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Category	*Min*	*Max*	Chosen
Requirement Analysis and Design	*0*	*20*	0
Theoretical Analysis	*0*	*25*	0
Experiment Design and Execution	*0*	*20*	20
System Development and Implementation	*0*	*20*	10
Results, Findings and Conclusions	*10*	*20*	20
Aim Formulation and Background Work	*10*	*15*	10
Quality of Paper Writing and Presentation	*10*		10
Quality of Deliverables	*10*		10
Overall General Project Evaluation (*this section allowed only with motivation letter from supervisor*)	*0*	*10*	0
Total marks		**80**	

A Tool to Elicit Awe Using Virtual Reality

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ABSTRACT

This user study (n=10) serves as a pilot investigation into a solution to inducing awe in a virtual environment, with the aim of assisting further research into the emotion and contributing to psychotherapy and the rehabilitation process of depression. The immersive environment comprises a range of known awe-inducing factors all encapsulated in a mountainous scene. Vast mountain landscapes viewed from high above, closeup steep cliffs, real-world audio, and intricate detail were all incorporated into the simulated environment to create an immersive scene. The built scene was tested against a control environment which induced no emotion. As anticipated, the findings demonstrated that the awe-inducing virtual environment elicited higher levels of awe and presence than the control VE. These results affirm the immersive potential of VR in generating awe and offer valuable insights for crafting awe-inspiring virtual environments.

KEYWORDS

Virtual Reality, Virtual Environment, Awe, Elicitation, Presence, Physiological

1 Introduction

The controlled elicitation of emotions is an area of increasing interest, owing to the impact emotions have on one's thoughts and behaviour. Virtual reality (VR) is a technology that uses specialized equipment for users to navigate through a computer-generated, three-dimensional (3D) simulation. VR provides means to transport users beyond spatial constraints into a new artificial world. With sufficient resources, a lifelike scene can be mimicked for the user to explore. VR applications designed to evoke emotions serve various purposes. One popular use involves exposure therapy, in which environments are designed to trigger specific fears, assisting individuals in conquering these anxieties [2]. Another domain of use is psychotherapy, where VR environments are tailored to induce stress related to patients' specific past traumas, aiding them in their journey to healing [4,42]. Realistic simulations find applications in education and training, particularly in scenarios where real-life practice is too dangerous, and emotions can influence behaviour. Emotion-inducing VEs are also valuable for the study of human behaviour and decision-making, as well as for assisting individuals dealing with depression and enhancing overall well-being and social skills [23,25,16,24].

An area with less attention to date, although increasing significantly, is the elicitation of awe using VR. The heightened attention in recent years has been driven by research indicating that awe is linked to transformative changes, encompassing both physical and psychological aspects [16,3] Awe is a complex emotion that is both intensely pleasurable and slightly fearful [15]. Feelings of awe can be both positive or negative and can be triggered by a range of stimuli [12, 14]. In 2003, Keltner & Haidt proposed five features that "flavour" awe experiences, which are beauty, threat, ability, virtue, and supernatural causality [15]. Threat-based awe often comes hand in hand with fear. Situations that may trigger this kind of awe include natural disasters or extreme landscapes. On the other hand, beauty-based awe is seasoned with sensory satisfaction, and can be evoked by a person, natural setting, or artwork. When it comes to ability-based awe, it is typically linked to our admiration for a person's exceptional ability, talent, and skill. Virtue-based awe, which we experience when we encounter individuals displaying remarkable virtue and strength of character, often accompanies feelings of elevation. Lastly, supernatural causality-based awe, which might be triggered by encounters with entities like angels, ghosts, or peculiar floating objects, carries with it a mysterious aspect. This aspect can be either terrifying or glorious, depending on the source of the experience.

Awe is generally linked to extreme feelings of wonder, connectedness, and surprise [3,8]. It is characterized by perceived vastness and a need for accommodation, referring to something large or complex to comprehend, which challenges one's mental schemas [2, 15]. An experience triggers a need for accommodation when it contradicts our normal understanding of the world. When a stimulus surpasses our expectations in any manner, it may incite an effort to modify the mental frameworks we use to make sense of the world. The concept of perceived vastness can result from observing something of substantial physical size, such as the Grand Canyon, or from a more abstract, perceptual sense of vastness, such as when encountering a complex idea.

Awe experiences yield numerous benefits, including transforming one's perspective, worldview, and self-perceptron, improving wellness, satisfaction with life, social interaction and even protecting the immune system [3,5,8,9]. Furthermore, exploration increases while aggression declines, and people become encouraged to care for the planet [8,10]. However, financial constraints and physical restrictions make it difficult for people to experience awe-inspiring activities.

The intersection of awe and VR is a relatively unexplored area which presents a compelling opportunity to unearth VR's capacity to evoke awe, while also deepening our comprehension of awe's triggers within virtual environments (VE) and VR's influence on human emotions and experiences. This study seeks to investigate a solution to induce awe. The core objective of this project is to address the pivotal question: "Can a mountain VE designed with numerous awe-eliciting features generate an awe response?" This paper will present the system's design and outline the experimental procedure.

2 Related Work

There are limited studies on the use of VR to elicit awe. On the other hand, there has been extensive research on general emotion elicitation using VR. It has been established that there is no universal solution for emotion elicitation, but visual stimuli, music and recalling positive personal experiences are the key mediums to induce an emotional response [6]. Rather than testing these mediums in isolation, VR supports the testing of combinations of them which is also known to be more effective [6].

2.1 The role of presence

Literature suggests that VR serves as one of the best tools to elicit an emotional response owing its immersive abilities which increase the involvement and sense of presence a user experiences [4,7,8]. Presence refers to the feeling of really being there and the strength of this presence a user experiences in the simulated environment is correlated with the effectiveness of a VR application in eliciting an emotion [11]. While various models concerning the concept of presence have been put forth, most studies agree that presence is a multifaceted phenomenon that encompasses numerous sub-elements [20,13]. The first element is essentially the perception of being transported to an alternative physical location. The second element relates to perceptual realism, which measures how closely the virtual stimuli resemble their real-world counterparts on which they are based [18]. Another element is the feeling of immersion, which is the extent to which users feel surrounded by the environment [7]. The core considerations of a VE to increase immersion include visual vividness and depth that a 3D environment enables, as well as the wealth of information they offer through multiple senses like images, sound, scents, and touch sensations [9]. Lastly, a crucial element of presence concerns the level of interest users have in a VE, otherwise referred to as their level of engagement. [19].

2.2 Virtually induced awe

Research on awe has grown great interest of late, but VR has only been used as an elicitation method very recently. Although new, VR is clearly more effective at producing awe in controlled environments than older methods such as 2D videos [3]. Awe elicitors are most commonly found in nature [15,16,17]. For this reason, all recent studies have implemented natural scenes and prioritized the scaling of objects, vastness, and aesthetic beauty in the VEs. Chirico et al. constructed three VEs to evoke feelings of awe, each featuring natural landscapes [3]. The initial environment portrayed a forest, emphasizing vastness through the height of tall trees. The second environment showcased a lofty snow-covered mountain, highlighting expansiveness as a key element of vastness. Lastly, they created a view of Earth from deep space, which was perceived as a representation of conceptual vastness. Quesnel & Riecke expand further to suggest that real-world simulations of environments which users choose themselves can prove very successful [9]. Participants were free to choose any scene from Google Earth VR, an application that offers a multitude of stereoscopic 3D locations, featuring real-time imagery. Users generally chose a place that was familiar to them. Another important consideration noted by literature is the level of engagement the user has. More engagement is known to induce higher levels of awe [3]. Engagement refers to the involvement or perceived connection a user feels from a VE and can come in the form of interactivity, compelling designs, and multisensory experiences.

2.3 Measuring awe

Awe can be assessed through various methods, which fall into two categories: objective physiological measurements and subjective self-reported evaluations.

A study in 2011 by Shiota et al. explored the connection between positive emotions and the autonomic nervous system (ANS) [27]. The ANS consists of the sympathetic branch, which controls the “fight or flight” responses, and the parasympathetic branch, which is responsible for the “resting and digesting” functions. The results largely indicated that parasympathetic activity increases, and sympathetic activity decreases with awe. Parasympathetic activity promotes a state of relaxation, meaning heart rate (HR) tends to slow down. The only exception to their findings was an increase in respiration rate (RR), which is associated with the sympathetic nervous system. However, a more recent study by Gordon et al. suggests that ANS responses to awe may vary depending on the type of awe experienced [30]. This study found that experiencing threat-based awe, triggered by watching a video with ominous content, led to increased sympathetic nervous system activity. These findings imply that different forms of awe, including threat-based awe, may have distinct physiological effects compared to more positive forms of awe. The ANS controls another physiological response in which awe can present itself: goosebumps [9]. The study by Quesnel & Riecke showed there is a positive correlation between awe experienced and physical goosebumps. To record goosebump activity, an instrument with a small camera was designed and placed on the lower forearm of subjects. Goosebumps stand out as a distinctive physiological measure, especially since ANS activation can be a response to a range of emotions, posing a challenge in pinpointing the specific emotional reaction.

Self-report measures are frequently employed for assessing awe, typically taking the form of questionnaires or interview inquiries. Questionnaires usually come in the form of a Likert scale whereby participants are required to rate the extent to which they experience an emotion or feeling. In the study completed by Quesnel & Riecke, participants had to score the degree to which they felt awe, wonder, curiosity, and humility. The latter three emotions have been known to be linked to awe and so provided a more diverse way to measure awe [15,14,24]. Other studies have focused more on the underlying attributes of awe, rather than one simple rating of the emotion itself. As mentioned previously, awe is identified by perceived vastness and a need for accommodation. Chirico et al. implemented a questionnaire containing four items to measure perceived vastness, and four items to measure need for accommodation [3]. The former section focused on a sensation of feeling diminished, and the latter was based on difficulty to comprehend what was witnessed. Interview questions generally tend to assess awe in a similar, indirect way. Questions related to the aspects of awe are almost always asked.

2.4 Limitations

At present, research exploring the elicitation of awe through VR remains notably limited. Existing studies have primarily concentrated on visual stimuli as agents of awe induction, yet there exists a substantial scope for investigating a broader spectrum of VR stimuli and interaction patterns as potential awe triggers. Furthermore, the assessment of awe poses unique challenges, given its potential overlap with physiological responses associated with other emotions. Therefore, there is a pressing need for a deeper understanding of optimal strategies for evoking awe within VR environments, as well as for refining the methods used to assess this complex emotional experience.

3 System Development and Implementation

The final system includes a tutorial scene as well as a mountain scene. An agile methodology was followed which is further described in section 3.3.

3.1 Overview of system features

The tutorial room, which served as the baseline, was kept as simple as possible with no awe-evocative aspects, while the mountain VE was designed with a range of awe-eliciting features. The scene was based off Mount Hua in China, one of the Five Great Mountains of China. Mount Hua was chosen as the inspiration due to its myriad awe-inspiring attributes. The mountain is rich with natural beauty, cultural heritage, and challenging terrain. These qualities of Mount Hua served as the primary source of inspiration when designing the VR environment. In the VE, the user is initially situated at a significant elevation within a mountainous landscape, a deliberate choice aimed at invoking a sense of threat-based awe. Commencing from a secluded vantage point within a rocky enclave, the user's view is intentionally obscured, encouraging a sense of the need for accommodation for what lies behind - a hallmark of the awe experience.

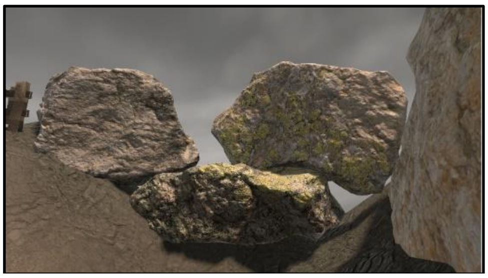

Figure 1: the rock enclosed spawn point

As users progress through the VE, strategically placed objects pique curiosity and further enhance the need for accommodation through this sense of surprise. Along the mountain's precipitous edge, a vast panorama of the mountainous terrain stretches to one side, while a steep rock cliff looms on the other, accentuating the concepts of spatial vastness both horizontally and vertically, respectively. Continuing the journey, users encounter meticulously crafted statues, an ornate archway, and an intricately detailed pagoda, mirroring the artistic grandeur often associated with awe-inducing stimuli. Positioned as the ultimate viewpoint, the pagoda offers users an immersive 360° panorama of the awe-inspiring mountain range. A wind sound was also added to enhance the presence a user would feel by targeting a new sense.

Figure 2: the pagoda in the final VE

3.2 Requirements gathering

Several sources were referenced to determine the project requirements. A design document was produced in the initial phase of the project to visualise the idea. Throughout the development process regular meetings with the project supervisor were scheduled to ensure the scope was suitable. The scope involved redesigning and developing the VE, as well as running thorough tests of the system to evaluate it. A number of resources were required to complete the project. Firstly, the UCT Computer Science Department supplied the VR equipment and assets from the Unity asset store. Along with this, a Vrije Universiteit – Ambulatory Monitoring System (VU-AMS) device and all the additional required pieces were provided for user experiments. The project owner was expected to know how to develop in Unity and to gather self-report measures which were found in literature. Microsoft Teams was used for all communication.

3.3 Design approach
The implementation of the project followed an agile design methodology.

Iteration 1

The terrain was first raised to be sufficiently high and to resemble that of a mountain. A suitable skybox was selected, and the user's starting position was lowered to create the ditch to narrow their view. A brick archway was added along with some brick fences to prevent the user from falling off the mountain edge. A few mountain assets were added to the scene and a realistic cliff-like rock texture was chosen for the mountain above and surrounding mountains.

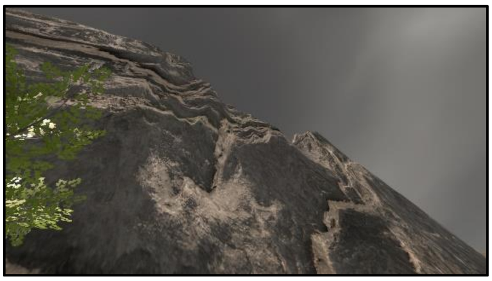

Figure 3: the steep mountain above in the final VE

Iteration 2

The surrounding mountain textures were not rendering well which prompted the developer to find new materials to use. The user was also not restricted with where they could move, which led to additional fences being added. The brick material for the archway and fences did not seem suitable for the Chinese theme and were consequently changed to a more rock-like texture. Additional Chinese inspired objects such as the pagoda, lamps, statues, and trees were integrated into the scene.

Figure 4: statues and lamps in the final VE

Iteration 3

The rock texture of the terrain would render well from nearby but was too repetitive from a distance. As a result, three additional textures were added and were varied to enhance the realism of the terrain. The trees were also too bright which prompted the developer to find more realistic trees to replace them. The statues, fences and pagoda were all scaled too large. Thus, the size of all these objects was adjusted accordingly. The ditch was also changed to have rock objects surrounding the origin.

Figure 5: detail of the pagoda in the final VE

Iteration 4

In the final iteration of development grass textures were painted onto the terrain. Time constraints meant the VE was also deemed too long. To fix this the starting point was brought closer. The user also had collision issues with the updated trees. Hence, mesh colliders had to be added to the tree objects. A mesh collider is a component that gets attached to a GameObject in Unity to give it a collision shape that matches the geometry of a 3D mesh. The snow material on the surrounding mountains did not appear real which resulted in new materials being chosen to replace the old ones. The natural aspect of the scene required a high sense of realism to ensure participants would experience a greater sense of presence. A light fog was added to give a more realistic impact and the user's viewing distance was adjusted to prevent disappearing objects. The movement speed was also increased to match that of the real world and a wind audio was added to increase immersion.

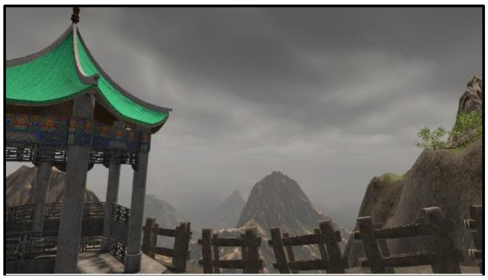

Figure 6: the vast landscape in the final VE

3.4 Testing
Throughout the development of the VE, both functional and non-functional testing techniques were performed.

Functional tests

In the early stages, unit tests were run to ensure the physics and character movement matched that of the real world. Following this, regular unit tests as well as integration tests were performed to verify the collision between GameObjects was working as intended.

Non-functional tests

Performance was an important consideration throughout the project. The frame rate had to be kept above 60 frames per second (fps) to limit the lag a user would experience. Latency in VR can have several negative consequences. Motion sickness is one of the most significant issues that arises with lag. This delay can also disrupt immersion as user's actions become disconnected from the system's response. Lastly, framerate instability can detract from the realism of the VE due to display juddering. There were regular issues with the computational load which had to be addressed. Consequently, textures needed to be compressed and the level of detail (LOD) of GameObjects had to be altered to reduce the load. Ultimately, the VE transformed into a scene balanced between quality and performance. Towards the end of development, a thorough alpha test was performed by the project owner to uncover any bugs or unexpected responses from the system. A final Beta test was performed by two Computer Science Honours students to externally validate the usability of the VE.

In the later stages of development, the project supervisor evaluated the heuristics of the VE in the form of a video analysis. This was predominantly due to unforeseen circumstances. The realism of the VE was deemed adequate as distractions that may break immersion were minimalised. The navigation within the VE was considered satisfactory, largely attributed to the texture of the stony path. The issues brought up were in respect of the mitigating motion sickness. The speed of locomotion had to be lowered and the path had to be smoothed in steeper areas to prevent abrupt camera movements. It was unfortunate that time constraints prevented a physical viewing, as this should result in a more thorough evaluation and consequently more effective solution.

4 Experimental Design and Execution

The independent variable for this experiment is the VE in which the user is immersed into. A within-subjects study was conducted to determine whether the VE would elicit awe in participants.

4.1 Participants

The user study comprised of 10 individuals who were sampled from both undergraduate and postgraduate UCT students. The limited sample size is primarily a result of this study serving as a pilot investigation aimed at collecting preliminary data for a larger future study. The current experiment is specifically designed to detect a sizable effect, making a smaller sample size adequate for this purpose. The participants were required to complete a Google Form which outlined the experiment procedure and highlighted key points for them to consider. These included electrode placement, time requirements, VR side effects and potential emotion elicitation effects. Participants were only selected if they were comfortable with what was stated in the online form. The resulting participant pool consisted of six males and four females, representing a diverse and heterogenous group.

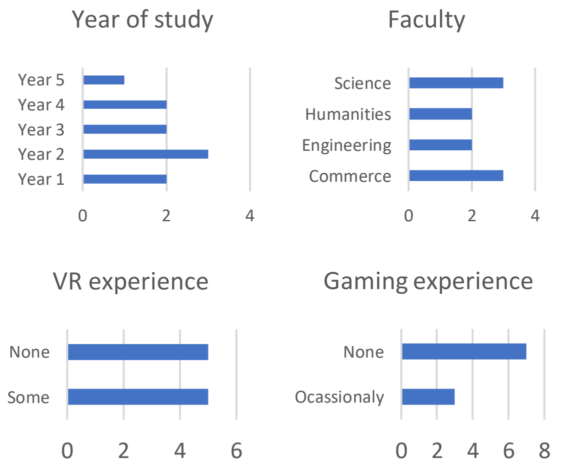

Figure 7: characteristics overview of participants

4.2 Ethical considerations

Ethics clearance was crucial for this VR experiment in order to protect the rights, safety and well-being of the human participants. Clearance was obtained for all UCT students. Outlined below are important considerations made regarding good ethical practice.

4.2.1 Concealing the Study's Purpose

Emotion inducing studies are known to be susceptible to the Hawthorne Effect [1]. Participants have been known to change their behaviour and subjective responses when testing outcomes are known. To avoid skewed results the study was masked as a broad VR emotional study as opposed to simply targeting an awe response. To ensure the deception was in line with acceptable practice, the American Psychologists Association's Criteria for Ethical Deception was consulted [33]. Firstly, the research contribution to the field of psychology was considered significant enough to be justifiable, and nondeceptive methods would degrade the research integrity. Next, the pre-experiment Google Form ensured anyone vulnerable to motion sickness was excluded from the study. Participants were also informed they could stop the experiment at any point should they experience simulator sickness. Finally, in the debriefing directly after the questionnaires were completed, participants were made aware of the actual reason behind the study. They were then given the option of having their results discarded if they wished.

4.2.2 Other Considerations

Participants were required to complete a VR consent form at the start of each run. The study was a paid participation and followed standard UCT research practice. All responses were also anonymised to protect the participants, and all the experimental data will remain within this study.

4.3 Measurements

Awe can be measured through physiological recordings as well as qualitative self-report. This study incorporated a combination of the two techniques for a thorough approach.

4.3.1 Physiological

Physiological measures were taken throughout immersion using a VU-AMS device. This device records Electrocardiography (ECG) as well as Impedance Cardiography (ICG). A configuration of 7 electrodes, placed on the front and back of the subject, was required for the readings. An isotonic gel applied to the transistor ensured a good reading on the device. For the purpose of this experiment, we required heart rate (HR) and respiration rate (RR) measurements of the participants. HR was quantified in beats per minute and an average measure was taken over the entire duration of each VE. RR, measured in breaths per minute, similarly yielded an average computed throughout the immersion period. Literature suggests that the change of these measures one can expect depends on the aspects of the VE. Threat-based aspects will cause an increase in the sympathetic function of the ANS where one can expect to see an increase in HR and a decrease in RR [30]. In contrast, having non-threatening aspects will more likely increase parasympathetic function of the ANS and one can expect to see a decrease in HR and an increase in RR [27]. As a result, in this experiment, we aimed to detect changes in both HR and RR, rather than focusing solely on an increase or decrease in either one.

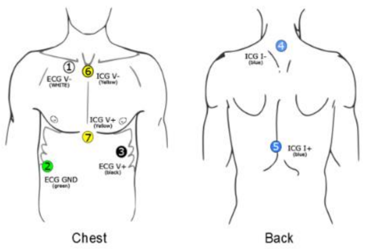

Figure 8: electrode placement for measurement of HR and RR using the VU-AMS device

4.3.2 Self-report

Subjective qualitative measures were gathered post-immersion in the form of a self-report questionnaire (SRQ). The Brief Presence Questionnaire (BPQ) served as a tool to assess the participants' perception of presence within the VE - a method validated by Diemer et al. in 2015 [7]. It involves a straightforward inquiry, asking participants to rate their sense of actually being present in the VE on a scale ranging from 0 to 100. In this study, a modified version of the BPQ was utilized, where participants were asked to provide their responses on a scale of 1 to 10. Participants were also given eight distinct emotions – anger, joy, sadness, pride, awe, amusement, fear, and disgust – and they were required to rate the extent to which each emotion was experienced on a 5-point Likert scale (1 = nothing; 5 = extremely). This method of assessment follows that used by Chirico et al. where a 7-point Likert scale was employed instead [3]. In that study it seemed difficult to differentiate particular points on the scale. Longer scales can also sometimes lead to response fatigue. Using 5 levels reduced the complexity of the scale, providing clearer distinctions and making it more user-friendly.
Along with this, the Awe Experience Scale (AWE-S) questionnaire was also included in the assessment. The AWE-S questionnaire is a dependable tool that measures awe using six factors [14]. It combines past research on awe and enables new investigations into awe's various aspects. It supports the assessment of the role several dimensions of awe have on outcomes. The AWE-S questionnaire consists of 30 questions, each requiring a rating on a 5-point scale of an "experience" or perception the user encounters. The ratings are summed, and a higher score is indicative of more awe experienced.

4.4 Procedure
Each of the trials started with an initial briefing of the participant. They were once again informed on the study's objectives and procedures before being asked to provide demographic information, which encompassed inquiries about their gaming and VR experiences. Following this, the participant had to sign the consent form before the electrodes were connected according to the VU-AMS manual. The electrode placements were then optimised for accurate readings before the device started recording responses. The participants would then enter the tutorial room where they would learn the basic VR controls. Once they were comfortable with the controls, they would have to complete the SRQ for the first time. After this they would be immersed into the awe-inspired VE where they would explore for no longer than ten minutes. They were then tasked to complete the SRQ once again before they were debriefed. Four VU-AMS timestamps were taken throughout the procedure – one each time they entered or exited each of the VEs. In the debriefing participants were informed about the true purpose of the experiment and they were assessed for any simulator sickness before they were remunerated and could leave.

4.5 Statistical Analysis
Descriptive statistics of both the objective and subjective measures were generated to analyse the data. A Shapiro-Wilk test was employed to verify the normality of the data. In cases where the data did not meet normality assumptions, we conducted outlier detection through visual inspection of boxplots and removal procedures before retesting the data for normality. If the data continued to deviate from a normal distribution after these steps, it was considered non-normally distributed.

5 Results and Discussions
The statistical analysis and findings of measurements are explained hereunder. All reported effects maintain a significance level of 0.05.

5.1 Physiological results
One of the readings from the VU-AMS device was corrupt and had to be disregarded from the data.

Table 1: summary of tests for significant change

Test description	Sample size	Test type	P(T<t)/P-value	Significant?
Heart rate change	8	Two-tailed t-Test	0.07401	NO
Heart rate increase	8	Upper-tailed t-Test	0.037	YES
Respiration rate	9	Two-tailed t-Test	0.7382	NO
Respiration rate decrease	9	Lower-tailed t-Test	0.3691	NO

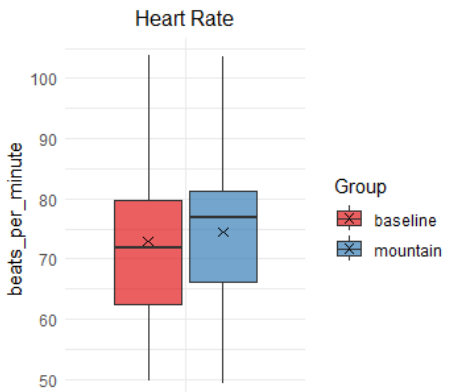

Figure 9: boxplot of HR with superimposed means (X)

From figure 9 above, there are indications that there was an increase in the HR of participants from the tutorial VE to the mountain VE. The results were first tested for a significant change, but this change was not deemed significant at the 0.05 level according to a paired sample, two-tailed t-test. The results were then tested with a paired sample one-tailed t-test for an increase only. This test confirmed that there was a significant increase in HR from the baseline VE to the mountain VE at the 5% significance level ($p < 0.05$).

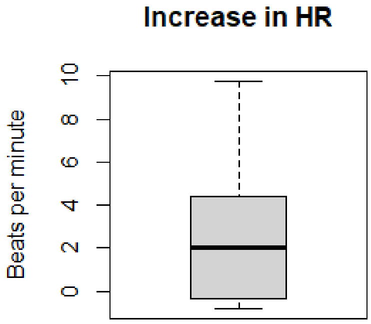

Figure 10: increase in HR from baseline

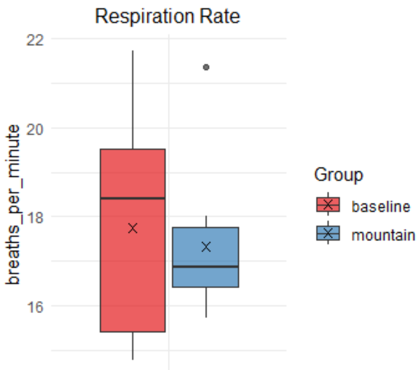

Figure 11: boxplot of RR with superimposed means (X)

In figure 11 above, the obvious outlier in the mountain VE was irrelevant as it did not significantly influence the differences, and the analysis focused on the differences. There is evidence that there was a decrease in the RR of participants from the tutorial VE to the mountain VE. The results were first tested for a significant change, but this change was not deemed significant at the 0.05 level according to a paired sample, two-tailed t-test. The results were then tested with a paired sample one-tailed t-test for a decrease only. There was, however, no significant decrease from the baseline VE to the mountain VE at the 5% significance level ($p > 0.05$).

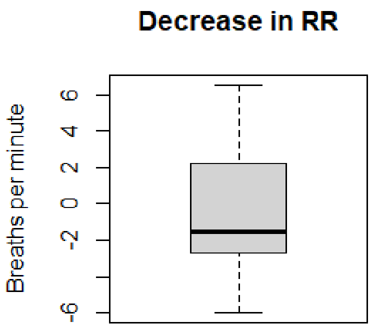

Figure 12: decrease in RR from baseline

5.2 Self-report results
Given that the self-report measurements were collected as responses on a scale, it is important to note that many of these measurements did not exhibit a normal distribution. In order to mitigate the influence of outliers and address data skewness, thorough outlier checks were conducted within the group differences. If the data continued to deviate from normality even after outlier management, the Wilcoxon paired sample t-test was employed, as it is recognized for its robustness in handling non-normally distributed data.

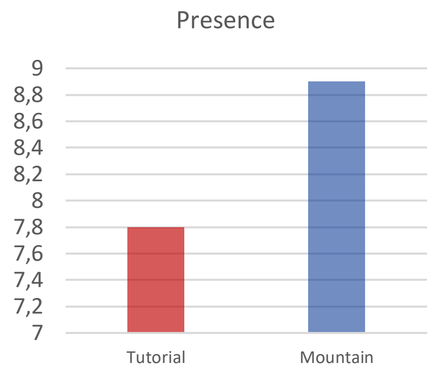

Figure 13: mean presence rating of the VEs

The first measure in the questionnaire assessed the presence a user felt which is a measure of how much the user felt as though they were physically there. The average presence experienced in both VEs is high, but there is a noticeable increase from the tutorial VE to the mountain VE. This increase was significant according to a Wilcoxon paired sample t-test ($p < 0.05$).

Table 2: summary of tests for significant difference

Test description	Sample size	Test type	P(T<t)/P-value (upper-tailed)	Significant?
Presence	10	Wilcoxon t-Test	0.003004	YES
Emotion Joy	10	t-Test	0.04787	YES
Emotion Pride	10	Wilcoxon t-Test	0.1855	NO
Emotion Awe	10	Wilcoxon t-Test	0.02838	YES
Emotion Amusement	10	Wilcoxon t-Test	0.00519	YES
Emotion Fear	10	Wilcoxon t-Test	0.1165	NO
AWE S score	9	Wilcoxon t-Test	0.007074	YES

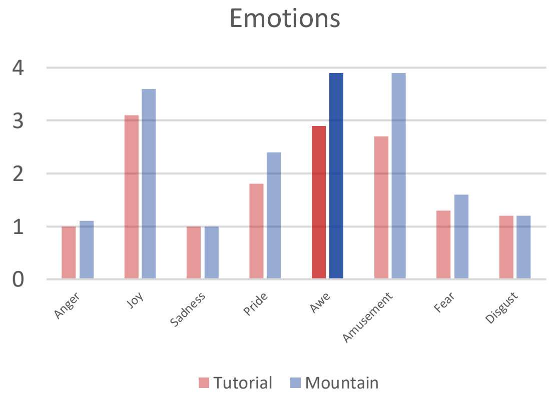

Figure 14: mean ratings of each emotion

There are observable increases in feelings of joy, pride, awe, amusement, and fear, whereas changes in the emotions of anger, sadness and disgust appear to be negligible. These three emotions were excluded from subsequent analysis. A noteworthy observation to highlight from the data is that all emotion ratings received from the subjects for the mountain VE were at least as high as the corresponding figures from the tutorial VE. The evident increases of the five emotions were then tested for significance with multiple upper-tailed paired sample tests. Joy, awe, and amusement each had a significant increase from the tutorial VE to the mountain VE at a 0.05 level. In contrast, the increase in pride and fear was not deemed significant at a 5% significance level.

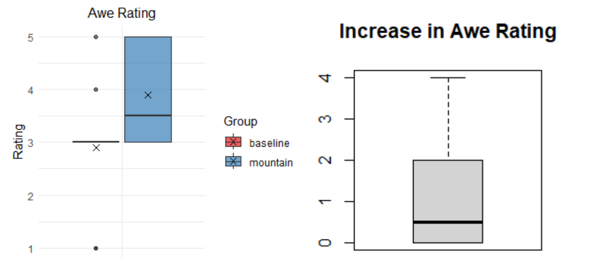

Figure 15: awe rating boxplot for the VEs alongside boxplot of the increase from baseline

The clear outliers in figure 15 were irrelevant as they did not significantly influence the differences, and the analysis focused on the differences or change.

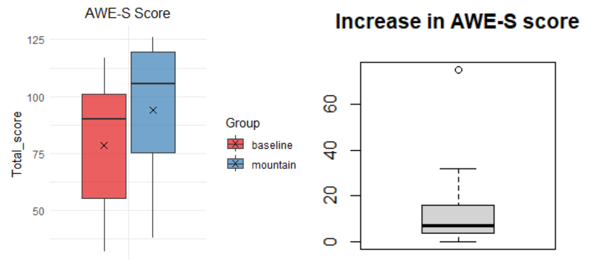

Figure 16: AWE-S score boxplot for the VEs alongside boxplot of the increase from baseline

There is an apparent indication of an increase in the AWE-S score obtained from the tutorial VE to the AWE-S score obtained from the mountain VE. However, there is an obvious outlier in the differences between the two VEs. We addressed and subsequently removed the outlier from the dataset for further analysis. Given that the new data did not exhibit a normal distribution, we conducted a Wilcoxon paired-sample upper-tailed t-test to assess the significance of the increase. The increase was significant at a 0.05 level ($p < 0.05$).

5.3 Discussions

The first result to address is the high presence subjects experienced in both VEs. This reinforces assertions in previous literature highlighting the immersive potential of VR [3,5,9]. The statistically significant augmentation of presence perceived by subjects when shifting from the baseline VE to the mountain VE ($p < 0.05$) is expected due to the multisensorial nature and enhanced visual vividness of the latter, compared to the control room, which is known to intensify the immersion one experiences in a VE [9]. Immersion, in turn, is one of the key elements which impacts the sense of presence felt [7].

An upward trend was also observed in the ratings of five out of the eight emotions as the independent variable changed. While statistical significance was only found in three (joy, amusement, and awe) of these instances, these increases align with prior research, suggesting that an intensification of sense of presence is associated with the VR application's efficacy in eliciting emotional responses [11].

In terms of physiological changes, HR was confirmed to significantly accelerate as the independent variable changed ($p < 0.05$), whereas RR showed signs of decreasing in participants, but this was not statistically significant. An increase in HR can be associated with several of the emotions whose strength intensified. Firstly, various patterns are observed in physiological responses to joy, but HR and RR typically tend to increase with joy [41]. The significant increase in HR from the experimental study validates the statistically higher ratings of self-report joy from participants, suggesting subjects felt more elation.

The physiological response pattern of amusement is more variable and can be identified by HR deceleration, no change or acceleration [41]. Increased heart rate variability (HRV) is commonly observed, but this would require a more comprehensive examination of the data collected within the VEs and more frequent monitoring would be necessary to substantiate this. Lastly, the increase in HR from the results is a known associate of threat-based awe [30]. The mountain VE did contain features which could be considered slightly fearful, in particular the precipitous cliffs. Although comprehensively assessing physiological responses to awe poses difficulties, there is a wealth of research on physiological indicators associated with more frequently studied emotions that share commonalities with awe. A strong link to awe is the extreme feeling of wonder or surprise [8]. Physiological responses that are observable from surprise include HR acceleration and a drop in RR [41], the prior being statistically detected in this study along with signs of the latter.

The responses show indications that the mountain VE elicited an increase in feelings of awe, and this rise was further validated by the findings of the AWE-S questionnaire. The participants' total score on this questionnaire from the mountain VE was proved to be significantly higher than that from the control ($p < 0.05$). A higher score indicates the participants experienced more awe [12]. These findings confirm the developed VE was able to induce awe in participants.

5.4 Limitations

One primary limitation to acknowledge is the relatively small sample size employed in this study. Regrettably, due to time constraints and resource limitations, the availability of the VR laboratory was shared among multiple researchers, thereby restricting the ability to conduct a more extensive series of user experiments. A larger sample size would have not only increased the likelihood of detecting significant trends during statistical analysis but also strengthened the validity of the trends identified in this paper, thus warranting consideration for future research.

The increased levels of awe cannot be solely attributed to the VE designs themselves, as half of the subjects were first time VR users. A few of the participants also vocalized their astonishment upon entering the tutorial room, with a collective "wow," even though the room's design was intentionally devoid of emotional triggers. VR experiences alone are known to induce awe in people [9]. Future studies could look to add further experimental conditions so that effects can be tested in better depth. A good consideration would be to split block the pool by VR experience, essentially having a low VR experience group vs a high VR experience group.

Assessing awe through physiological means presents certain challenges. Given that various emotions trigger responses within the ANS, distinguishing between these emotions can be intricate. To enhance the precision of such assessments, it is advisable to explore additional, distinctive physiological indicators, such as the occurrence of goosebumps.

Moreover, there is a discernible correlation between emotional responses and the sense of presence within VR. VR technology boasts the capacity to engage multiple sensory modalities. While this study exclusively integrated visual and olfactory stimuli, more advanced VR equipment and more sophisticated experimental setups can be harnessed to effectively engage additional senses, such as touch, taste, and smell, thereby enhancing the richness and depth of the immersive experience.

6 Conclusions and Future Work

In summary, this study successfully contributed to the understanding of how VR emotion elicitation works. The VE developed effectively evoked feelings of awe, and the approach to measuring this emotion allowed for a broad analysis of its impact. The results of the user study largely indicate that higher levels of awe were experienced in the mountain VE compared to the control VE. Future studies can enhance the robustness of these findings by conducting a similar experiment with increased control measures. We suggest a larger participant pool, an improved training setup or blocking of subjects to mitigate the impact of lack of VR experience, and a small camera to record goosebumps to develop a more comprehensive understanding of the emotion.

7 References

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Appendix A – Final VE design

Appendix B - Experiment Procedure

1. Brief participant of the procedure and side effects of VR.
2. The participant will sign a consent form if they agree to continue.
3. Collect demographic information from the participant including age and VR/ Gaming experience.
4. Attach probes to the participant (male to attach probes to males and female to attach probes to females).
5. Ensure the VU-AMS device is on and recording measurements.
6. Place headset on participant and hand them the controllers.
7. Guide them through a tutorial room to familiarise themselves with the controls.
8. Stop the control environment (tutorial) and provide a time stamp on the VU-AMS device
9. Complete the Awe Experience Scale questionnaire and a 5-point Likert scale questionnaire to capture participant's emotional state as a baseline. This likert scale questionnaire will have eight distinct emotions, including awe, and the participant will be required to indicate the extent to which they experienced each emotion. Along with this the participant will complete a modified version of the Brief Presence Questionnaire (BPQ). The adapted version of the BPQ will require the participant to rate their impression of really being in the virtual environment on a scale of 0-10.
10. 5 minute meditation to negate any effects the control environment may have had on the participants emotional state.
11. Once they are comfortable we shall immerse them into our environment and add another time stamp on the VU-AMS device.
12. They will walk around for 10-15 minutes in the experimental awe environment.
13. Stop the virtual experience and add a timestamp and stop the VU-AMS device.
14. They will then fill out the Likert scale questionnaire and Awe Experience Scale Questionnaire again.
15. Thank them for their time and provide them with compensation.

Appendix C – VR consent form

Virtual Reality Consent

Researcher: Zenan Shang, Erin Heath, Ben Brent

Introduction:
You are invited to participate in a research study examining the effects of virtual reality on human emotions. The study involves the use of virtual reality equipment, which includes a headset and a computer. You will be asked to enter a virtual environment and respond to various stimuli while wearing the headset. The purpose of this study is to better understand the emotional impact of virtual reality and to explore its potential benefits.

Risks and Benefits:
There are no known risks associated with participating in this study, although some individuals may experience dizziness, headaches, or motion sickness as a result of using the virtual reality equipment. Participants may benefit from a better understanding of the emotional impact of virtual reality, and their participation in this study may contribute to the development of new therapeutic interventions.

Confidentiality:
All personal information collected during the study will be kept strictly confidential. Your data will be assigned a unique identifier to protect your identity. The data will be used for research purposes only and will be stored in a secure location.

Voluntary Participation:
Participation in this study is completely voluntary, and you have the right to withdraw at any time without penalty. If you choose to withdraw from the study, any data collected up until that point will be destroyed. You also have the right to ask any questions you may have before, during, or after the study.

Contact Information:
If you have any questions or concerns about the study, you may contact the Zenan Shang through email: shnzen001@myuct.ac.za

Consent:
I have read and understood the above information and agree to participate in this study. I understand that I have the right to withdraw at any time without penalty. I agree to allow the researcher to collect and use my data for research purposes.

Participant's Signature: ___________________________

Date: ______________________________

Appendix D – Self-report questionnaire

Questionnaire

1. How much did you have the impression of really being in the virtual environment (1 = not at all; 10 = extremely)?

1 O 2 O 3 O 4 O 5 O 6 O 7 O 8 O 9 O 10 O

2. Please rate the extent to which each emotion was experienced:

	1. Not at all	**2. Very slightly**	**3. Moderately**	**4. Very much**	**5. Extremely**
Anger	O	O	O	O	O
Joy	O	O	O	O	O
Sadness	O	O	O	O	O
Pride	O	O	O	O	O
Awe	O	O	O	O	O
Amusement	O	O	O	O	O
Fear	O	O	O	O	O
Disgust	O	O	O	O	O

3. Please rate the following:

	1 Strongly Disagree	2 Moderately Disagree	3 Neutral	4 Moderately Agree	5 Strongly Agree
I sensed things momentarily slow down	O	O	O	O	O
I experienced a reduced sense of self	O	O	O	O	O
I had chills	O	O	O	O	O
I experienced a sense of oneness with all things	O	O	O	O	O
I felt that I was in the presence of something grand	O	O	O	O	O
I felt that my sense of self was diminished.	O	O	O	O	O
I noticed time slowing	O	O	O	O	O
I had the sense of being connected to everything	O	O	O	O	O
I felt small compared to everything else	O	O	O	O	O
I perceived vastness	O	O	O	O	O
I felt challenged to understand the experience	O	O	O	O	O
I felt my sense of self shrink	O	O	O	O	O
I felt closely connected to humanity	O	O	O	O	O
I gasped	O	O	O	O	O
I felt my sense of self become somehow smaller	O	O	O	O	O
I had a sense of complete connectedness	O	O	O	O	O
I struggled to take in all that I was experiencing at once	O	O	O	O	O
I felt my eyes widen	O	O	O	O	O
I experienced something greater than myself	O	O	O	O	O
I found it hard to comprehend the experience in full	O	O	O	O	O
I perceived something that was much larger than me	O	O	O	O	O
I felt my sense of time change	O	O	O	O	O
I felt my jaw drop	O	O	O	O	O
I felt challenged to mentally process what I was experiencing	O	O	O	O	O
I had the sense that moment was lasting longer than usual	O	O	O	O	O
I felt in the presence of greatness	O	O	O	O	O
I felt a sense of communion with all living things	O	O	O	O	O
I had goosebumps	O	O	O	O	O
I experienced the passage of time differently	O	O	O	O	O
I tried to understand the magnitude of what I was experiencing	O	O	O	O	O

Appendix E – Statistical measures

HR change

```
Paired t-test

data:  Heart_rate by Group
t = -0.99628, df = 8, p-value = 0.3483
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 -5.140951  2.038951
sample estimates:
mean difference
         -1.551

One Sample t-test

data:  data_no_outlier_HR
t = 2.0988, df = 7, p-value = 0.07401
alternative hypothesis: true mean is not equal to 0
95 percent confidence interval:
 -0.3347034  5.6192034
sample estimates:
mean of x
  2.64225
```

HR increase

```
One Sample t-test

data:  data_no_outlier_HR
t = 2.0988, df = 7, p-value = 0.037
alternative hypothesis: true mean is greater than 0
95 percent confidence interval:
 0.2570625       Inf
sample estimates:
mean of x
  2.64225
```

RR

```
Paired t-test

data:  Respiration_rate by Group
t = 0.34613, df = 8, p-value = 0.7382
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 -2.443615  3.306726
sample estimates:
mean difference
      0.4315556
```

RR decrease

```
One Sample t-test

data:  d_RR
t = -0.34613, df = 8, p-value = 0.3691
alternative hypothesis: true mean is less than 0
95 percent confidence interval:
     -Inf 1.886965
sample estimates:
 mean of x
-0.4315556
```

Presence

```
Wilcoxon signed rank test with continuity correction

data:  Presence by Group
V = 0, p-value = 0.003004
```

```
alternative hypothesis: true location shift is less than 0
```

Joy

```
Paired t-test

data:  Joy by Group
t = -1.8605, df = 9, p-value = 0.04787
alternative hypothesis: true mean difference is less than 0
95 percent confidence interval:
         -Inf -0.007365702
sample estimates:
mean difference 
           -0.5
```

Pride

```
Wilcoxon signed rank test with continuity correction

data:  Pride by Group
V = 0, p-value = 0.1855
alternative hypothesis: true location shift is less than 0
```

Awe

```
Wilcoxon signed rank test with continuity correction

data:  Awe_rating by Group
V = 0, p-value = 0.02838
alternative hypothesis: true location shift is less than 0
```

Amusement

```
Wilcoxon signed rank test with continuity correction

data:  Amusement by Group
V = 0, p-value = 0.00519
alternative hypothesis: true location shift is less than 0
```

Fear

```
Wilcoxon signed rank test with continuity correction

data:  Fear by Group
V = 3, p-value = 0.1165
alternative hypothesis: true location shift is less than 0
```

AWE S

```
Wilcoxon signed rank test with continuity correction

data:  data_no_outlier_AweS
V = 36, p-value = 0.007074
alternative hypothesis: true location is greater than 0
```