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Interactivity in VR Therapy: Assessing Efficacy Across Acrophobia Severity

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Abstract: Virtual Reality (VR) and Artificial Intelligence (AI) have gained popularity in medical treatments, including for acrophobia- a common but often untreated fear of heights. Traditional therapies are often expensive and complex, making VR therapy a convenient and safe alternative. This study evaluates the efficacy of an AI-augmented interactivity VR therapy for acrophobia, focusing on user satisfaction and treatment outcomes. Graded exposure VR therapy was used where participants were gradually exposed to VR environments tailored to their severity levels of acrophobia, guided by an AI agent based on the Behavioral Avoidance Test (BAT). Participants engaged in interactive tasks such as collecting flowers or coins, enhancing immersion and reducing anxiety. The participants were included based on the visual Height Intolerance Severity Scale (vHISS), which measured post-therapy fear levels with the Attitudes Towards Heights Questionnaire (ATHQ). Results showed a significant decrease in anxiety levels, with ATHQ scores dropping by an average of 25% across all severity groups ($p<0.05$). These findings suggest that AI-augmented VR therapy is a promising tool for treating acrophobia. Future research should explore optimizing interactivity to maximize therapeutic effectiveness for various severity levels.

Keywords: Virtual Reality, Artificial Intelligence, Acrophobia, Biophysical Measurement, Interactivity

Introduction

Acrophobia, identified as a natural environmental phobia, affects about 5% of the global population (Coelho and Wallis, 2010). Those afflicted experience profound and irrational anxiety in elevated settings or situations involving heights (Cleveland Clinic, 2021). Acrophobia can manifest in severe symptoms such as abdominal discomfort, balance loss or dizziness, heart palpitations, restlessness or pacing, tremors, nervousness, fear, knee weakness, chest tightness and a general sense of tension (Hodges *et al.*, 1995). These symptoms can significantly impede an individual's ability to engage in daily tasks or high-altitude activities, such as using step stools or ladders, cleaning ceiling fans, hanging curtains or even accessing tall buildings for work or study purposes, significantly distressing and disrupting a person's life (Antony and Rowa, 2007). Individuals with acrophobia exhibit a range of symptoms and severity levels, which can be assessed through both subjective self-reporting and physiological measures of arousal. Subjective fear is an individual's internal sense of fear (Immigration and Refugee Board of Canada, 2011). Various methods, such as the widely used Acrophobia Questionnaire-Anxiety Subscale (Cohen, 1977), can assess subjective anxiety levels. Acrophobia anxiety can induce physiological arousal, characterized by heightened heart rate and blood pressure, resulting from autonomic and neuroendocrine activation (Steimer, 2022).

Traditional Treatment Methods and Drawbacks

Acrophobia can be treatable through various therapies. Combining Cognitive-Behavioural Therapy (CBT) with medication has shown notable alleviation of symptoms and enhanced engagement in height-related activities (Kapfhammer *et al.*, 2015). Nevertheless, many individuals with acrophobia find it challenging to overcome their fear without external support (Andrews, 2007). Traditional acrophobia treatments, including CBT and medication, have shown some effectiveness, but they present several drawbacks:

- High cost and complexity: Traditional therapies often require significant financial and time investments, which can deter individuals from seeking treatment (Olfson *et al*., 2014)
- Safety concerns: Real-life exposure therapy, a common CBT method, can be risky and impractical for severe cases of acrophobia (Gega *et al*., 2007)
- Low acceptance: Many patients are unwilling to engage in vivo exposure due to fear, leading to high dropout rates (Öst, 1989)

Despite the effectiveness of traditional therapies for acrophobia, they face challenges such as high cost, safety concerns and low patient acceptance. This study aims to overcome these challenges by integrating AI and VR technologies to provide a safer, more cost-effective and engaging therapeutic alternative.

Virtual Reality and Artificial Intelligence in Therapy

Virtual Reality (VR) has been found to be applicable in the treatment of acrophobia, and its efficacy has been augmented by its integration with artificial intelligence (AI) across diverse therapeutic contexts (Maples-Keller *et al*., 2017). Traditional therapies involving real-life height exposure can be risky for acrophobic individuals. Acrophobia therapy requires repeated and controlled exposure, making a safe environment important. A VR environment can elicit acrophobia responses effectively by simulating real-world environments. VR can replicate genuine high places and facilitate users in confronting and managing their anxiety related to such environments (Suyanto *et al*., 2017). To address safety concerns, the VR environment offers a secure setting for therapy, enabling individuals to realize that their fear response is not justified and that they can manage the situation without significant harm.

Innovative Approach: AI-Integrated Virtual Therapy

In acrophobia therapy, integrating AI can help overcome the constraints of traditional methods. The therapist's encouragement and guidance are essential in this process. Thus, incorporating AI into the VR environment as an Artificial Virtual Agent (AVA) plays a significant role as a therapist during therapy sessions. Machine learning can automate the task of building analytical models and performing cognitive tasks (Janiesch *et al*., 2021). The integration of AI in mental health treatment holds the potential to improve the efficiency and effectiveness of therapies. 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.

The integration of AI as the foundation of AVA entities is aimed at facilitating interactions with users within a VR environment, exhibiting human-like behaviour and performing designated tasks. Fear can interrupt processes in the human brain's decision-making abilities (Delagran, 2012). 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 AVA's ability to offer instant, calming suggestions during moments of heightened fear could be revolutionary in therapeutic contexts. AVA can provide real-time guidance, encouragement and support throughout VRT sessions.

Understanding Individual Differences and Therapy Customization

Some phobic 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). Therefore, adopting a comprehensive approach to addressing acrophobia, including the categorization of individuals based on the severity of their condition before therapy initiation, is paramount. Understanding individual differences sheds light on fundamental variations among humans (Jackson, 2009). Various treatment methods are employed to tackle acrophobia, such as Virtual Reality Therapy (VRT), desensitization therapy, in vivo exposure therapy and graded exposure therapy, among others. Each method entails gradually exposing individuals to real-life situations or environments that elicit their fear. Biophysical measurements can evaluate the anxiety levels of individuals with acrophobia and confirm whether the VR environment has elicited their fear. Hang *et al*. (2022) suggest notable changes in brain regions, including the orbitofrontal cortex, medial prefrontal cortex and visual areas, among individuals with acrophobia. Biophysical measurement facilitates the development of targeted interventions and preventive strategies for acrophobia. Thus, this study involves biophysical measurements, such as Heart Rate (HR) and Electroencephalogram (EEG) data, which offer insight into subjective fear levels.

Leveraging Interactivity in VR Therapy

In recent years, advancements in technology have provided new avenues for addressing phobias, such as acrophobia, through innovative approaches like VR therapy. Building upon the principles of interactive learning environments, this study explores the integration of interactivity within VR-height experiences to mitigate acrophobia. Interactivity in learning environments refers to the dynamic engagement between the learner and the content (Laurillard, 2013), allowing for real-time feedback and adaptation based on the learner's actions. Interactive elements, such as tests, simulations and worked examples, serve as the tools that facilitate this interactivity by providing opportunities for active participation and immediate response. Atkinson and Renkl (2007) emphasize the effectiveness of these interactive elements in facilitating effective learning processes, particularly through the processing of worked examples. Ortiz and Elizondo (2023) highlight that interactive elements generate events and responses that could influence the sense of agency experienced by users during the interaction. Consequently, user engagement with these elements within the VR environment is likely to significantly impact their emotional state. Dozio *et al.* (2022) developed a methodology for designing effective Virtual Environments (VEs), categorizing emotions into five main categories (happiness, sadness, fear, anger and disgust) and identifying various design elements influencing emotional experiences, including valence, arousal and dominance. Their research demonstrates that interactivity within VR environments can effectively evoke emotional arousal in individuals. By incorporating interactive features into VR therapy sessions, users are provided with opportunities for active engagement and learning, thus enhancing their ability to confront and manage their fear of heights.

Theoretical Foundation

The approach to treating acrophobia through VRT with integrated AI draws upon several established psychological and technological theories and frameworks:

- Cognitive-Behavioural Therapy (CBT): CBT is a cornerstone in the treatment of anxiety disorders, including phobias. CBT focuses on altering maladaptive thought patterns and behaviours through structured interventions. In our approach, VR is employed as a tool for exposure therapy, a critical component of CBT, allowing patients to confront their fear of heights in a safe and controlled virtual environment
- Exposure therapy: Exposure therapy involves systematic desensitization through gradual exposure to feared stimuli. Traditionally implemented in vivo, exposure therapy helps patients reduce their anxiety responses over time. By leveraging VR technology, realistic height scenarios can be simulated, providing repeated and controlled exposure without the risks associated with real-life high places
- Interactive learning environments: Interactive learning environments are based on the principle that active participation enhances learning and retention. Our VR therapy incorporates interactivity that requires users to engage actively with the virtual environment. This engagement is designed to enhance the therapeutic process by keeping users immersed and focused, thereby facilitating better outcomes
- Artificial intelligence and machine learning: AI and machine learning enable the development of adaptive and personalized therapeutic interventions. The AI agent in our VR therapy acts as an Artificial Virtual Agent (AVA), providing real-time guidance, feedback and adjustment of exposure tasks. This adaptability ensures that the therapy is tailored to the individual's anxiety levels and progress, optimizing the treatment's effectiveness
- Biophysical measurement and feedback: Objective biophysical measurements, such as Heart Rate (HR) and Electroencephalogram (EEG) data, are critical in assessing the physiological arousal associated with acrophobia. These metrics provide real-time feedback on the user's anxiety levels, allowing for precise adjustments to the therapy. This data-driven approach ensures that the therapeutic interventions are responsive to the user's current state, enhancing the overall efficacy of the treatment

Our approach combines these theoretical foundations to create a comprehensive and innovative treatment method for acrophobia. By integrating CBT principles with advanced VR and AI technologies, we aim to provide a more effective, engaging and personalized therapeutic experience.

Objectives

This study aims to assess the efficacy of such interactivity in VR therapy, with a specific focus on examining variations based on initial fear levels. Unlike existing VR therapies that rely solely on pre-programmed scenarios, our approach incorporates an AI agent and task-based method that guides users through graded exposure tasks to provide real-time, adaptive interactions that are tailored to the user's individual anxiety levels and responses, enhancing engagement and immersion. Participants' anxiety levels are measured using both subjective Attitudes Toward Heights Questionnaire (ATHQ) and objective Behavioral Avoidance Task (BAT) metrics before and after therapy sessions. The main focus of this study is:

- Enhanced interactivity: The AI agent provides interactive tasks, making the therapy sessions more engaging and tailored to individual needs
- Personalized treatment: AI customizes the exposure levels based on real-time feedback, optimizing the therapy's effectiveness
- Comprehensive evaluation: Utilized both subjective questionnaires and objective

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behavioural tests to comprehensively assess the outcomes of therapy interactivity

To achieve this objective, the study employed the Kruskal-Wallis test to determine whether the effects of interactivity are influenced by the severity of acrophobia using the hypothesis below:

H_0: There are no significant differences in the Attitudes Towards Heights Questionnaire (ATHQ) scores among the three severity groups of acrophobias, indicating similar associations with interactivity

H_1: Significant differences exist in the ATHQ scores among the three severity groups of acrophobias, implying distinct associations with participants' subjective fear levels

Materials and Methods

VRT has gained traction in treating various phobias, including acrophobia, agoraphobia and fear of public speaking. Research demonstrates VRT's efficacy in addressing the fear of heights by providing controlled and repeated exposure to height-related stimuli (LeBeau *et al*., 2010). However, traditional therapies such as CBT and in vivo exposure have several drawbacks: High cost and complexity, safety concerns and low patient acceptance. This study aims to address these limitations by integrating AI into VR therapy, creating a more engaging and effective treatment for acrophobia. Thus, graded exposure VRT is utilized.

Graded Exposure VRT

In this study, graded exposure VRT is applied with the assistance of an AVA with AI core, guiding individuals to suitable experience levels. The VR therapy employs VR to simulate height-related situations with varying exposure levels. The therapy is implemented as an application developed using Unity 2019.4.20f1. The application features seven height levels: 1, 10, 20, 40, 60, 100 and 220 meters, with city and mountain landscape views. The graphic quality is set to ultra for realistic visuals.

Hardware and Software Configuration

The application is compatible with android versions 4.4-11.0, supporting XR-plugin management with 'None' and 'Cardboard-16-bit depth' multi-pass stereo rendering mode for VR and touch screen modes, interacting with the user without a VR controller. The VR equipment used is Google Daydream View, offering a 75.9-degree field of view. Walking within the VR environment is initiated by tilting the player's VR camera down by 30 degrees, enhancing immersion and user control, as illustrated in Fig. (1).

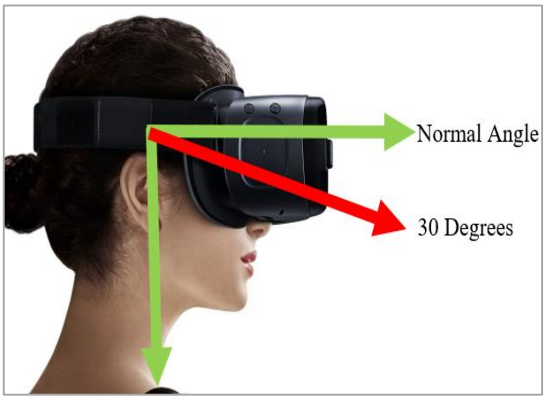

Fig. 1: Walking initiation view

Interactivity and AI Integration

The application integrates an AVA with an AI core to guide users through graded exposure tasks. The AVA provides real-time encouragement, level suggestions and task assignments, enhancing user engagement. The AVA model uses the decision-making capabilities offered by Unity's rule-based systems. Unity's platform provides flexibility for implementing and experimenting with reinforcement learning algorithms, enabling effective training of intelligent agents within the VR environment (Sam, 2013). These algorithms allow the AVA to make choices based on predefined rules and conditions. The Unity platform provides a flexible framework that facilitates the implementation and experimentation of various reinforcement learning algorithms, ensuring the effective training of intelligent agents. Juliani *et al*., 2018; Abdullah *et al.*, 2021 mention that immersion and realism play crucial roles in enhancing the relaxation experience. Baylor and Kim (2004) concluded that agents with more realistic images and expert roles facilitated the greater transfer of learning for individuals. In this study, 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.

Immersive and Realistic Environments

The application had graphics API levels 19-30. All VR 3D models are built using Blender 3D computer graphics software and Unity-free assets. To enhance immersion, the VR environments include city views with office buildings, traffic lights, streetlights, industrial areas and moving vehicles, as well as mountain views with snow-capped mountains, trees, rivers, waterfalls and foggy skyboxes. Soundtracks are added to reinforce the realism. Figure (2) illustrates an example of the city view and mountain view for the VR application.

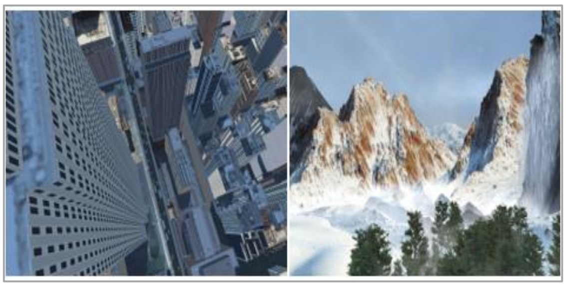

Fig. 2: City view and mountain view of the VR application

In this study, to enhance immersion and realism, the AVA is programmed to perform various actions, including blinking, looking around (Up and Down) and flying. These actions are implemented using a state-machine approach, which organizes animations in a structured and modular manner for efficient management and maintenance of the agent's logic. The AVA recognizes the user through the player tag and follows their movements, utilizing real-time distance processing to analyze the data related to the distance between itself and the player. This allows the AVA to make decisions and adapt its behaviour accordingly, ensuring it always follows the player and faces them at a speed of 3 units per frame with a distance of 2 units.

Behavioural Avoidance Test (BAT) Integration

The Behavioral Avoidance Test (BAT) is integrated into the VR environment to assess users' anxiety levels and guide the AVA in suggesting appropriate exposure levels. A BAT test observes an individual's approach to a feared situation until the individual is unable to go any further (Baylor and Kim, 2004). The BAT features a 220-meter-high staircase, with the AVA providing real-time support and encouragement throughout the task (Steketee *et al.*, 1996). The AVA accompanies the user throughout this BAT environment, following them closely. Throughout the BAT, AVA encourages users by displaying the words: Great Job! Keep Going! You've got this! Onward and Upward! No fear can befall you! and more. Figure (3) illustrates the BAT environment with the AVA positioned alongside the user, commencing the described rule.

Interactive Tasks for Enhanced Engagement

Interactivity in VR therapy, such as collecting coins or flowers in city and mountain scenes, is incorporated to divert users' attention from their fear and engage their logical thinking. This approach is based on the principle that interactivity occurs when there is a reciprocal relationship, such as conversation, databases, games, or social relationships, between two elements within a system (Tekinbas and Zimmerman, 2003). In this sense, interactivity facilitates engagement and communication between users and the virtual environment in the VR therapy sessions. The interaction between the AVA and the user through the demonstration section, encouragement, and suggestion section explicitly involved the interaction of the therapy. Anton *et al.* (2020) utilized a mathematical quiz to divert the user's attention away from the game, engaging their logical thinking while deactivating the emotional hemisphere. Similar to mathematical quizzes, this study involves collecting tasks which require the user to focus on the goal of collecting coins/flowers to direct attention away from other stimuli or emotional responses. Through interactive experiences, users can actively explore and engage with the therapeutic content, leading to a more immersive and effective therapy session. Figure (4) illustrates the task Scene for collecting coins and flowers in a city or mountain scene.

By integrating AI with VR therapy, our approach addresses the limitations of traditional acrophobia treatments, offering a safe, engaging and personalized therapeutic experience. This section detailed the development and implementation of our graded exposure VRT, highlighting its innovative features and theoretical foundations. The following sections will present the experimental design, results and a comprehensive comparison with state-of-the-art methods.

Participant Recruitment and Selection

This study employed a comprehensive recruitment approach, utilizing both online and offline methods. The survey link (https://docs.google.com/forms/d/e/1FAIpQLSeTxl3N-gR4fZwD2zOJUrbMK7h9gnYbTIExdNT9O_3ncZCVEg/viewform?usp=pp_url) was disseminated through various social media platforms such as Facebook, WhatsApp groups and Instagram.

Fig. 3: BAT Section with AVA of VR Application

Fig. 4: City View Task Scene and Mountain View Task Scene

Potential participants accessed and completed the Google Forms survey, which evaluated their eligibility by examining recent experiences with acrophobia, past attempts to seek help and the presence of claustrophobia or fear triggered by heights.

Interested individuals who completed the survey received detailed information about the study, including ethical clearance. Participants whose acrophobia and severity levels were confirmed using the Visual Height Intolerance Severity Scale (vHISS) questionnaire were contacted via WhatsApp or phone call for an initial meeting. During this meeting, they were provided with detailed information about the study.

Initial Assessment

In the initial phase, participants were assessed using the vHISS (Huppert *et al*., 2017), which provides a continuous quantification of acrophobia severity on a scale from 0 to 13. Based on the vHISS scores, participants were categorized into three severity levels: Low, medium, or high. After the assessment, participants provided informed consent to participate in the therapy sessions.

Biophysical Data Collection

Biophysical data, including heart rate and Electroencephalogram (EEG), were collected before the therapy and throughout the duration of the study. This data collection aimed to provide objective measures of participants' physiological responses to height-related stimuli during the VR therapy sessions.

Therapy Sessions

Each participant underwent VR therapy sessions at their own pace, scheduled twice a week for two weeks, totalling four sessions. The therapy sessions were administered using a mobile application-based graded exposure VR program. During these sessions, the VR environment featured interactivity tasks designed to enhance user engagement and immersion.

Data Collection and Analysis

After each therapy session, participants completed the Attitudes Towards Heights Questionnaire (ATHQ) to assess their current fear levels. The ATHQ responses, along with participants' exposure levels to height, were recorded for analysis. Quantitative methods, specifically the Kruskal-Wallis test (Kruskal & Wallis, 1952), were employed to compare the ATHQ results among the three severity groups (low, medium, high) of acrophobia. The Kruskal-Wallis test, with a significance level of 0.05 and degrees of freedom of 2, was used to analyze the H statistic. This statistical analysis aimed to evaluate the efficacy of the interactivity incorporated into the VR therapy sessions.

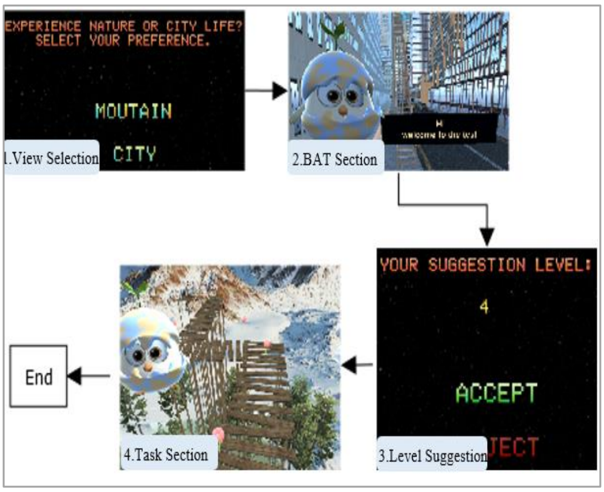

Fig. 5: Storyboard of the graded exposure VRT

Graded Exposure VRT Framework

In GVR therapy, users initially select a view on the "View Selection" interface, guiding them to the BAT section. When users enter the VR world, the AVA starts the test by giving instructions on navigating the VR environment. Afterwards, users commence the BAT test by ascending the stairs. If a user struggles with the height, they need to move forward to the glass area for a 10-second pause to allow the AVA to propose alternative levels. Decision-making algorithms trigger these suggestions based on the height. Once accepted, the user switches to the task scene and collects coins/flowers within the VR scene, tracking progress. After collecting all the items, the user advances to the end scene. Throughout, the AVA offers encouragement based on the user's score. Each session adapts to the user's pace. Figure (5) illustrates the storyboard of the graded exposure VRT.

Comparison with State-of-the-Art Methods

- Traditional exposure therapy: Conventional exposure therapy methods typically involve real-life exposure to heights, which can be logistically challenging and potentially distressing for patients. Unlike traditional methods, GVR therapy offers a controlled and safe environment where exposure levels can be precisely managed and adjusted according to individual tolerance
- Standard VR exposure therapy: While standard VR exposure therapy has been effective, it often lacks the dynamic and adaptive features that GVR therapy provides. Most VR therapies involve static scenarios without interactivity or AI-guided adjustments. The integration of AVA with AI capabilities in GVR therapy offers real-time, personalized guidance and encouragement, enhancing the therapeutic experience and potentially leading to better outcomes

- Self-guided VR applications: Self-guided VR applications are available for acrophobia treatment, but they may lack professional oversight and adaptive complexity. The GVR therapy framework combines AI-driven guidance with customizable exposure levels, ensuring that users receive a more tailored and supportive therapy experience compared to self-guided alternatives

Anxiety Assessment

Participants' heartbeats were measured using an Arduino KY-039 5V Finger Detection Heartbeat Sensor Module connected to an Arduino Uno microcontroller board. The recorded data was saved directly to an Excel file. 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 HR data had been filtered to ensure data accuracy.

The Emotiv Epoc+ device is utilized to detect the participant's EEG. The headset contains 14 electrodes, with EEG data sampled at 128 samples per second. A built-in digital 5th-order Sinc filter is used to eliminate noise and artefacts from the EEG signal, ensuring data quality. Additionally, Electrooculography (EOG) electrode sensors in the headset help reduce artefacts caused by eyeblinks, eye movements and extreme values. Choong *et al*. (2021), employing the 14-channel wireless Emotiv Epoc+ device, revealed that the FC6_F4 channel pair exhibited the highest correlation in the beta band for emotions such as anger, fear and surprise. This channel pair demonstrated a stronger functional relationship between the two brain regions and the corresponding emotional states. The EEG investigation primarily focuses on the fear responses associated with acrophobia (fear of heights) from participants. As a result, the analysis will primarily concentrate on the beta band channel pairs FC6_F4.

To gauge participants' fear of heights, the ATHQ (Abelson and Curtis, 1989), was used. Table (1) shows the ATHQ questionnaire.

This study utilized the Kruskal-Wallis test to compare the H statistic among the three severity groups of acrophobias (low, medium, high) and their corresponding ATHQ results, with a degree of freedom of 2 and a significance level of 0.05. The formula for calculating the *H* statistic is as follows:

$$H = \frac{n-1}{n} \cdot \sum_{i=0}^{k} \frac{n_i \cdot (\bar{R}_i - E_R)^2}{\sigma_R^2} \quad (1)$$

where:

n = Total sample size
n_i = Number of cases in each group
$\bar{R}_i$ = Mean rank sum
E_R = The expected value of the rankings
σ_R^2 = Rank variance

Table 1: Attitudes Toward Heights Questionnaire (ATHQ)

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

The Kruskal-Wallis test was conducted to determine significant differences in ATHQ scores across severity groups of acrophobias. This analysis aims to assess whether the effects of interactivity are influenced by the severity of acrophobia:

H_0: There are no significant differences in the ATHQ scores among the three severity groups of acrophobias, indicating similar associations with interactivity
H_1: Significant differences exist in the ATHQ scores among the three severity groups of acrophobias, implying distinct associations with participants' subjective fear levels

The BAT was incorporated into the VR environment, allowing the AVA to suggest exposure levels to users. The BAT provides a direct assessment of individual acrophobia levels by observing how far they can go in fear-inducing situations, allowing for a thorough examination of fear responses and accurate insights for therapy. BAT height data, indicating the extent of height exposure experienced by individuals with acrophobia, was recorded during each of the four therapy sessions for subsequent analysis.

Results and Discussion

Participant Characteristics and Demographics

This section provides an overview of the participants' characteristics and demographics. Initially, eighteen participants were involved in the research, but six

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discontinued treatments for autonomous reasons. Consequently, the final sample size totalled 12 participants, consisting of 2 male and 10 female participants aged between 19 and 26 years old. They represented diverse racial backgrounds, including Malay, Iban, Chinese, Indian and others. Among the 12 participants, only two had sought help for acrophobia before their inclusion in the study, and 3 had previous experience with VR environments. All participants reported a fear of heights, had at least a post-secondary education, specifically pre-university education and were students at UNIMAS in Malaysia. Additionally, none of them had any sudden illnesses that could pose safety concerns during the study. After conducting the Visual Height Intolerance Severity Scale (vHISS), the severity of acrophobia fear was measured and categorized for each participant. Table (2) displays the vHISS scores categorized by the severity of acrophobia.

In summary, an average of four participants could be categorized under each of the low, medium and high levels of acrophobia.

Biophysical Data Analysis

Figure (6) illustrates images of the participants with (a) Biophysical measurements of HR and (b) Biophysical measurements of EEG in the VR experiment.

The Arduino KY-039 5V Finger Detection Heartbeat Sensor Module was utilized to detect and record participants' heartbeats. To ensure data accuracy, the heartbeat data recorded by the Arduino IDE underwent a filtering process to remove unwanted values, such as heart rates exceeding 170 bpm.

Table 2: Severity levels of each participant with corresponding vHISS scores

No.	Severity level	vHISS scores
1	Low	4
2	Low	3
3	Low	3
4	Low	5
5	Medium	7
6	Medium	6
7	Medium	7
8	Medium	8
9	High	10
10	High	12
11	High	11
12	High	10

Fig. 6: Participants with (a) Biophysical Measurements of HR and (b) Biophysical Measurements of EEG

Table (3) illustrates the average heartbeat data for one participant, showing heart rate measurements in both normal and task states. The data reveal that the average heart rate of each participant increased when engaged in the assigned tasks at each level, confirming the effectiveness of the VR in provoking fear of heights.

For EEG data collection, the Emotiv Epoc + device was employed. According to the study by Choong *et al*. (2021), the 14-channel wireless Emotiv Epoc + device was utilized, with each channel paired and subjected to a one-way analysis of variance to assess variability among different emotional states, 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, indicating a stronger functional relationship between the two brain regions and their corresponding emotional states. This research primarily aimed to elicit responses to fear associated with acrophobia (fear of heights) from participants while they engaged in specific tasks within a VR environment. Consequently, the analysis will focus mainly on the beta band for the FC6-F4 channel pairs. Figure (7) displays the EEG band power frequency for the FC6-F4 channel pair for one participant during the test, highlighting the elevated values observed in the beta band throughout the task sessions.

Table 3: Average heart rate measurements for one participant in normal and task states

Number of times	Average heartbeat (BPM)	
1	N	82.99174
	IT	100.1099
2	N	82.83854
	IT	99.13343
3	N	82.92168
	IT	98.61356
4	N	83.19474
	IT	99.37713

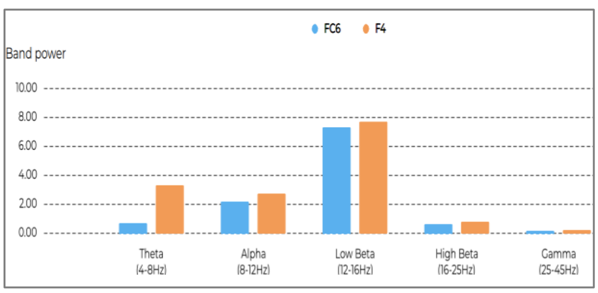

Fig. 7: EEG band power frequency for the fc6 - f4 channel pair of participants on task

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Attitude Toward Heights Questionnaire (ATHQ) Data Analysis

Table (4) presents the ATHQ scores of each participant at four different testing times. The participants' scores, divided into low, medium and high acrophobia severity groups, were recorded after they underwent graded exposure to VRT using the application.

Given the ATHQ results and a sample size of n = 12, the Kruskal-Wallis test is conducted to assess for differences across severity groups. The test statistic, denoted by the H statistic, is calculated. Initially, the ATHQ results from all severity groups are averaged over the four instances. These average scores are then ranked and ordered, resulting in combined ranks ranging from 1 to 12, as illustrated in Table (5).

The sum of ranks for the low-severity group is R_A = 19 (4+5+8+2), average rank sum $\bar{R}_A$ = 4.75 (19/4), for the medium severity group is R_B = 30 (1+10+12+7), the average rank sum is $\bar{R}_B$= 7.5 (30/4) and for the high-severity group is R_C = 29 (6+3+9+11), the average rank sum is $\bar{R}_C$= 7.25 (29/4). The H statistics are computed as follows:

$$H = \frac{12-1}{12} \cdot \left(\frac{(4.75-6.5)^2 + (7.5-6.5)^2 + (7.25-6.5)^2}{11.92}\right)$$

$$H = 1.4231$$

After calculating the *H* statistic value manually and obtaining a result of 1.4226, *R* software was employed to independently verify the calculation, yielding the same value. This confirms the accuracy of the calculated *H* statistic value.

Table 4: Attitudes Toward Heights Questionnaire (ATHQ) scores

No.	Severity level	ATHQ scores			
		1	2	3	4
1	High	49	28	24	23
2	High	41	22	22	21
3	High	34	38	38	29
4	High	43	48	42	42
5	Medium	13	16	15	10
6	Medium	38	38	38	37
7	Medium	44	49	43	42
8	Medium	35	31	31	30
9	Low	20	35	33	30
10	Low	30	27	33	33
11	Low	30	33	33	32
12	Low	24	23	22	22

Table 5: Average ATHQ results with ranks

Average ATHQ result					
Low - Rank		Medium - Rank		High - Rank	
29.5	4	13.5	1	31	6
30.75	5	37.75	10	26.5	3
32	8	44.5	12	34.75	9
22.75	2	31.75	7	43.75	11

To assess the significance of the *H* statistics, the critical value from the Kruskal-Wallis test was examined. At a 5% significance level, the critical value for accepting the null hypothesis is 5.991. The test statistic is H = 1.423. Since H = 1.423 is less than the critical value, H_0 is accepted and the alternative Hypothesis (H_1) is rejected. Thus, there is no significant difference in the ATHQ scores among the three severity groups of acrophobias, indicating similar associations with interactivity, supporting the null Hypothesis (H_0).

The acceptance of the null Hypothesis (H_0) suggests that there is no significant difference in the ATHQ scores among the three severity groups of acrophobias, indicating similar associations with interactivity. In conclusion, the Kruskal-Wallis test did not reveal any distinct impact of severity groups of acrophobias on interactivity in the VR environment for acrophobia treatment.

Effectiveness of Interactivity in VRT Across Different Acrophobia Categories in Participants

The ATHQ responses, along with BAT height data, indicating the extent of height exposure experienced by individuals with acrophobia, were recorded during each of the four therapy sessions for subsequent analysis. Figure (8) illustrates the BAT height data of the four therapy sessions for each participant.

Analysis of the BAT height data depicted in Fig. (8) reveals a consistent increase in BAT height achieved across therapy sessions. Among these participants, the highest increment in BAT height was observed in participant 6, who had a medium severity level of acrophobia, reaching a BAT height difference of 106 meters (61 meters in the first therapy and 167 meters in the fourth therapy). Conversely, the participant with the lowest improvement throughout the therapy was Participant 1, who had a high severity level of acrophobia, with a BAT height difference of 5 meters (9 meters in the first therapy and 14 meters in the last therapy).

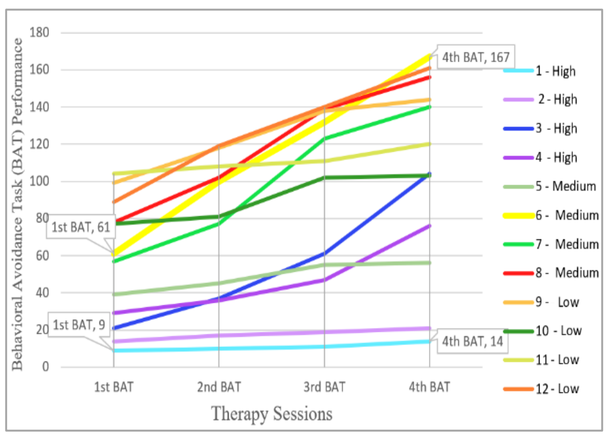

Fig. 8: Behavioral Avoidance Task (BAT) performance across therapy sessions

On average, participants demonstrated a 45% increase in BAT height, indicating significant progress in overcoming their fear of heights through the graded exposure VRT. The differences in the increment across the therapy sessions may be attributed to variations in the adaptability of individuals with acrophobia. According to the concept of Field Dependence-Independence Theory (Witkin and Goodenough, 1977), individuals differ in their ability to perceive and interpret visual information. Specifically, all participants demonstrated higher performance in the fourth BAT session compared to the initial session. This upward trend suggests that the interactive elements (such as AVA agents, encouragement, and collecting task elements), which enhance interactivity in the therapy application, effectively contribute to mitigating acrophobia.

Post-Therapy User Feedback

Additionally, post-therapy user feedback provided valuable insights into the user experience of the graded exposure VRT application. Feedback from individuals in different categories of acrophobia is illustrated in Table (6).

The comments collected from participants with varying degrees of acrophobia shed light on different insights for designing the virtual environment.

Low fear level analysis: Participants with low levels of acrophobia displayed a slight fear of heights but were able to divert their attention to wider or more distant points in the environment. One participant with low acrophobia found it entertaining to observe the agent looking around. They demonstrated a clear awareness of their surroundings, possibly due to feeling in control and perceiving the built environment as safe.

Table 6: Post-therapy user feedback

Feedback
Low Acrophobia Group
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; I know that I won't fall from the building
Medium Acrophobia Group
Experiencing different environments brought a sense of novelty
The agent attracted my attention
I suggest including some people walking around the building, like those living there.
I hope I can experience this therapy with a friend
High Acrophobia Group
I suggest having a more secure height environment, like a fence surrounding the high areas.
I hope there are handrails available during the therapy
I hope there are more protected areas, like solid wall barriers at the edge
I hope there is no glass area because it is a bit scary

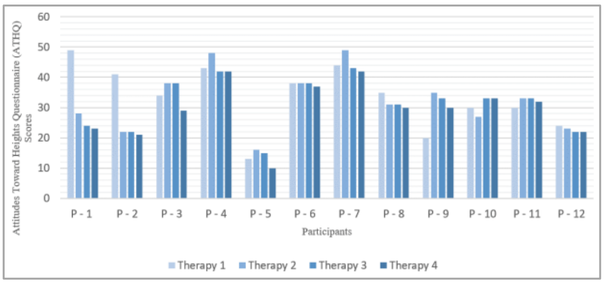

Fig. 9: The ATHQ scores of the acrophobia participants of each therapy session

Medium fear level analysis: Feedback from participants with medium levels of acrophobia suggested that they, too, could redirect their focus to the surroundings, possibly seeking a sense of companionship. One participant mentioned that experiencing different environments brought novelty and helped in diverting attention. They also suggested including models of people walking around the building to attract attention.

High fear level analysis: Individuals with high levels of acrophobia tended to focus more on their immediate surroundings. Their feedback, such as suggesting the inclusion of fences and handrails or removing glass barriers, indicated a need for a completely secure environment. They may require an interactive environment that can more directly capture their attention, such as tasks involving rescuing animals or people from dangerous situations, engaging in high-altitude photography, or simulating window washing on tall buildings.

This analysis reinforces the potential of the diverse needs of interactivity in graded exposure VRT as an effective approach for managing acrophobia across different fear levels.

ATHQ Score Changes

Personalized height levels, tailored to each individual's fear, led to a decrease in ATHQ scores across different acrophobia groups. Individuals with varying acrophobia severity responded differently; varied height levels were used to observe changes during therapy. All participants experienced these different height levels over the course of the therapy sessions, and ATHQ scores shifted accordingly. Furthermore, the gradual increase in height levels, combined with ATHQ results, showed a steady decrease in fear, indicating an improvement. Figure (9) illustrates the ATHQ scores of the four therapy sessions for each participant.

Limitations

- Participant diversity limitations: While the sample includes a range of ethnic backgrounds, the age range (19–26 years) and gender distribution (predominantly female) may limit the generalizability of the findings

Additionally, the relatively small sample size restricts the robustness of our conclusions. These demographic limitations suggest that future studies could benefit from a broader participant pool that spans diverse age groups, educational backgrounds and gender representation to enhance the applicability of results across various populations

- Restricted interaction complexity: Although the AI agent provides encouragement and guidance, its interaction capabilities are limited by predefined responses, resulting in reduced conversational flexibility. Users with high anxiety might benefit from a more sophisticated conversational model that can interpret and respond to a wider range of verbal and nonverbal cues, making the experience feel more natural and supportive
- Absence of immersive sensory elements: High-resolution, realistic VR settings are designed to evoke a fear response to create a more immersive and lifelike experience. Some participants with lower acrophobia levels suggested that wind or vibration effects would enhance realism and better induce a fear response. Unfortunately, due to resource constraints, these features could not be implemented, though they represent valuable opportunities for future development

These limitations highlight areas where improvements could enhance the VR and AI therapy's effectiveness and applicability. Addressing these factors in future research may strengthen the therapeutic impact and broaden the generalizability of findings, ultimately advancing VR-based treatments for acrophobia.

Conclusion

This study aimed to compare the relationships of different severity groups of acrophobias with ATHQ scores and the influence of interactivity on them in the context of VRT for individuals suffering from acrophobia. By examining these relationships, this study aimed to assess the differences in how acrophobia severity levels correspond with self-reported fear levels in the ATHQ. The research primarily indicated no significant difference in the ATHQ scores among the three severity groups of acrophobias, suggesting similar associations with interactivity. This underscores the potential for interactivity to effectively improve therapy outcomes across different severity levels.

Additionally, the efficacy of interactivity was not uniform across all subjects. Feedback provided by participants with varying levels of acrophobia offers invaluable insights into tailoring the design of interactivity for therapeutic interventions. Participants with low levels of acrophobia demonstrated a stronger capacity to manage their fear by focusing on distant points, indicating they have a sense of control and safety. Those with medium levels of acrophobia sought companionship and novelty in the virtual environment, suggesting the importance of incorporating interactivity that fosters engagement. Conversely, individuals with high levels of acrophobia prioritized the immediate surroundings and emphasized the need for a completely secure environment. Their feedback underscores the significance of integrating interactivity that captures attention effectively and provides a sense of security.

These insights provide a roadmap for refining graded exposure VRT, ensuring it meets the diverse needs of interactivity for individuals with different severity levels of acrophobia and maximizing its therapeutic effectiveness. The study was constrained by the small sample size of 12 participants. While the results provide valuable insights, the limited size of the participant pool may not capture the full scope and diversity of the population suffering from acrophobia. When harmoniously integrated with AI, these elements can provide a comprehensive and detailed perspective of acrophobia, thereby making treatment more effective and nuanced. Specific AI techniques, such as machine learning algorithms for adaptive feedback and real-time emotional state monitoring, could further refine therapeutic interventions. Although the findings are promising, they indicate the potential of applying diverse interactivity into therapy with VR and AI technologies to effectively mitigate acrophobia. Continued research in this area could lead to significant advancements in mental health treatment, providing tailored, effective solutions for individuals with various phobias.

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Author’s Contributions

Chiew Mei Chan: Conceived and designed the research, developed the research plan, acquired, analyzed, and interpreted the data, wrote the majority of the manuscript, and played a significant role in creating new software used in the work.

Soo See Chai: Provided guidance and oversight on the research concept, analyzed and interpreted the data, and revised the manuscript.

Kok Luong Goh: Was involved in constructing the instruments and the conceptual design of the study.

Sze Kiat Sim: Reviewed the manuscript and provided feedback.

Ethics

All participants provided informed consent and the research received ethical approval from the Human Research Ethics Committee (Non-Medical) with reference no: HREC (NM)/2022 (1)/24 at Universiti Malaysia Sarawak (UNIMAS).

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