a noticeable impact on the ATHQ scores, indicating a variation in the effectiveness of therapy for acrophobia. In the result analysis section, the Mann-Whitney U test shows there is statistical evidence of no significant difference in ATHQ outcomes between the two biophysical measurement sets. Despite not finding a significant difference between the two biophysical measurements, it is still worthwhile to focus on exploring a combination of various biophysical treatments. This approach can help in assessing the optimal biophysical measurement for treating acrophobia and evaluating therapy performance. By combining multiple biophysical measurements, researchers can gain a more comprehensive understanding of the physiological and psychological responses during therapy sessions, potentially leading to more effective and targeted treatment strategies for acrophobia. The inclusion of different biophysical measurements may offer valuable insights into how individuals respond to therapy, even if no significant differences are observed between specific measures individually. This comprehensive approach could contribute to a more holistic understanding of acrophobia treatment and the factors influencing therapy outcomes. Below are some benefits and limitations of EEG and HR measurement:

Benefits:

- Valuable Insights Beyond Fear Assessment of EEG

EEG provides valuable insights into brain activity patterns, cognitive processes, and emotional states, going beyond fear assessment. This contributes to a comprehensive understanding of fear experiences and the underlying mechanisms involved.

- Comprehensive Understanding Using EEG

EEG helps researchers and clinicians gain a deeper understanding of how fear is processed in the brain, allowing for a more holistic approach to studying and treating fear-related conditions.

- Direct and Immediate Information Using HR

HR measurement provides direct and immediate information about fear levels, offering a straightforward indication of the user's nervousness and fear responses.

- Real-time Investigation Using HR

In real-time situations, HR measurement is more beneficial for investigating fear responses and providing timely feedback during fear-inducing tasks or therapy sessions.

Limitations

- Real-time Fear Detection using EEG

EEG has limitations in real-time fear detection, as it often requires additional processing and analysis to accurately interpret the brain activity patterns associated with fear.

- Interpretation Challenges Using EEG

Slight differences in EEG readings may require careful follow-up observation and interpretation, as the data can be complex and nuanced.

- Limited Insights Beyond Fear Assessment using HR

Unlike EEG, HR measurement primarily focuses on assessing fear levels and may not offer the same depth of insights into cognitive processes or emotional states.

The study results indicate that there is no significant difference between the two types of biophysical measurements concerning the subjective fear responses of individuals with acrophobia. Based on these results, as there is no discernible distinction between the two types of biophysical measurements, it is reasonable to suggest that a suitable choice for biophysical measurement in the context of combating acrophobia in a VR environment with an AVA can be either one of the biophysical measurements or a combination of the various types. Utilizing these measurements individually or in combination allows us to leverage their respective advantages while addressing their limitations. Opting for a single biophysical measurement can enhance the therapy experience by offering advantages such as convenience for therapy participants, streamlining the treatment process, and potentially reducing treatment costs. Using a single biophysical measurement can also simplify the process of detecting anxiety in individuals with acrophobia. If the research study aims solely to investigate anxiety levels, one type of biophysical measurement should suffice, given that there is no significant difference between the two types. The absence of a significant difference between the two biophysical measurements suggests that participants may not be burdened by the additional sensors. The choice of using one or both biophysical measurements can be guided by the specific research

objectives and the level of precision required. Using a single measurement may offer simplicity and cost-efficiency while combining measurements can provide enhanced insights when needed.

However, if the study aims for precision in measuring anxiety levels, combining two or more types of biophysical measurements may prove beneficial during the current experiment or post-experiment analysis. For instance, combining two biophysical measurements, such as heart rate (HR) and electroencephalography (EEG), offers advantages in research development. HR can provide real-time supervision, while EEG can facilitate detailed analysis and investigation. Combining EEG and Heart Rate (HR) measurements in a multi-modal approach can harness the benefits of each method. It enables researchers and clinicians to gain a more comprehensive understanding of fear experiences, combining direct physiological responses with insights into brain activity patterns. Combining various biophysical measurements enhances researchers' understanding of the data. The use of a multi-modal approach can lead to a more nuanced and comprehensive understanding of fear, allowing for a more effective and targeted approach to fear assessment and therapy. Overall, EEG and HR measurements have their strengths and limitations, but when combined in a multi-modal approach, they can complement each other, providing a more complete picture of fear experiences and facilitating improved treatment strategies for fear-related conditions.

The study findings demonstrate that the combination of graded exposure therapy and a virtual reality (VR) environment with an AVA leads to automated therapy and improvement in acrophobia symptoms. The use of biophysical measurements must be convenient and provide immediate detection of changes, informing therapists about fear conditions and facilitating relaxation approaches. In the low acrophobia group, significant improvement in fear is indicated

by their ATHQ scores. These individuals exhibit a positive attitude towards facing the VR environment and show reduced nervousness in response to environmental changes. The medium acrophobia group expresses slight differences between the VR environment and real-life conditions but still experiences fear through the simulated environments. The high acrophobia group focuses more on the height they experience, whereas the low acrophobia group maintains some attention on environmental changes. The study reveals that individuals with high acrophobia may require a longer time for significant improvement. However, more height levels need to be created to find the ability to manage acrophobia symptoms through automated therapy. It is important to note that individual responses may vary. Overall, the findings emphasize the effectiveness of the combined therapy approach and highlight the diverse experiences and challenges faced by individuals with different levels of acrophobia.

The findings from this study highlight the potential impact of using virtual reality (VR) and artificial intelligence (AI) in the treatment of acrophobia. There are several potential impacts on acrophobia treatment that can be identified such as automated therapy which reduces the need for constant therapist presence with lower cost and effective treatment. Besides, a VR environment with an AVA can provide personalized treatment based on individual responses and needs to suit the specific needs of each person, enhancing the effectiveness of treatment. The graded exposure approach can gradually expose the user in a controlled and safe setting. The presence of AVA enhanced engagement and motivation in providing direct encouragement to users for better therapy outcomes. In summary, the combination of VR and AI approaches would personalize, effectiveness, ultimately helping individuals overcome their fear of heights.

In conclusion, the integration of VR with AVA shows promising potential for the future. It offers acrophobic individuals a convenient and accessible method to combat their fear using VR headsets. The convenience of these technologies has the potential to bring about significant positive changes in their lives. While not everyone with acrophobia may find a complete cure, for those seeking treatment, there is hope. Although therapy effectiveness may vary based on individual mentality, autonomy, and ability to control their fear, the existence of these technologies provides a ray of hope for a better quality of life.

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APPENDICES

Appendix A: Acrophobia Virtual Reality Therapy Statement of Consent

(A) Acrophobia Virtual Reality Therapy Statement of Consent

PURPOSE OF THE STUDY

To evaluate a suitable choice of biophysical measurement on combating acrophobia with the assistance of a VR environment with a virtual agent and artificial intelligence.

ASSURANCE OF CONFIDENTIALITY

All information taken from the study will be coded to protect each participant's name. No names or other information that might identify you will be used when discussing or reporting data in conferences, seminars or journal papers. The survey data will be keyed into an Excel sheet for analysis.

WHY IS THIS STUDY BEING DONE?

To create the best solution for the treatment of acrophobia individuals. The simulated environment will not put sufferers in danger and can help them to cure.

(A) Exclusion Criteria.

You cannot participate in this study if you meet any one of the following conditions:

- You do not have a history of fear of heights.
- You are under 18 years old or are older than 55 years old.
- You regularly use medication.

- You have claustrophobia.
 - You experienced any kind of sudden illness below:
 - Heart diseases
 - Mental illness
 - Diabetic coma
 - Stroke
 - Bipolar disorder
 - High blood pressure
 - Asthma
 - Epileptic seizure
 - Fainting
 - Or **ANY** other sudden illness experienced before while you were experiencing a high environment. List it out:
-

WHAT WILL HAPPEN DURING THIS STUDY?

The participant in this experiment would have to fill in the questionnaire. The experiment will first start with the **Visual Height Intolerance Severity Scale (vHISS)**. The first responded answer to the questionnaires would be the initial condition of the acrophobia individuals. The participant will be classified into different categories of fear levels. Next, the participant will be led to the experiment phase, which will be randomly distributed to one type of biophysical measurement [Heart rate (HR), skin conductance response (SCR) and Electroencephalogram (EEG)] to continue on the graded exposure therapy. After each session of graded exposure therapy, the participants will be required to fill in the ATHQ questionnaire to record their perceived level of fear. The questionnaire session is carried out every time the participant completes the treatment. The biophysical data of each participant under normal state and experiment state will both be recorded for the prediction of the artificial intelligence model to

suggest a suitable level of the high environment to experience. Each of the tests of graded exposure therapy would be 8 minutes long. The selection of graded exposure therapy height to experience is based on the condition of acrophobia individuals (A suitable level of the high environment will be suggested to the user through Behavioural Avoidance Test). The above procedure would repeat four times which twice a week. The experiment results including the questionnaire session as well as each of the levels of height exposure experienced by the user will be recorded. The level of acrophobia of each corresponding level would be compared and analysed. The analysis result would show how is the efficiency of the system with artificial intelligence and find out the best choice or combination of physiological characteristics.

WHAT ARE THE HARMS AND BENEFITS OF THIS STUDY?

The participant may experience a panic attack while experiencing graded exposure therapy in this study. The participant may experience symptoms below while experiencing height environment based on their condition:

➤ Tension	➤ Faint	➤ Panicky
➤ Stress	➤ Difficulty in concentrating	➤ Losing Balance
➤ Irritable or angry	➤ Heart beat fast	➤ Migraines or tension headaches
➤ Difficulty breathing	➤ Sweating	➤ Mouths Dry

- | | |
|-----------------------------------|--------------------|
| ➤ Tinnitus or ringing in the ears | ➤ Cold extremities |
|-----------------------------------|--------------------|

The participant has the right to stop the experiment urgently. The experimental site is guaranteed to be safe and no life-threatening situations will occur. The symptoms of acrophobia would be treated successfully using graded exposure therapy in a virtual reality environment.

VOLUNTARY PARTICIPATION

You can help in this study by agreeing to fill in the questionnaire. It takes about 15-20 minutes to fill in. Although your input to this research will be very valuable, participation in this study is voluntary and you are under no obligation to take part. You are free to withdraw from the study at any point. You can also withdraw questionnaire data up to 2 weeks after completing the survey by emailing the lead researcher, Chan Chiew Mei.

(B) Agreement to participate in a treatment study

You are being asked to consider taking part in a research study. Before agreeing to take part in this research study, you must read the information in this research consent form. It includes details you need to know to decide if you wish to take part in the study. If you have any questions, ask the study handler. You should not sign this form until you are sure you understand the information. All research is voluntary. This studying is being conducted as part of a graduate student's research supervised by Dr Chai Soo See, a senior lecturer at the Department of Computing and Software Engineering at the Faculty of Computer Science and Information Technology (FCSIT) in Universiti Malaysia Sarawak (UNIMAS).

(C) Agree to the treatment. (Circle the answer selected.)

Do you agree to have an acrophobia treatment using Graded Exposure Therapy in a Virtual Reality environment?

YES / NO

STATEMENT OF CONSENT

Study Title: Combating acrophobia with the use of virtual reality and artificial intelligence.

The research study has been explained to me, and my questions have been answered to my satisfaction. I have been informed of the alternatives to participation in this study. I have the right not to participate in this study. As well, the potential harms and benefits (if any) of participating in this research study have been explained to me. I know that I may ask now, or in the future, ask any questions I have about the study. I have been told that records relating to me will be kept confidential and that no information will be disclosed without my permission unless required by law. I have been given sufficient time to read the above information. I consent to participate.

****NOTE**** All information taken from the study including your name will be coded to protect your personnel policy and right.

Name:

Signature: _____ Date: ____/____/202__

Appendix B: Visual Height Intolerance Severity Scale (vHISS)

(B) Visual Height Intolerance Severity Scale (vHISS)

Visual Height Intolerance Severity Scale (vHISS)		
Question	Yes ☐	No ☐
Have you already experienced Visual Height Intolerance (vHI) while looking from a		
Continue to fill out the rest of the questionnaire only if you	Continue	Finished
1. Because of your vHI, how much difficulty did you recently have doing sports?	0 ☐ 1 ☐	No difficulty Any difficulty (a little/moderately/quite a lot/very much).
2. Because of your vHI, how much difficulty did you recently have in your daily activities?	0 ☐ 1 ☐ 2 ☐	No difficulty A little Moderately/quite a lot/very much

3. Because of your vHI,		
how much is your quality	0 ☐	Not at all
of life affected?	1 ☐	A little
	2 ☐	Moderately/quite a lot/very much
4. I have vHI when		
exposed to heights	0 ☐	... occasionally
	1 ☐	... often/frequently/always
5. Now I have vHI that		
is ...	0 ☐	... less strong than before
	1 ☐	... just as strong as before
	2 ☐	... stronger than before
6. I have/had vHI for		
longer than 6 months	0 ☐	No
	1 ☐	Yes
List A	☐	a. Trembling
7. What bodily symptoms	☐	b. Palpitations
do you feel when exposed	☐	c. Inner agitation
to heights? (multiple	☐	d. Sweating/moist hands
answers possible)	☐	e. Light-headedness
	☐	f. Postural (to-and-fro) dizziness
	☐	g. Weakness in the knees
	☐	h. Instability of stance and gait
	☐	i. Malaise/queasy feeling in the stomach

		☐	j. Oppression
		☐	k. Fearfulness
		☐	l. Mental image of falling
		☐	m. Gait disorder
		☐	n. Others
		☐	None of the above
List B	☐	Standing on or climbing up a tower	
8. vHI is induced by			
my ... (multiple answers	☐	Standing on or walking over a bridge	
possible)			
	☐	Standing on or walking up steps	
	☐	Standing on or climbing up a ladder	
	☐	Standing on or walking on a balcony	
	☐	Looking out of a window	
	☐	Standing or walking on a scaffolding	
	☐	Standing or walking on a roof	
		☐	Riding on a carousel or a Ferris wheel
		☐	Riding in a ski lift or gondola

☐	Hiking/mountain climbing
☐	Rock climbing
☐	Other situations. If yes, please name
	
	

Additional questions for the diagnosis of acrophobia

9. Do you feel very intense	☐	Yes
fear or extremely strong	☐	No
fear when exposed to		
heights?		

10. I try in advance to avoid	☐	No
exposure to heights	☐	Yes

Scoring instructions for the vHISS.

The scale is based on a set of eight questions for determining the severity of vHI. Two of the questions are listed: one of the symptoms and one of the triggers. Two additional questions are for the assessment of acrophobia.

1. The severity of vHI.

- Sum up the score of items 1–6.
- Add up the number of symptoms reported from List A (item 7). If there are less than 4 symptoms, add 0 to the total score; if there are 4 or more symptoms, add 1 to the total

score. • Likewise, add up the number of triggers from List B (item 8). If there are less than 4 triggers, add 0 to the total score. If there are 4–6 triggers, add 1 to the total score. For 7–9 triggers, add 2 to the total score. For 10 or more triggers, add 3 to the total score.

The sum of items 1–6, plus items of List A plus items of List B yields the total severity score. Severity score:

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9	10	11	12	13	

2. Diagnosis of acrophobia.

To meet DSM-V criteria for the diagnosis, one must have

- At least one of the vegetative symptoms (a.–d.) from List A.
- Two other additional symptoms from List A.
- A positive response to item 6 (duration of at least 6 months) of the severity scale (yes).
- A positive response to items 9 and 10 (yes).

Acrophobia:

☐	☐
--------------------------	--------------------------

yes no

Appendix C: Attitude Towards Heights Questionnaire (ATHQ)

Attitude Towards Heights Questionnaire (ATHQ)

Question: How do you feel about the height experienced? (✓ on the selected score)

Item	Scoring										
	0	1	2	3	4	5	6	7	8	9	10
Good (0) – Bad (10)											
Comfort (0) – Terrible (10)											
Pleasant (0) – Unpleasant (10)											
Safe (0) – Dangerous (10)											
Non-threatening (0) – Threatening (10)											
Harmless (0) – Harmful (10)											
Total:											
Total Score:											