Identifying Strategies to Mitigate Cybersickness in Virtual Reality Induced by Flying With an Interactive Travel Interface

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Abstract

Virtual Reality (VR) is a versatile and evolving technology for simulating different experiences. As this technology has improved in hardware, accessibility of development, and availability of applications its interest has surged. However, despite these improvements, the problem of Cybersickness (CS) remains, causing a variety of uncomfortable symptoms in users. Hence the need for guidelines that developers can use to create experiences that mitigate these effects. With an incomplete understanding of CS and techniques yet to be tried, this thesis seeks to identify new strategies that mitigate CS.

In the literature, the predominant theories attribute CS or closely related sicknesses to the body rejecting inconsistencies between senses and the body failing to adapt to conflicts or new dynamics in an experience. There are also a variety of user, hardware, and software factors that have been reported to affect it. To measure the extent of CS, the Simulator Sickness Questionnaire (SSQ) is the most commonly used tool. Some physiological responses have also been associated with CS that can be measured in real-time.

Three hypotheses for mitigation strategies were devised and tested in an experiment. This involved a physical travel interface for flying through a Virtual Environment (VE) populated with models as a control condition. On top of this, three manipulation conditions referred to as Gaze-Tracking Vignette (GV), Personal Embodiment (PE), and Fans and Vibration (FV) could be individually applied. The experiment was designed to be between-subjects, with participants randomly allocated to four groups. Overall, 37 participants did the experiment with Heart Rate (HR), eye-tracking data, and flight data recorded. Post-exposure, they also filled out a survey that included the SSQ.

To analyse the data, statistical tests and regression models were used. These found significant evidence that a vignette that changes intensity with speed and scope position with eye-gaze direction made CS worse. The same result was found from adding personal embodiment with hand tracking. Evidence was also found from the SSQ that directional fans with floor vibration did not cause a difference. However, an overall lowering of HR for this condition indicated that it might help, but could be due to other factors. Additionally, comments from participants identified that many experienced symptoms consistent with CS, with dizziness as the most common, and some issues with the usability of the travel interface.

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Table of Contents

List of Figures

List of Tables

Abbreviations

ANOVA Analysis of Variance.

BPM Beats Per Minute.

CS Cybersickness.

CT Control (Condition).

DOF Degrees of Freedom.

ECG Electrocardiogram.

EEG Electroencephalography.

FOV Field of View.

FV Fans and Vibration (Condition).

GSR Galvanic Skin Response.

GV Gaze-Tracking Vignette (Condition).

HMD Head-Mounted Display.

HR Heart Rate.

IPD Interpupillary Distance.

IQR Interquartile Range.

MDF Medium Density Fibreboard.

MS Motion Sickness.

MV Movement Variable.

OBS Open Broadcaster Software.

OLED Organic Light-Emitting Diode.

PE Personal Embodiment (Condition).

PLA Polylactic Acid.

PPG Photoplethysmography.

SS Simulator Sickness.

SSQ Simulator Sickness Questionnaire.

VE Virtual Environment.

VR Virtual Reality.

CHAPTER 1

Introduction

Virtual Reality (VR) is a computer-generated simulation of real-world stimuli [1] that is experienced through the use of specialised Head-Mounted Displays (HMDs) which are designed to maximise immersion. These can deliver 3D content from two displays with lenses, track head position, and provide auditory feedback. Typically, they are used in conjunction with tracked controllers and peripheral devices, allowing for movement control in physically finite space, object interaction, and haptic feedback. Integral to VR experiences, the Virtual Environment (VE) is a product of what the computational hardware and the software can generate. In this domain, physics, scale, and space can be manipulated. 3D objects can also easily be created, copied or destroyed. This makes VR ideal for simulating a range of different experiences that can be run independently of physical location and with little cost or risk. Specifically, VR has applications in areas such as entertainment, education, training, health care, retail, and tourism [1]. Therefore, there is significant value in what this technology can simulate and can offer many potential benefits to society.

In recent decades VR has had varying levels of interest. During the last decade, VR hardware has improved substantially. HMDs have lower latency times, wider Field of Views (FOVs), lighter frames, greater portability, more adjustability, and are more affordable. There have also been improvements in the availability of software development tools with the rise of Unity3D and Unreal Engine. This has led to an increase in interest [1] as shown by Google Trends search data (Figure 1.1). In 2020 it was anticipated that 52.1 million people would use VR at least once per month in the USA [2]. Looking ahead, estimates predict significant increases in VR sales by the year 2024 [1]. VR technology could play a significant role in the future. However, significant improvements are yet to be made to increase computational capability, usability, convenience, and hardware specifications before its value can be fully realised.

Despite improvements in VR hardware and software, there is a lingering problem with the usability of VR. During usage, people can experience a variety of discomforting symptoms which are referred to as Cybersickness (CS) or sometimes VR sickness. These include nausea, disorientation, oculomotor disturbances, drowsiness, eye strain, headache, pallor, sweating,

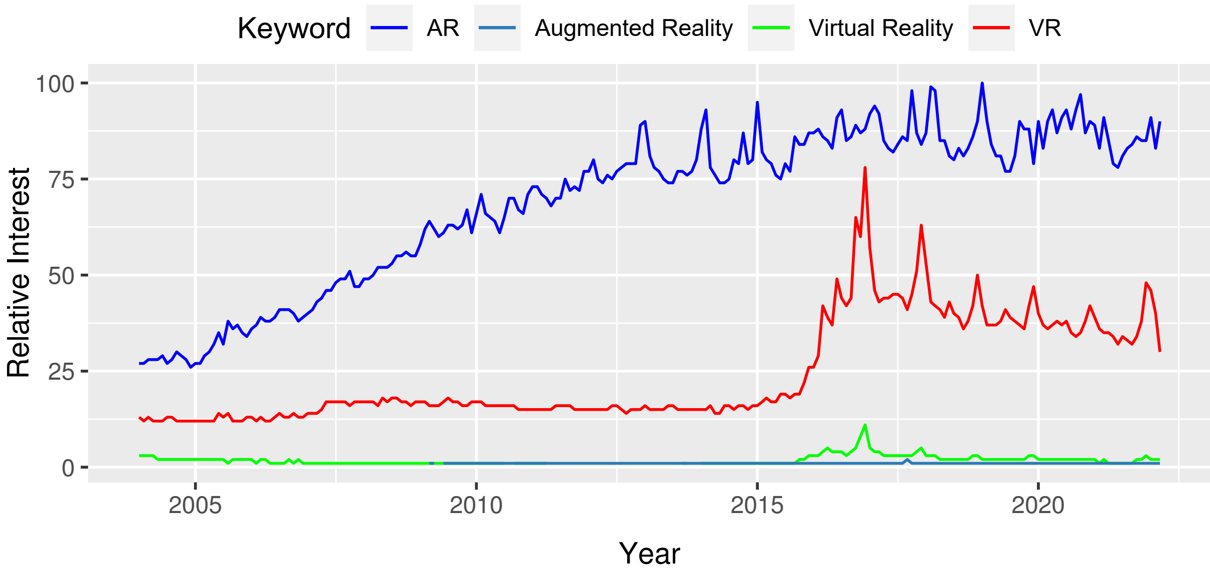


Figure 1.1: Google Trends data on web searches for Extended Reality (XR) technologies from 2004 to 2022.

dryness of mouth, fullness of stomach, vertigo, coordination impairment (ataxia), and vomiting (emesis) [1, 3]. Longer exposure to VR has been found to produce more of these symptoms [4]. While it seems the majority of people can tolerate prolonged exposure, there is a small number of users that experience retching or an emetic response [5]. Effects can also remain long after exposure, compromising postural stability, hand-eye coordination, visual functioning, and general well-being. These are attributed to the user adapting to the immersive experience [1]. However, it has been found that users can develop a tolerance to Simulator Sickness (SS) over repeated sessions [4, 6]. CS has similarities to Motion Sickness (MS) but is different since it is caused by visually induced motion [3]. SS is another type of sickness closely related to CS, often used interchangeably. However, there is evidence that there is a distinction, with oculomotor (relating to motion of the eye) symptoms appearing to dominate for SS and disorientation being the predominant symptom for CS. Overall, it has been found that the severity of the symptoms is worse for CS [7].

It is useful for developers to have guidelines on how to design VR experiences. For example, Oculus has provided a guide on the best practices for VR development [8]. This contributes to the knowledge of developers on how to improve the usability of VR applications. By improving the usability of this technology, consumers will have better experiences engaging with applications. This will lead to a more positive perception concerning its usefulness and value. However, there is still much that is unknown about the causes and effects of CS. There are also techniques that are yet to be tried, especially for an increasing number of applications with different types of interaction and different interfaces. Therefore, this thesis seeks to identify and understand strategies that can mitigate CS. To identify novel strategies, three hypotheses were devised and developed into conditions referred to as Gaze-Tracking Vignette (GV), Personal Embodiment (PE), and Fans and Vibration (FV), forming the basis of an experiment. To test each condition, a cybersickness-inducing experience was created, involving a physical travel interface for control of its virtual counterpart through a VE. During each experiment, the level of CS was assessed using objective and subjective measurements. The data was then analysed using a variety of statistical methods to assess the significance of the results.

In Chapter 2 (Background), information is provided on the current state of CS research and relevant details to understand the formation of the hypotheses and the design of the experiment in Chapter 3 (Method). This is followed by the results of the experiment in Chapter 4, a discussion in Chapter 5, and a conclusion in Chapter 6.

CHAPTER 2 Background

This chapter contains information on theories of what is behind CS, what factors have been found to influence it, strategies that have been applied to reduce it, and details on travel interfaces relevant to the experiment detailed in Chapter 3 (Method).

2.1 Theories on What Causes Cybersickness

There are different ideas about what the underlying causes of CS or closely related sicknesses are and what indicates whether a person will be susceptible to an experience. Some of the predominant theories are described in this section.

2.1.1 Sensory Conflict Hypothesis

This hypothesis postulates that CS is due to sensory conflicts in expected signals from visual, auditory, tactile, kinaesthetic, and vestibular activity [1, 9]. For example, a user could be experiencing movement through a VE in VR, yet in the real world remain stationary, an effect referred to as vection. This is reported to be the most widely cited theory [1] in literature.

2.1.2 Multisensory Reweighting Hypothesis

Relating to the sensory conflict theory, this hypothesis suggests that susceptibility to CS may be associated with an individual's ability to quickly reweight multisensory cues that conflict [1, 9]. An example of this could be reconciling acceleration experienced visually and vestibular cues.

2.1.3 Poison Hypothesis

This theory deals with the origin of MS. It postulates that sensory cue conflicts accidentally trigger an innate poison defence system. The brain interprets the motion stimuli disorganisation as a toxin, leading to nausea or an emetic response [1].

2.1.4 Postural Instability Hypothesis

This theory postulates that MS is caused by alterations in postural control. Postural instability arises when new dynamics in an experience are failed to be perceived and controlled with the appropriate actions [1, 10].

2.1.5 Postural Sway Indicator

When exposed to 3D stimuli in VR a physiological mechanism called the “righting reflex” does not work as well and can increase postural sway [11]. Chardonnet et al. [11] conducted an experiment that identified a positive relationship between the variation of body sway signals and the level of visually induced MS experienced.

2.2 Factors That Influence Cybersickness

There are factors of experiences, some of which relate to the popular theories, that have been reported to affect CS. However, these do not necessarily apply to everyone, since people have different sensitivities and susceptibilities. Several of these factors are explored below.

2.2.1 User Factors

Ergonomics

VR headsets typically have an adjustable Interpupillary Distance (IPD) between visible displays. If this is not set correctly or the range does not fit the user, then the VR displays are not positioned in front of each eye. This has been found to lead to worse symptoms of CS [12]. Interestingly, Stanney et al. [12] asserted that a significantly higher proportion of females than males do not fit headsets such as the Oculus Quest and the HTC VIVE based on IPD range. This might explain why past studies have claimed that women have a greater susceptibility to CS than men [1].

Level of Control

Rolnick and Lubow [13] conducted a study to test the impact of control of rotation and head movement on MS. This found that those with control reported fewer MS symptoms than those who experienced the same stimulus passively. It is, therefore, reasonable to expect similar results for VR applications. Indeed, Stanney and Hash [14] investigated whether user-initiated control can suppress CS in VR. Their testing found that complete control reduced the symptoms of CS compared with passive control. A combination of active and passive control was also tested, which was found to be yet more effective at CS suppression.

2.2.2 Hardware and Software Factors

Latency

Latency in VR is the time delay between the motion of the headset or control actions and the screen updating to reflect the change. This is typically a product of the hardware capability and how optimised an experience is [8]. Pierre et al. [15] explored the relationship between varying the latency of an HMD and SS. This involved comparing constant latencies and sinusoidal latencies at 0.2 Hz. The results found that varying the latency was associated with more SS than the constant latency. Kinsella et al. [16] compared 0.2 Hz to a frequency of 1 Hz but found that 0.2 Hz induced more SS. In an earlier study by Draper et al. [17], different constant latencies above 48 ms (<21 Hz) were tested. This resulted in no significant difference in SS.

Field of View

Humans have a total horizontal FOV of about 180°, with a 120° overlap region (binocular) and 30-35° unique to each eye (monocular) [18]. There is much variation in the FOV of different VR HMDs which seems to range from about 90° to 210° horizontally [19]. It has been found that as the horizontal FOV increases so do the symptoms of CS and the level of presence. However, above 140° the difference in symptoms has not been found to be significant [18].

Flicker

Jarring changes in brightness, referred to as display flicker, can occur in VR experiences. This impacts the oculomotor component of SS, leading to eye strain, fatigue or headaches. However, people have different sensitivities to it. It is perceived most strongly in the periphery of the FOV and is worse with bright or high-contrast content, rapidly alternating content, fine patterns, and a low refresh rate. Organic Light-Emitting Diode (OLED) displays can also contribute to some degree of flicker [8, 20].

Binocular Display

HMDs use binocular disparity as a depth cue. However, stereoscopic content can lead to discomfort [8]. Ehrlich and Singer [21] found that a stereoscopic display induced more SS than a monoscopic display, especially with a greater number of near and far focal transitions.

Virtual Movement and Altitude

The rate of the onset of SS has been identified as being proportional to the speed of navigation [22]. While with constant speed there is no expected vestibular response, during acceleration there is. According to the sensory conflict theory, this leads to discomfort. Specifically, the Oculus Best Practices guide notes that the severity of discomfort is a product of the frequency, size, and duration of acceleration [8]. Another related factor is altitude. When a player is close to the ground, it tends to fill their FOV creating a more intense visual flow during movement [8]. This could have some interaction with speed or acceleration on the severity of CS symptoms.

2.3 Strategies to Mitigate Cybersickness

The literature has been examined on strategies that have been tried to mitigate the symptoms of CS and the closely related SS. Several are outlined below.

Prediction Cues

Jeng-Weei Lin et al. [23] found that SS from a driving simulator was significantly greater when prediction cues of turns during passive movement were not available. This could be closely related to the level of control. With more control, it follows that there would be higher predictability of movement.

Independent Visual Background

Prothero et al. [24] proposed a technique that provides a reference frame of the real world inside a VE. This frame is consistent with the vestibular response and aims to help with spatial judgments. In different cases, it has been implemented using grids (Figure 2.1) and horizons [24, 25]. Studies have found that this technique was successfully able to reduce the level of SS [26].

Figure 2.1: An example of an independent visual background [25] with a grid as a reference frame.

Teleportation

Teleportation is a common type of locomotion used in first-person VR applications. It usually involves using a controller with an arc to select a new location to instantly move to (Figure 2.2). Clifton and Palmisano [27] found that teleportation led to less CS than a continuous steering based approach on average. However, with some participants finding teleportation more sickening, it was concluded that it depends on the individual to some extent. Weißker et al. [28] also found that "jumping" (teleportation) led to significantly less SS. However, Bowman et al. [29] and Bhandari et al. [30] found that instant transportation correlated with disorientation.

Figure 2.2: A typical implementation of teleportation in which an arc is used to select a new location to move to [30].

Field of View Manipulation

Fernandes and Feiner [6] conducted an experiment in which the FOV was dynamically adjusted using a vignetting technique (Figure 2.3). This was intended to be subtle to avoid decreasing the sense of presence and to minimise the user's awareness of intervention. When there was a mismatch between the physical and virtual motion the FOV was reduced, but when both were consistent the FOV was normalised. Based on a study they found evidence to suggest that this technique reduced the degree of VR sickness and helped participants adapt to VR. Norouzi et al. [31] found that vignetting with amplified head rotations as an input caused participants to experience significantly more VR sickness. However, this is in contrast to similar work involving vignetting that used controller-based input.

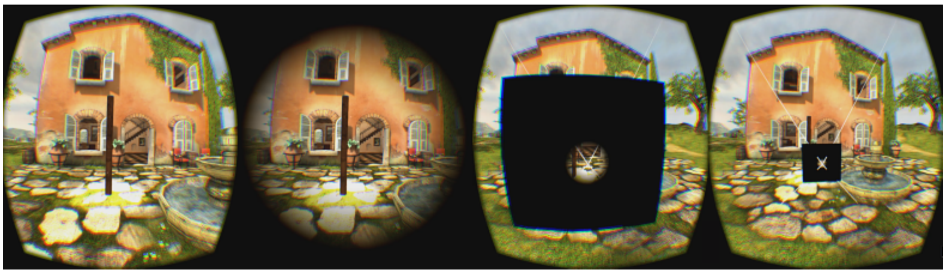


Figure 2.3: A demonstration of how a masking layer has been used at different proximity levels relative to the camera for FOV manipulation [6].

Resolving Sensory Conflict with Vibration

Jung et al. [32] conducted a study that aimed to reduce CS by reducing sensory conflict. This involved a custom vibrating floor that delivered vestibular stimuli, matching the vibration characteristics of an off-road driving simulation designed to be cybersickness-inducing. The results of this study found evidence that adding the element of vibration reduced measures positively correlated with CS compared to the no-vibration condition.

Stability and Embodiment

Studies have found that sitting can reduce CS [10]. Zielasko and Riecke [33] suggest that standing might be related to increased postural instability which leads to increased levels of MS. They also argued that the degree of embodiment can strongly impact CS. Debarba et al. [34] conducted an experiment that involved manipulating the amount of visible embodiment that a user sees in VR (Figure 2.4). The Simulator Sickness Questionnaire (SSQ) was used to see if there was an effect on SS. But this found no significant difference between conditions. However, it should be noted that this testing did little to induce CS with users remaining seated.

Visual Blurring

Budhiraja et al. [35] used a technique that blurred the screen whenever a rotation occurred. This was found to reduce CS levels and delay the onset of symptoms. Interestingly, those particularly susceptible to CS benefited greatly. Hussain et al. [36] also tried a technique based on the

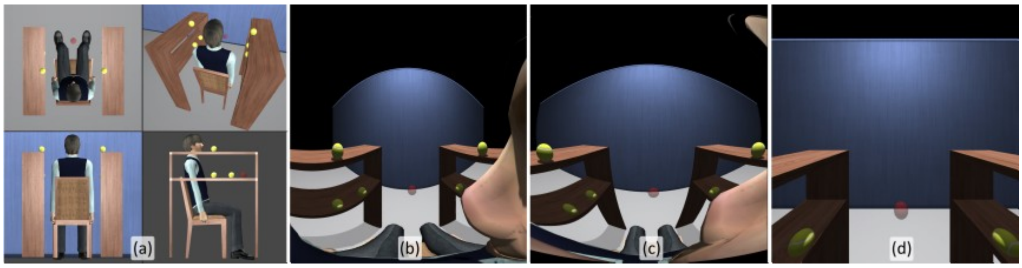


Figure 2.4: The different perspectives of embodiment used in the experiment by Debarba et al. [34].

concept of foveated rendering that used the depth of field captured by an eye-tracking headset to blur different display regions based on the visual acuity of the eye (Figure 2.5). A study they conducted found that SSQ scores were reduced by approximately 66%.

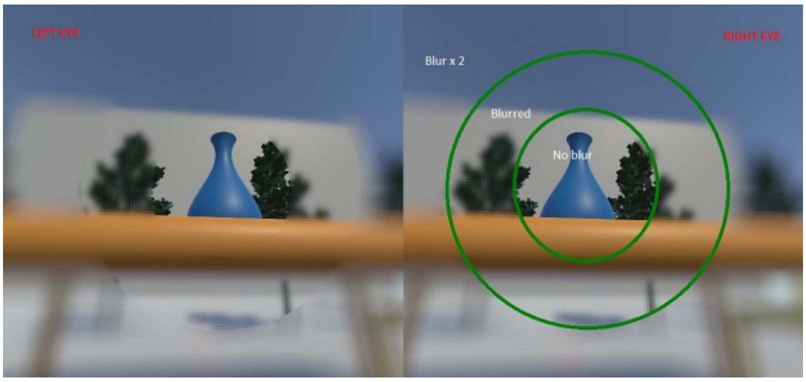


Figure 2.5: The different levels of blur used by Hussain et al. [36] based on eye-tracked depth of field.

2.4 Measures of Cybersickness

In the literature, different measures have been used to identify the level of CS or SS. Of these, subjective measures provide insight into what participants feel and think. Alternatively, objective measures provide information independent of the observer and what participants think.

2.4.1 Subjective

The SSQ has been frequently used in literature to measure the effects of CS. This questionnaire was based on the Pensacola Motion Sickness Questionnaire (MSQ). There were found to be enough differences between MS and SS to motivate the creation of the SSQ. The questionnaire is administered post-exposure and aims to collect information on 16 symptoms, each of which is answered with a four-point Likert scale. Symptoms are split into the components of disorientation, nausea, and oculomotor issues. These can be summarised with a total severity index [37]. Another questionnaire is the VR Sickness Questionnaire (VRSQ), a variation on the SSQ. This was designed as a measurement index specifically for VR rather than simulators in general. Instead of the three components of the SSQ, it is limited to oculomotor and disorientation. The number of symptoms is also reduced from 16 to 9, with no overlap between components [38].

A problem with questionnaires is that they cannot be presented during exposure. The Fast Motion Sickness Scale (FMS) aimed to solve this by using a verbal rating scale [39] that is presented during exposure. The user is asked to rate their feeling of nausea, general discomfort, and stomach problems out of 20 every minute. This was found to be a valid and reliable method to obtain MS data. Similarly, McHugh et al. [40] devised a method to capture subjective measurements of CS during exposure using a Microsoft Surface Dial. This was used to select a rating with visual feedback provided in the VR experience.

2.4.2 Objective

CS and SS have been associated with changes in Heart Rate (HR), Galvanic Skin Response (GSR), skin conductance, Electroencephalography (EEG), postural stability, electrogastrography (EGG), eye-tracking data, voluntary duration of experience, and reaction time [8, 41, 42].

HR is regulated by the sympathetic (fight or flight) and parasympathetic (calm and relaxed) systems of the autonomic nervous system. CS has been found to have a positive correlation with HR [41]. It has also been found to be elevated in subjects experiencing pronounced nausea [43]. Additionally, strenuous exercise, fear, stress, and anxiety are common factors that influence HR [44].

While an Electrocardiogram (ECG) is ideal for accurately monitoring and recording HR, it is not always practical. It requires at least three bioelectrodes and can greatly restrict a person's flexibility of motion [45]. Alternatively, Photoplethysmography (PPG) is an uncomplicated and inexpensive option [45]. An LED illuminates the capillaries in the skin and an optical sensor determines the absorption and refraction of the light. This provides information on the frequency at which blood is pumped (skin perfusion) [46]. As for the accuracy, Pietilä et al. [47] found that for two PPG wrist-worn devices, the absolute difference compared to an ECG was less than 10 Beats Per Minute (BPM) 90-99% of the time for one device and 81-97% for the other. It was also found that the accuracy and reliability of the devices decreased with increased hand movements. Additionally, Bent et al. [48] found from testing a range of PPG sensors that they were good for resting or prolonged elevated HR, but not so much for responding to changes in activity.

With certain headsets, it is possible to gather information about users' eyes. Data can be collected on gaze origin, gaze direction, pupil position, pupil size (dilation), saccade speed, blink rate, and eye openness. With this information, it can be determined what a user is focusing on and how they physiologically respond to stimuli. In particular, pupil size has been associated with increased emotion and a sympathetic system response [49]. It can also be used to measure cognitive load and stress [50]. Pupil size has been examined alongside CS, but evidence has not been found of a clear link [51, 32]. However, Cebeci et al. [51] did find evidence that CS leads to a higher mean saccade speed.

2.5 Travel in Virtual Reality

Travel or first-person motion control through immersive VEs is key to exploring and experiencing scenes in VR. It has been defined as the control of the user viewpoint motion through a VE [29] and can be classified as a continuous movement that provides the sensation of motion, or discrete movement in which the user moves from one place to another instantaneously. In the following, different implementations of VR travel are introduced.

de Haan et al. [52] explored the use of a low-cost Wii Balance Board as an isometric input device. This was able to control up to three Degrees of Freedom (DOF), work with discrete or continuous inputs, and could be used while seated. It also allowed for secondary tasks to be completed by hand. But a downside of this control was the slight delay while users shifted their weight.

Similarly, Wang and Lindeman [53] presented a surfboard travel interface that consisted of a Reebok core board and a Wii Balance Board, classifying it as a device-directed interface. It allowed for travel in a VE using three DOF. But this did not include roll over concerns that it would cause the user to feel sick or lose orientation. Two modes were implemented that used rate control; one a tilt mode and another a balance mode. The tilt mode relied on the core board as an elastic interface, capturing the tilt angles. Alternatively, the balance mode relied only on the balance board as an isometric interface, capturing how users were leaning with pressure sensors. In both of these modes, an accelerometer was attached to users' arms. Based on the height of the sensor, users could control the forward speed. However, fatigue was identified as a downside of users raising their arms for long periods.

Beckhaus et al. [54] created two novel interfaces for navigation, including a dance pad input system and a Swopper chair-based input system. Both of these did not require the use of hands, freeing them for other tasks. These solutions were intended to have a small learning curve, and be intuitive enough that a novice could use the system. An informal user study was completed which found that novice users were easily able to understand how each method worked. In particular, the chair was found to be successful and fun to use, possibly relating to the low cognitive load. However, the dance pad had issues relating to balance and rotation.

Buttussi and Chittaro [55] carried out a comparative evaluation of three types of VR locomotion that can be used in a limited space. These included a joystick, teleportation, and leaning. It examined factors such as sickness, comfort, presence, performance, and usability. Teleportation was found to yield better performance than the other techniques, as well as causing the least sickness and having the highest usability score. Leaning also had a higher performance than the joystick. Across all types, it was found that there was no significant difference in presence between these techniques.

2.6 Discussion

Overall, the predominant theories in the literature attribute CS and related closely sicknesses to the body rejecting inconsistencies between senses and the body failing to adapt to conflicts or new dynamics in an experience. A range of factors and strategies for mitigating CS have also been identified. These mainly relate to the visual display, control, virtual movement, and multi-sensory elements.

CS reduction techniques have been used to alter the visual experience of users such as reducing FOV under certain conditions [6, 31], and blurring techniques [35, 36]. These were successful in reducing the level of CS, except when FOV was manipulated while using amplified head rotations as a control input [31]. Factors such as flicker and speed also have been identified as having a role in CS. However, manipulations that constrain the visual experience can compromise how convincing and engaging it is. It would therefore be useful to discover more ways of reducing CS with minimal disruption to the experience such as the depth of field blurring technique used by Hussain et al. [36].

The research by Debarba et al. [34] on changing the level of embodiment in a VE found no significant changes in CS. This was likely due to the lack of CS inducement from not moving in the VE. Interestingly, it has been suggested that embodiment could affect postural stability [34, 1, 10]. It would therefore be useful to test personal embodiment with a highly CS inducing experience with many sensory conflicts, significant visual flow, and variation in movement.

Jung et al. [32] conducted research using floor vibration to resolve a visual-vestibular sensory conflict. However, factors such as how well a simulated sense is matched to an experience and how similar it is to real experiences people are familiar with could have an impact on the level of CS. With many applications that do not recreate real experiences, understanding this effect could be important. Therefore, adding matching multisensory elements with an unfamiliar experience could provide this crucial insight.

In the following, Chapter 3 (Method), three hypotheses are devised based on the findings in this chapter. The experiment design for a user study is also described, as well as the steps that were taken to evaluate its results.

CHAPTER

3 Method

This chapter details the hypotheses, how the experiment was designed to test them, how it was conducted, and what was involved in the processing and evaluation of results.

3.1 Hypotheses

This thesis aims to identify and understand strategies that can mitigate CS. In the background chapter, a range of techniques were explored which have been employed with some success. However, in many cases, there is a trade-off and limited suitability for all applications. Considering what has been done successfully and what strategies are yet to be tried, the following hypotheses were formulated to form the basis of an experiment:

H1: Manipulating FOV in VR with a vignette based on speed and eye-gaze direction reduces CS.

H2: Adding personal embodiment to a VR experience reduces CS.

H3: Simulating vibration and airflow in a VR experience reduces CS.

3.2 Experience Design

A baseline VR experience was designed, consistent with several of the causes of CS. This involved designing a physical travel interface to control the locomotion of its virtual counterpart through a VE (Figure 3.1). To test each hypothesis, different experimental conditions were applied on top of this.

3.2.1 Travel Interface

A physical travel interface was created to resemble a broomstick to control a virtual counterpart (Figure 3.2, Appendix A.1). This involved a Swopper stool by Aeris [56] which could swivel 360°, tilt in any direction, and could have its height adjusted. Creating this interface involved replacing the seat from the stool with a wooden shaft (Appendix A.2). A custom fabricated bracket of mild

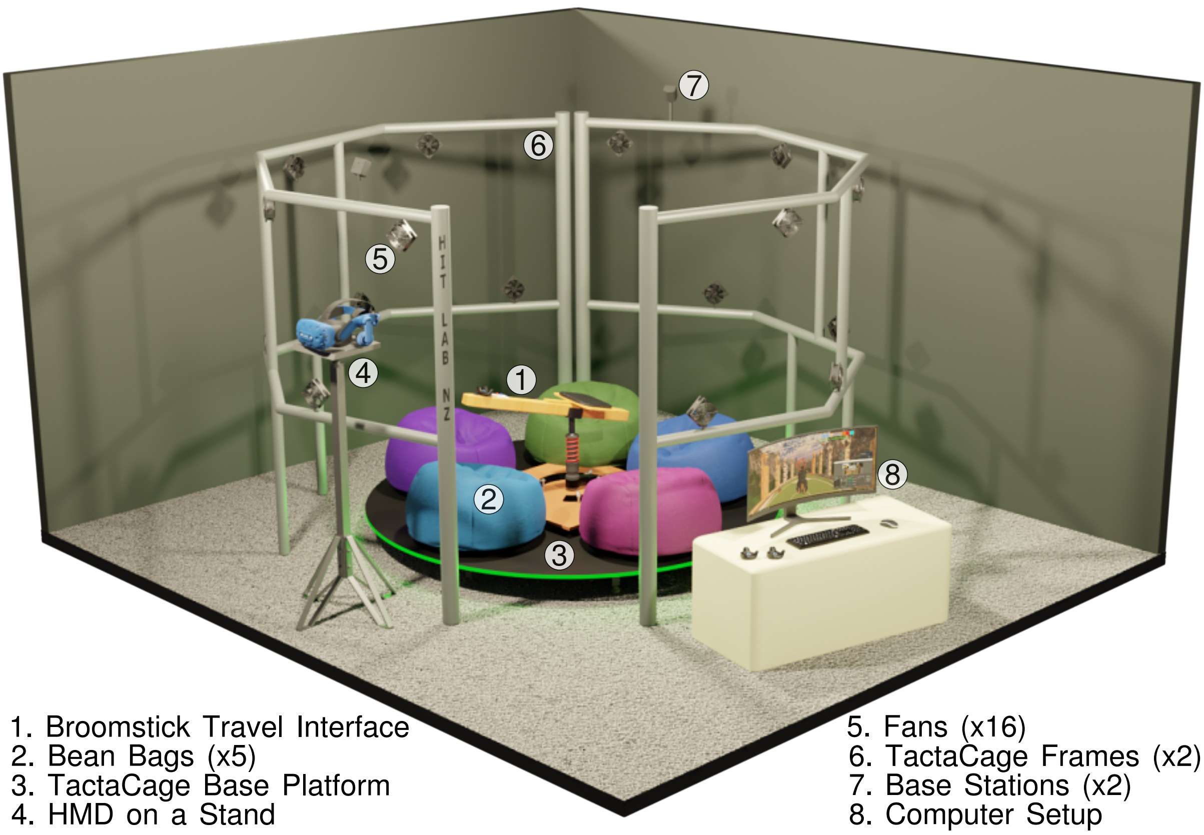


Figure 3.1: A render of the experience setup.

steel was used to affix the shaft onto the stool (Appendix A.3) by bolting its top to the shaft and wedging the stem of the stool into the hollow pipe at its bottom. A seat was also added, attached with three screws and glue. Above this, leather padding was placed, connected with VELCRO strips. Users were, therefore, able to sit astride the travel interface, holding the shaft in front, and manoeuvre it into different orientations by leaning and leveraging it around with their feet. To prevent the stool from toppling over, its base was fastened to a square of Medium Density Fibreboard (MDF) to brace against moments. Bolts and metal strips were used to anchor the chair at four different points which could be tightened with a spanner from above (Figure 3.3).

3.2.2 Control System

A four DOF control system was designed, capable of capturing the orientation of the interface shaft and the input of two buttons using a VIVE Tracker device (Figure 3.4). This was placed at the end of the shaft with a 3D printed mount [57] (Appendix A.4) and was able to capture

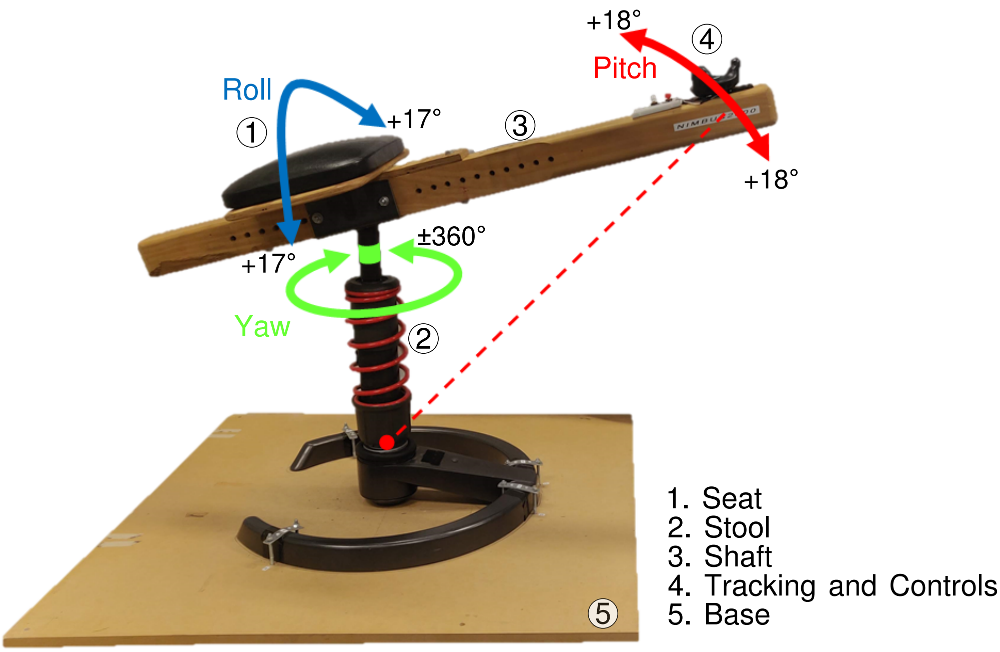


Figure 3.2: The travel interface, its DOF, and the approximate movement range for a user.

Figure 3.3: The fastening of the Swopper stool to the MDF base.

the roll, pitch, and yaw of the travel interface. With this information, the orientation of the virtual representation (Figure 3.5) was set.

Unlike the physical interface, the virtual counterpart was able to leave the ground and translate, effectively acting as a vehicle to the user. This was controlled by two buttons wired to digital input pins on the VIVE Tracker (Figure 3.4, Appendix A.5). One was for accelerating in the direction that the shaft pointed and another for braking by increasing the drag from the default level. These functions were applied by holding the buttons down, with the maximum speed capped at 200 ms^{-1}. Due to the limitation of the real interface to pitch forward and back,

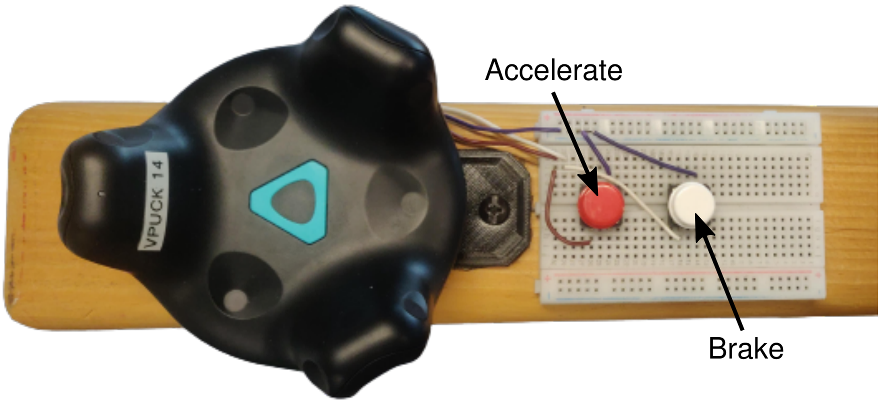
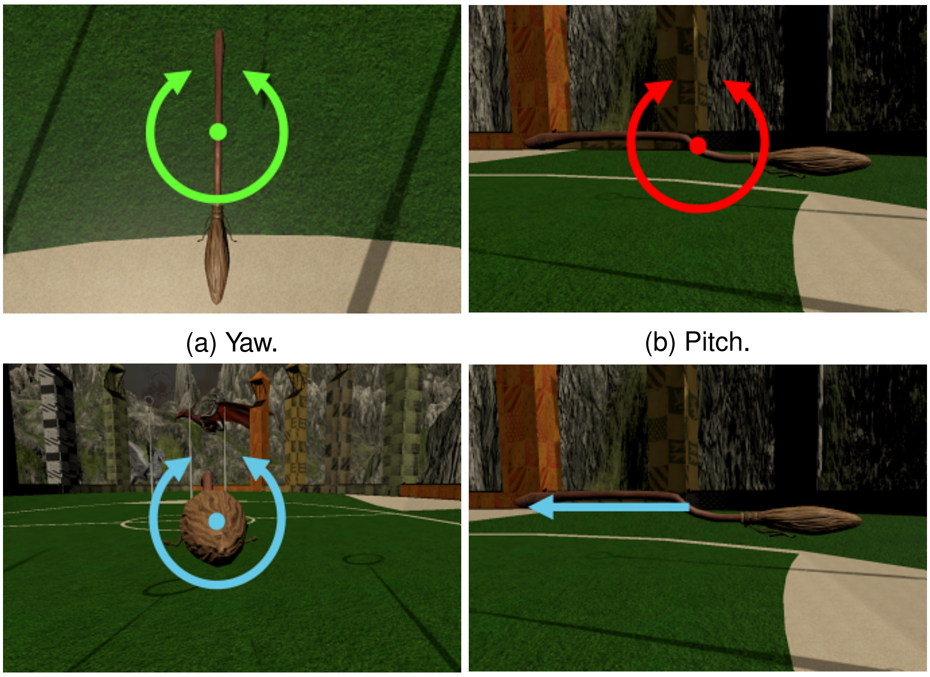


Figure 3.4: The orientation tracking and movement controller.



(a) Yaw.

(b) Pitch.

(c) Roll.

(d) Forward.

Figure 3.5: The controllable DOF in the VE.

vertical components of the virtual movement were incorporated based on upper and lower pitch thresholds of the interface to enable the user to move up or down more rapidly. During motion gravity was enabled, allowing the user to go faster downwards than upwards. But with no motion it was disabled so the player would hover. To simulate turbulence from air currents and induce higher levels of CS, the broomstick was set to move slightly in random directions. These movements were completed with the duration inversely proportional to height and the magnitude of translation proportional to height. However, with increased speed, the movements were reduced to be less noticeable.

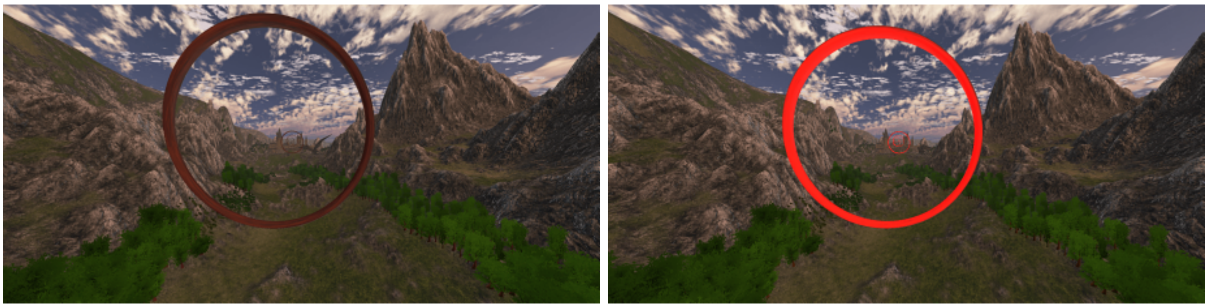
3.2.3 Virtual Environment

To enable users to fly around by interacting with the travel interface, a VE was created in Unity3D for VR. This was designed to be engaging with a clear objective that guided users through the level, but also provided them with the freedom to roam within certain bounds. The map consisted of a finite rugged terrain with many high peaks, sharp inclines, and was moulded into a basin with a ceiling to keep users on the map. Arranged in a loop, 27 hoops were placed on the map for users to fly through as shown in Figure 3.6. However, if a player hit a rim of a hoop, they would collide. To provide help with navigation between hoops, they were also set to periodically pulsate red (Figure 3.7). 3D models sourced from the internet were also added to the map such as a castle and a dragon to add interest. Some of these were animated and others were set to change position. Users start the map with a high density of models and hoops at the beginning (Figure 3.8). Then, as they progress further around the course, these become more scarce at higher altitudes. The map was designed to be fun, inviting, and evoke nostalgia. Therefore, consistent with the flying broomstick theme, models were chosen based on places, objects, and creatures that feature in the fictional world of Harry Potter. Collisions were enabled on these models to provide an additional sense of realism.

The point of view of the player in the VE was intended to be consistent with their position on the travel interface, allowing them to look around with the VR HMD. However, with the virtual broomstick translating through the VE, the virtual head (camera) was configured to remain offset relative to the origin of the broomstick. Sounds were also featured in this experience. During it, calming instrumental music was set to play in the background continuously. There were also sound effects that were played at certain events, movements, or positions. These included wind at high speeds, collisions, flying through hoops, and proximity to certain objects.

To ensure that the experience was responsive, a variety of optimisations were made such as occlusion culling, baking the lighting, and adjusting the plane clipping. The triangle count also had to be considered due to impacting the frame rate. This limited the density of models in certain parts of the VE and the level of detail each could have.

Figure 3.6: An overview of the 27 hoops in the course.



(a) Off. (b) On.

Figure 3.7: An example of a hoop pulsating to assist with navigation through the VE.

3.3 Experiment Design

An experiment was designed to test the hypotheses by comparing three manipulation conditions, applied on top of the baseline experience, to a control condition. This was done with a between-subject design, exposing each individual to only one of the conditions. While within-subject testing could have offered more confidence that only the independent variable was changing between trials, it was not chosen due to the lasting effects of CS symptoms and the potential for users to adapt to the experience. Participants who signed up for the study were randomly

Figure 3.8: The beginning of the course from the perspective of the player in VR.

allocated across four groups, with each group representing an experimental condition. To ascertain the extent of CS experienced by participants, a range of subjective and objective measurements were taken. An outline of the experimentation process is shown in Figure 3.9. Approval was also granted for this experiment by the University of Canterbury Human Research Ethics Committee (HREC) as shown in Appendix B.

3.3.1 Conditions

Gaze-Tracking Vignette

For this condition, a novel dynamic vignette effect was used to manipulate the FOV based on speed and eye-gaze direction as shown in Figure 3.10. A black vignette effect with an elliptical shape and a smooth gradient was generated using the post-processing effect in Unity, with its intensity set to be proportional to the speed of the player. This was configured to be unobtrusive at the maximum possible velocity. Additionally, using eye-gaze direction, the central position of the vignette scope was set to follow where users' eyes were looking by moving vertically and horizontally. This was implemented using an eye-gaze vector from the Tobii XR SDK on top of the VIVE SRanipal SDK in Unity and a VIVE Pro Eye VR headset capable of eye-tracking. This required calibration for each new participant. To improve the experience, an algorithm was

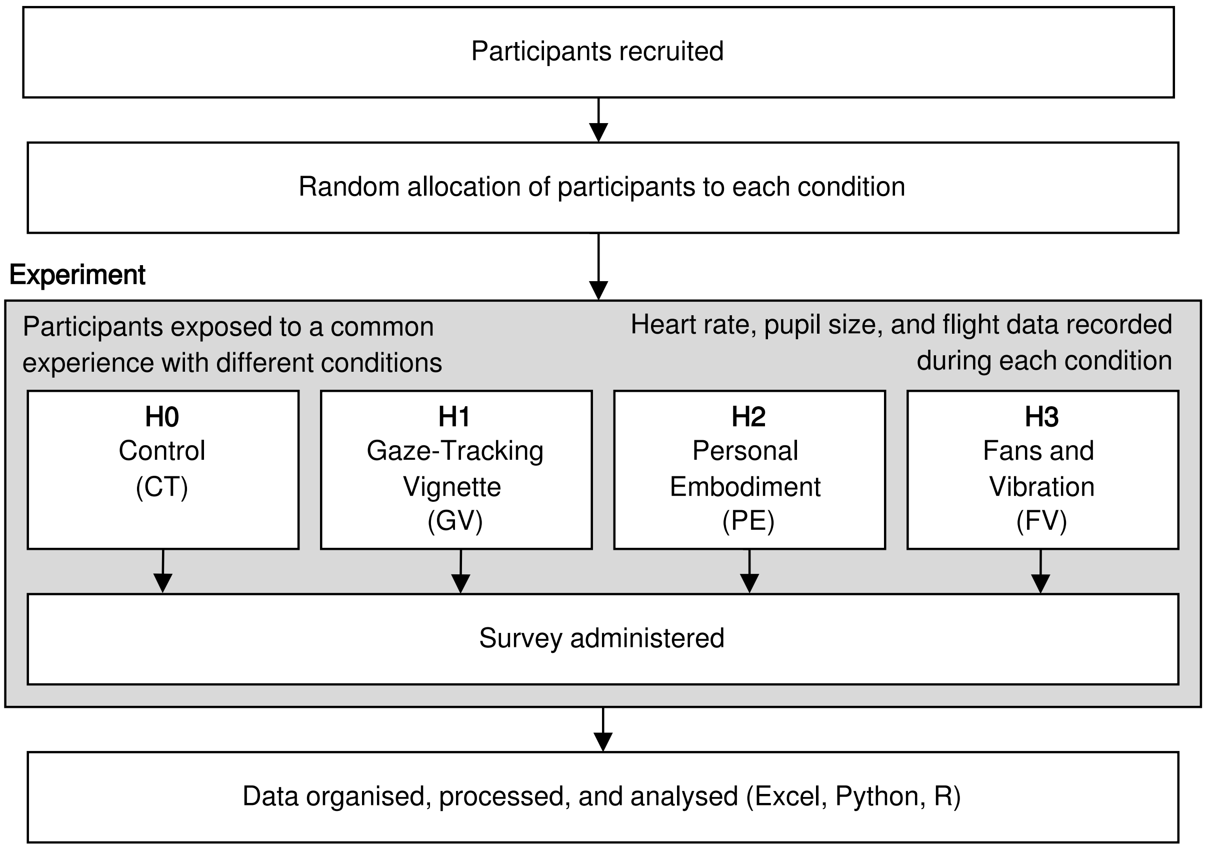


Figure 3.9: An overview of the stages and allocations to conditions involved in the experiment.

implemented to reduce the jitter in the vignette position by averaging the horizontal and vertical coordinates over ten frames. It, therefore, took at most ten frames to update the vignette to the most recent changes in eye-gaze direction.

Personal Embodiment

Personal embodiment in VR allows for users to experience a virtual character through its perspective, consistent with how they would experience themselves in real life. To implement this as a condition, a rigged model of a body was imported into Unity (Figure 3.11). This was adjusted to a sitting position with its knees bent and both hands clasping the shaft of the broomstick. Then the head of the character was masked out to avoid obstructing the camera tracking the VR headset, allowing users to look around and see different limbs.

To provide more realism, hand tracking was also implemented by fastening a designated VIVE Tracker to each wrist with adjustable straps (Figure 3.12) and performing inverse kinematics. Trackers were calibrated to be facing upwards, with the LHS and RHS labels facing forward.

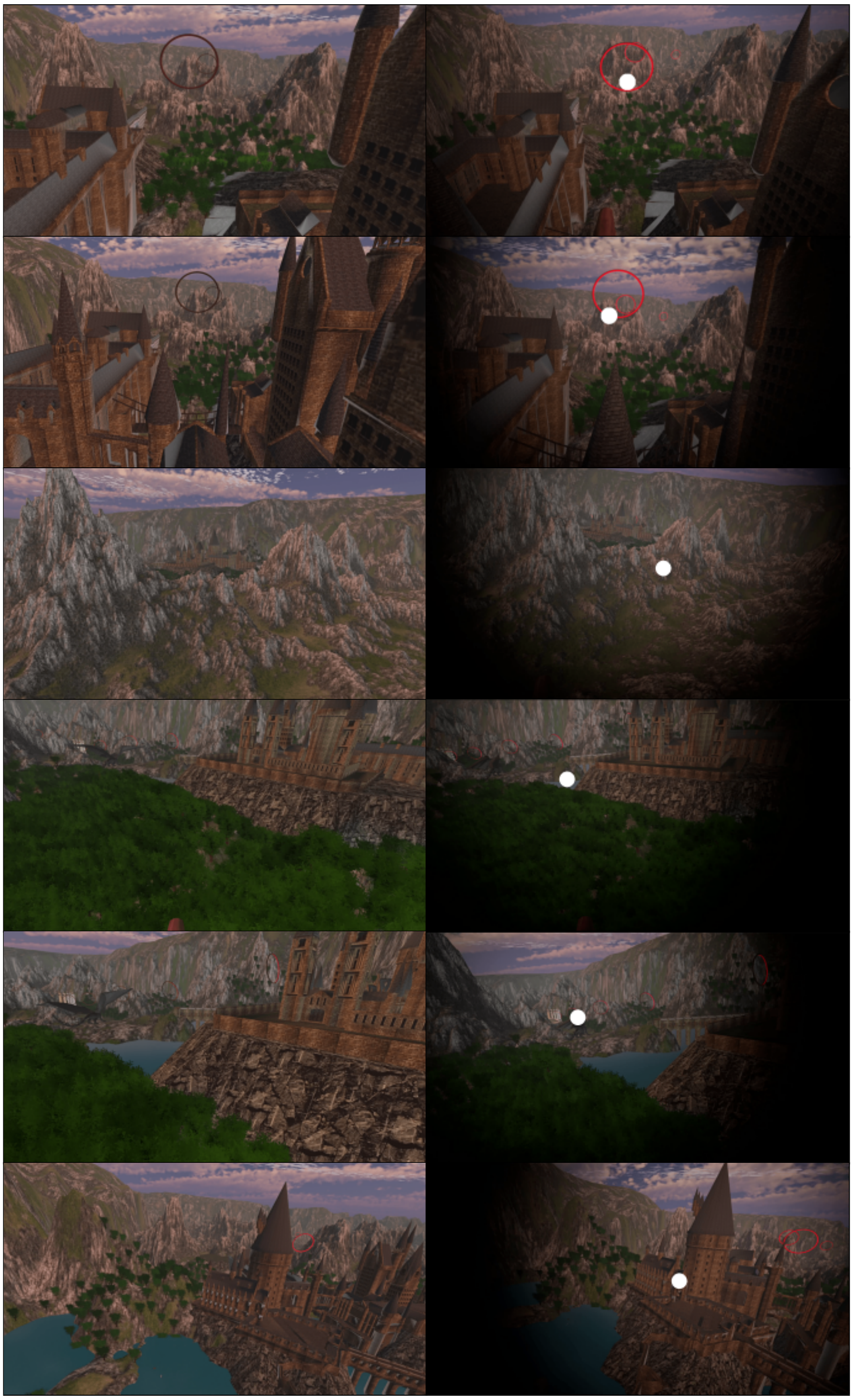


Figure 3.10: A comparison of frames from the point of view of the user between CT (left) and GV for different speeds and eye-gaze directions (right). White dots have been used to indicate the centre of each vignette on these images.

Figure 3.11: An external view of the rigged character model used for PE.

Based on the position and orientation of each Tracker, the entirety of each virtual arm could be moved. To avoid fingers overlapping with the broomstick and reduce minor inaccuracies, an approach was taken to guide hand placement on the shaft based on the proximity of the trackers by altering the weighted effect of the inverse kinematics. Without inverse kinematics, the hands reverted to the default position, clasping the shaft symmetrically with correct placement. Additionally, to allow for different positions along the shaft, sliding was also implemented. This used weighting with respect to predefined positions. Thus, the virtual hands of the character could be mapped to the position of the user's hands (Figure 3.13), allowing for a variety of different grips. This did, however, have some limitations. The guidance meant that the movement was restricted and therefore was not able to suit all users.

Examples of this condition are shown in Figure 3.14. These frames show a variety of views of PE from the point of view of the user at different head rotations and hand movements. However, there is some discrepancy between the FOV and the binocular disparity experienced in a VR headset compared with what is shown in these 2D images.

Fans and Vibration

To simulate different environments by engaging different senses, a custom fabricated enclosure referred to as a TactaCage (Figure 3.1) was used. This consisted of fans arranged on an

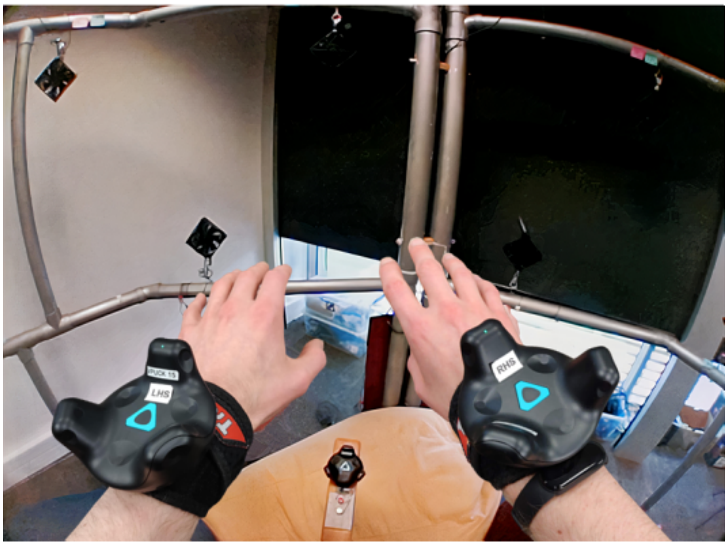


Figure 3.12: An example of how VIVE Trackers were strapped to each hand for embodiment tracking.

Figure 3.13: An example of gripping the interface shaft.

octagonal frame and a raised concentric platform with four haptic transducers (Buttkicker LFEs) mounted underneath (Figure 3.15), operated with a 1000 W amplifier [32].

The transducers provided the sensation of vibration. While these used the same audio channel as the headphones in the HMD, only low frequencies were transmitted. Therefore, to emphasise the lower frequencies of sounds, they were isolated with a low-pass filter and amplified. This was used to augment sound effects such as a dragon roaring, collisions, and airflow proportional in volume to the speed.

Figure 3.14: Frames from the point of view of the user showing PE at different head rotations and hand movements.

On each of the two tiers of the TactaCage, eight computer fans were arranged on each side of the octagon facing towards the centre (Figure 3.16). The fans served to simulate the sensation of local airflow that is experienced when moving through air at high speed (from air resistance). This involved tracking the rotation of the user and activating the corresponding fans in front of the player. These were activated at full intensity during any movement through the VE to be as

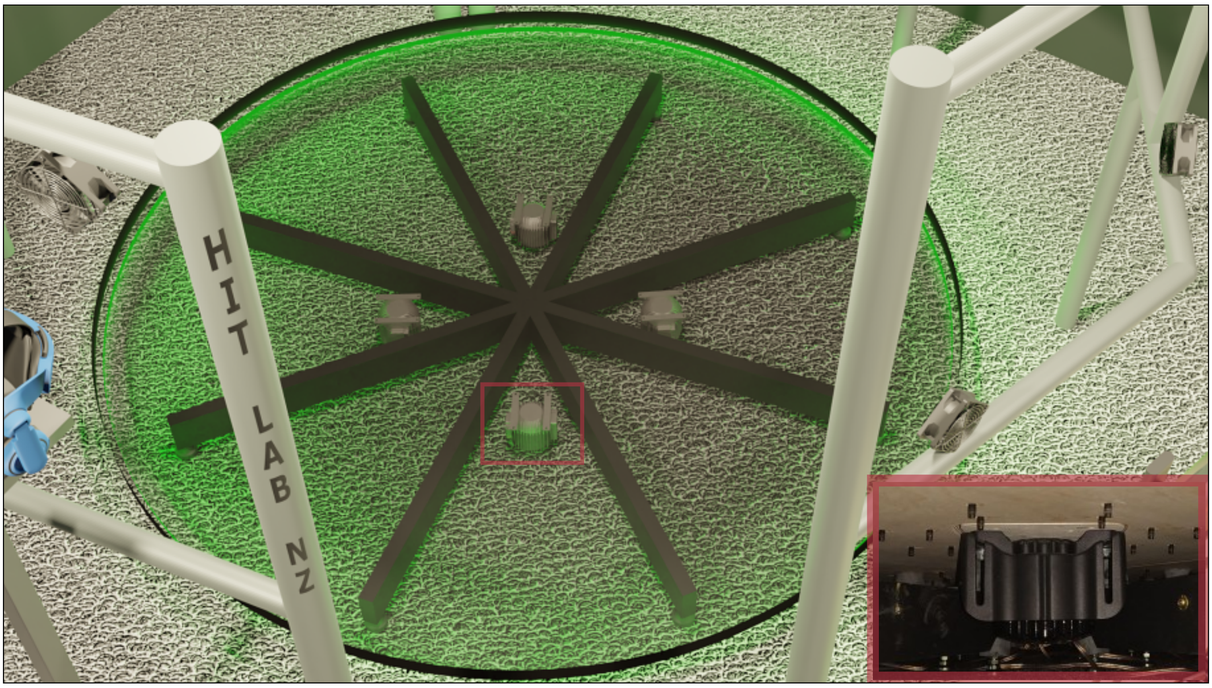


Figure 3.15: Buttkicker haptic transducers underneath the TactaCage platform.

noticeable as possible. There was also a global airflow that simulated wind coming from one direction irrespective of player movement. This meant that several of the fans were active the entire time, but set to low intensity. The fans were controlled using a WebSocket server written in Node.js that the Unity VR application was able to connect to. This was pinged periodically to ascertain a connection status that was indicated on a user interface.

(a) Front.

(b) Back.

Figure 3.16: A fan on the TactaCage in the second tier.

3.3.2 User Interface

For this experiment, it was important to be able to set up different conditions for each participant, ensure that data was successfully being collected, monitor the VE, and monitor what was happening in the real world. To satisfy these requirements and simplify the experiment, a dashboard overlay on the VR application was created that only shows on the computer (Figure 3.17). This allowed the researcher to switch between conditions, enter a participant identifier for file naming, control the game state, and activate eye-tracking calibration. It also displayed temporal readouts, game-play information, and the connection status of two WebSockets. Therefore, it was less likely that errors would be made and the researcher had more freedom to monitor the physical hardware and the safety of participants.

Figure 3.17: The user interface of the VR application for configuring, operating, and monitoring the experience.

3.3.3 Data Collection

Subjective and objective measurements were taken to gain insight into how each experimental condition affected participants. These included physiological responses, flight data from moving through the VE, user movements, survey responses, and visual recordings. To avoid human error during each trial, the collection and storage mechanisms were designed to automatically record and save data.

Heart Rate Data

A Xiaomi Mi Band 6 Fitness Tracker was used to collect HR data. This was given to participants to put on the wrists of their non-dominant hands. If they were doing the PE condition, the band was placed behind the VIVE Tracker strap. To record data, the band was connected to an Android phone via Bluetooth and an app called StraMi (v3.0) was used. As soon as the participant put the band on before the experience, the recording of HR values was started. Data readings were measured in BPM and were logged approximately every two seconds. The data was recorded in comma-separated form, with each line containing a timestamp and an HR value. Once the experiment was finished, the data was exported to a computer for processing.

Eye-Tracking Data

Eye-tracking data was collected from the headset using the SRanipal SDK in the VR application. This included the average pupil size of both eyes (internal diameters) in millimetres and the combined blink rate of both eyes. The same eye-gaze-ray direction used in the GV condition was also collected in the form of a normalised vector. The HMD eye-tracking sensor was able to operate at 120 Hz, but data was recorded at approximately 90 Hz. The recording was automatically started and stopped based on whether the application was in the playing or stopped state. Each of these measurements was saved directly to a separate CSV file for each participant as often as possible.

Flight Data

Time series data was collected about the players' flights through the VE at approximately 90 Hz. This was done automatically by the VR application during the experience. The flight data included the position and orientation of the broomstick as well as the headset. It also included hoop count, speed, distance travelled, and height above the ground. The orientation was expressed in Euler angles using degrees, the position in metres, and speed in metres per second. For reference, one metre in the Unity VE is approximately one metre in the real world. This data was saved in the same CSV files for each participant as the Eye-Tracking data in another column.

Visual Recording

Participants were recorded from three different angles using web cameras (720p Microsoft LifeCam HD-3000). These consisted of two views from the side and an aerial view from the ceiling. The maximised VR application window was also recorded, showing the point of view of the user. Open Broadcaster Software (OBS) was used to record the camera views and the application into a single feed. The arrangement of the feed elements is shown in Figure 3.18. This feed was captured at 30 FPS with a resolution of 1080p. To automate the capture in OBS, the obs-websocket add-on was used to run a WebSocket server. This allowed the Unity application to form a connection with OBS. Therefore, based on the playing and stopped states of the Unity application, the OBS capture could be started, stopped, or set to different file names. File names of captures were based on the User ID entered in the Unity application and were saved as a *.mkv* container.

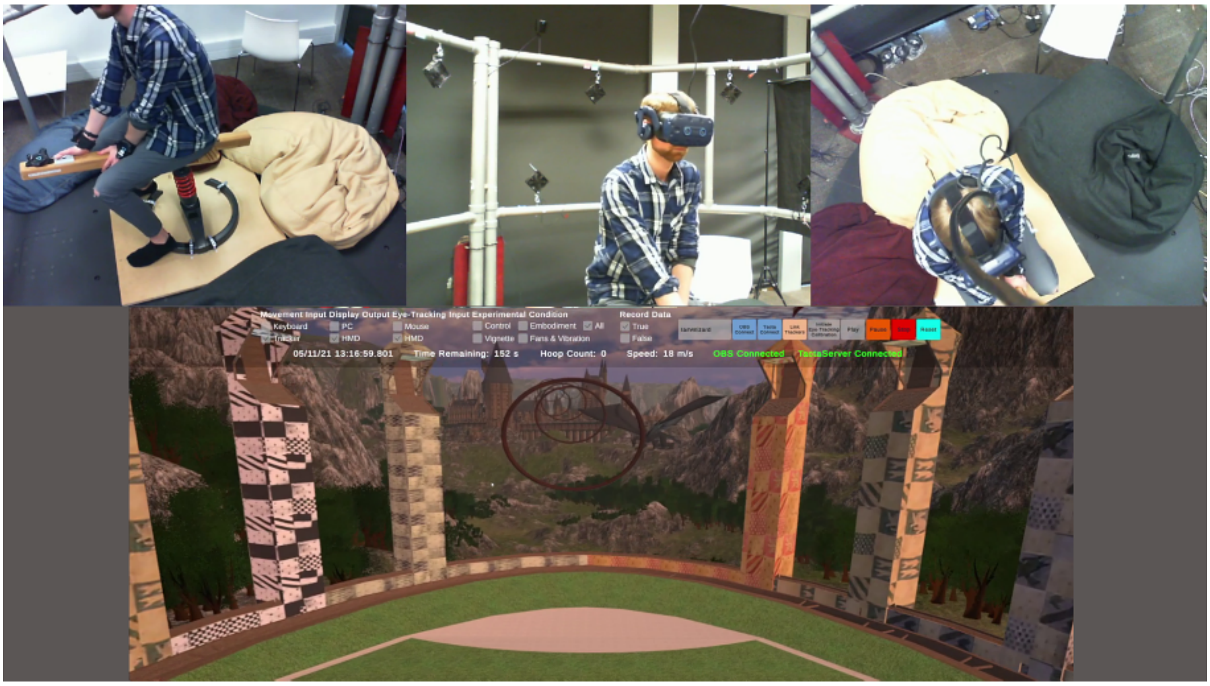


Figure 3.18: An example of the feed arrangement of the cameras and Unity VR application that was recorded by OBS.

Survey Data

Subjective data was collected with a survey post-exposure. This was administered using the online Qualtrics survey platform and required users to select options on Likert scales and write into text entry fields (Appendix C). The first part of this form was used to gather background information on participants. In the second part, the SSQ was used to assess the level of CS they experienced. After the responses were submitted the results of the survey were exported as a CSV file with numerical values representing the choices on Likert scales.

3.3.4 Data Processing

To prepare the numerical data for statistical analysis, CSV files were prepared, aggregated for each participant in folders and imported into RStudio. Then the data was sorted, manipulated into the correct format, and inserted into the correct data structures. In RStudio the data was organised by creating a hierarchy of lists, with each top-level list representing a participant with a unique five-digit identification code.

The raw HR data for each participant was extracted using a Python script. This involved converting timestamps from 13-digit Unix time strings to date-time strings and saving the data to a CSV file. Then each HR value was manually labelled using the experiment footage with one of four categories (before, during, after, outlier) using Excel. After importing the HR files into RStudio and splitting the values based on these labels for each participant, the timestamps were finally transformed into relative time from the start of the experience. Due to the variability of HRs between participants, values before the experiment were averaged to provide a baseline. The difference between this value and subsequent values during exposure were calculated and saved. Further processing involved detecting duplicate timestamps and consolidating the values by averaging.

For the flight and eye-tracking data, the date and times were combined for each reading, changed to the correct string format, and converted to R date-time objects. Errors in the recording of pupil size, represented by -1, were also removed. Additionally, the data for distance travelled was noisy and could not be numerically differentiated reliably. To resolve this, it was modelled for each data set using splines with 200 knots. This resulted in smooth lines that were able to be differentiated to speed and acceleration [58]. Furthermore, the flight and eye-tracking data were downsampled based on the HR data timestamps, enabling comparisons with HR as well as reducing the processing required for modelling and plotting.

The survey data and conditions were collated in a single CSV file using Excel and imported into RStudio. Initially, the response for each SSQ symptom was reduced by one to account for the Likert scales starting at one. These entries were then used to calculate the component scores based on the weightings of each symptom and a total severity score using the method described by Stanney et al. [37]. Finally, the scores, participant information, and condition allocations were assigned to each participant data structure using identification codes.

3.3.5 Data Analysis

To gain insight into the population sample, the survey responses participants gave were collected and plotted as histograms. This data included age, gender, experience with VR, and comfort with heights. These were split into four conditions in each figure to allow for comparisons.

To inspect the SSQ results, statistical summaries were calculated for each condition based on SSQ components. Box plots were also plotted with the conditions for each SSQ component in separate figures. Additionally, the effect sizes for each component were calculated using pooled standard deviations. To check for evidence of significant differences in the means of SSQ scores between conditions, a one-way Analysis of Variance (ANOVA) test was chosen. This was assigned a significance level, α, of 10% with the following null and alternative hypotheses:

$$\begin{aligned} &\mathrm{H}_0 : \mu_0 = \mu_1 = \mu_2 = \mu_3 \\ &\mathrm{H}_\mathrm{a} : \text{ The means are not all equal} \end{aligned}$$

To assess the validity of doing an ANOVA, a Shapiro-Wilk test was conducted to check the normality of the distributions (H_0 : Normal, H_a : Non-normal), followed by Levene's test to check the homogeneity of variances (H_0 : Homogeneous, H_a : Non-homogeneous). For each of these a 10% significance level was used. Based on the results from the statistical tests, a square-root transformation was applied to the data to satisfy the assumptions further.

Once the ANOVA was computed, the null hypothesis was rejected if the p-value was less than the significance level. This indicated if there was, indeed, a significant difference between means. To investigate each treatment group against the control group, a post hoc test was conducted using Dunnett's Method with the following hypotheses:

$$\begin{aligned} &\mathrm{H}_0 : \mu_0 = \mu_1 \quad \mathrm{H}_0 : \mu_0 = \mu_2 \quad \mathrm{H}_0 : \mu_0 = \mu_3 \\ &\mathrm{H}_\mathrm{a} : \mu_0 \neq \mu_1 \quad \mathrm{H}_\mathrm{a} : \mu_0 \neq \mu_2 \quad \mathrm{H}_\mathrm{a} : \mu_0 \neq \mu_3 \end{aligned}$$

To analyse the objective data for change in HR relative to the baselines of each participant multiple linear regression models with interactions were used. Due to each person's experience being different over time, variables with minimal dependence on time were used to make fair comparisons between participants. Referred to as Movement Variables (MVs), these included the distance travelled, speed, acceleration, deceleration, and height above the ground. Each model was in terms of one of these MVs and categorical variables for each manipulation condition applied on top of Control (CT). The interaction arises from the interplay between each condition and the MV having an impact on HR. The general model formula applied for each MV was:

$$y_{hr} = \beta_0 + \beta_{mv}x_{mv} + \beta_{gv}x_{gv} + \beta_{pe}x_{pe} + \beta_{fv}x_{fv} + \beta_{mv:gv}x_{mv}x_{gv} + \beta_{mv:pe}x_{mv}x_{pe} + \beta_{mv:fv}x_{mv}x_{fv} \quad (3.1)$$

where:

y_{hr} = heart rate
β_0 = constant term (y-axis intercept)
β_{mv} = movement variable coefficient
x_{mv} = movement variable
$\beta_{gv}, \beta_{pe}, \beta_{fv}$ = condition variable coefficients
x_{gv}, x_{pe}, x_{fv} = condition variables (1 or 0 based on which condition is enabled)
$\beta_{mv:gv}, \beta_{mv:pe}, \beta_{mv:fv}$ = interaction coefficients between movement variables and conditions

Hypothesis tests for the coefficients of each model were also conducted to determine if they were significant ($H_0 : \beta = 0$, $H_a : \beta \neq 0$). If a p-value was above a 10% threshold, the coefficient was rejected from the model due to a lack of evidence that it was not zero. Multiple r^2 coefficients, overall p-values, and residual standard errors were also found for each model. Additionally, scatter plots were used to display the data for each MV, split into four subplots for each condition with trend lines based on the associated model. To assess the validity of the models, each was checked using the linear regression assumptions for linearity, independence, homoscedasticity (constant variance), and normality of residuals. This involved examining residual standard errors, residual plots, and Quantile-Quantile plots.

Observations from the researcher and survey feedback from users on the experience were collated and summarised based on trends and notable results. This also included plotting histograms for the frequency of adjectives used by participants to describe the experience and the number of hoops users flew through in the VE.

3.4 Equipment and Software

3.4.1 VR and Tracking Hardware

Base Stations

To track the position and orientation of the VR headset and peripheral devices, two second-version SteamVR Base Stations were used (Figure 3.19). These were mounted on the TactaCage frame and tilted downwards (Figure 3.1), covering a space of up to 5 m by 5 m. Both were plugged into power sockets and were able to communicate with the computer via Bluetooth. Base Stations work by rapidly sweeping a space and emitting infrared light which is registered by sensors on tracked devices. Using trigonometry and inbuilt Inertial Measurement Units (IMUs), the position and orientation of each device can be determined [59, 60, 61]. However, this method of tracking does rely on a direct line of sight with a sufficient number of sensors to work.

Figure 3.19: Two SteamVR 2.0 Base Stations [59].

Head-Mounted Display

The chosen HMD was a VIVE Pro Eye (2019) by HTC (Figure 3.20). This is a tethered headset that requires a computer for graphical computation and power but includes features such as eye-tracking, built-in headphones and six DOF tracking. The specifications for this device are shown in Table 3.2.

Trackers

Three VIVE Trackers (2018) by HTC were used in this experiment (Figure 3.21). One was located at the end of the wooden shaft to track its orientation. This was affixed to the shaft using the 1/4-inch standard tripod mount on the underside of the tracker and a modified 3D printed mounting part made of Polylactic Acid (PLA) [57] (Appendix A.4) to offset the tracker from the

Figure 3.20: A VIVE Pro Eye HMD [62].

Release Date	6 June, 2019	
Screen	Display panel	Dual OLED 3.5" diagonal
	Resolution per eye	1440 x 1600 px
	Resolution combined	2880 x 1600 px
	Refresh rate	90 Hz
	FOV	110°
Eye-tracking	Output frequency	120 Hz
	Accuracy	0.5°–1.1°
	Calibration	5-point
	Trackable FOV	110°
Inputs	Dual microphones	
	Dual passthrough cameras	
Ergonomics	Adjustable headstrap and tightening knob	
Audio	Integrated stereo headphones (adjustable)	
Tracking	6 DOF (inside-out)	
IPD Range	61-72 mm	
Weight	550 g	

Table 3.2: VIVE Pro Eye VR HMD specifications [63, 64].

surface. These trackers are capable of 6 DOF, have a Micro-USB charging port, weigh 89 g and have a reported battery life of four hours [65]. There are also a series of general-purpose pins on the underside that were used in the control system (Appendix A.5).

Figure 3.21: A VIVE Tracker (2018) [65].

3.4.2 Computer Setup Hardware

The computer hardware used in this experiment was able to handle the Unity application, SteamVR, the SRanipal eye-tracking runtime, the server for the TactaCage, and OBS capture simultaneously. The specifications for the computer setup is shown in Table 3.3.

Processor	Intel Core i7-8700 (3.20-4.20 GHz)
Memory	32.0 GB
Graphics	NVIDIA GeForce RTX 2080
Storage	250 GB SSD (OS + Programs), 1 TB HDD (Unity Application + Data)
Operating System	Windows 10 Enterprise
System Architecture	64-bit (x64)
Screen	Philips 34" Ultrawide LCD Monitor (3440 x 1440 px)

Table 3.3: The specifications of the computer setup hardware used in the experiment.

3.4.3 Heart Rate Capture

A Xiaomi Mi Band 6 Fitness Tracker (2021), capable of PPG, was used to capture HR data (Figure 3.22). This wrist-worn device weighs 12.8 g, has a strap that can adjust from 155 mm to 219 mm, has a multi-day battery life, and uses Bluetooth for connectivity.

Figure 3.22: A Xiaomi Mi Band 6 Fitness Tracker [66].

3.4.4 Safety

Participants needed to be safe even if they fell off the stool. Therefore, five bean bags were arranged around the interface (Figure 3.1). Cabling extensions were also added to enable the headset to be routed via the roof (Figure 3.23) and avoid it tangling around participants on rotation. To minimise the initial slack in the cable for users, the HMD was placed on a tall stand to be closer to head height. However, if necessary, the slack could be adjusted by pulling the cable on either side of the connection to the roof. Additionally, a bucket was kept in the vicinity in case of sudden emesis and antibacterial wipes were used to clean the headset between experiments.

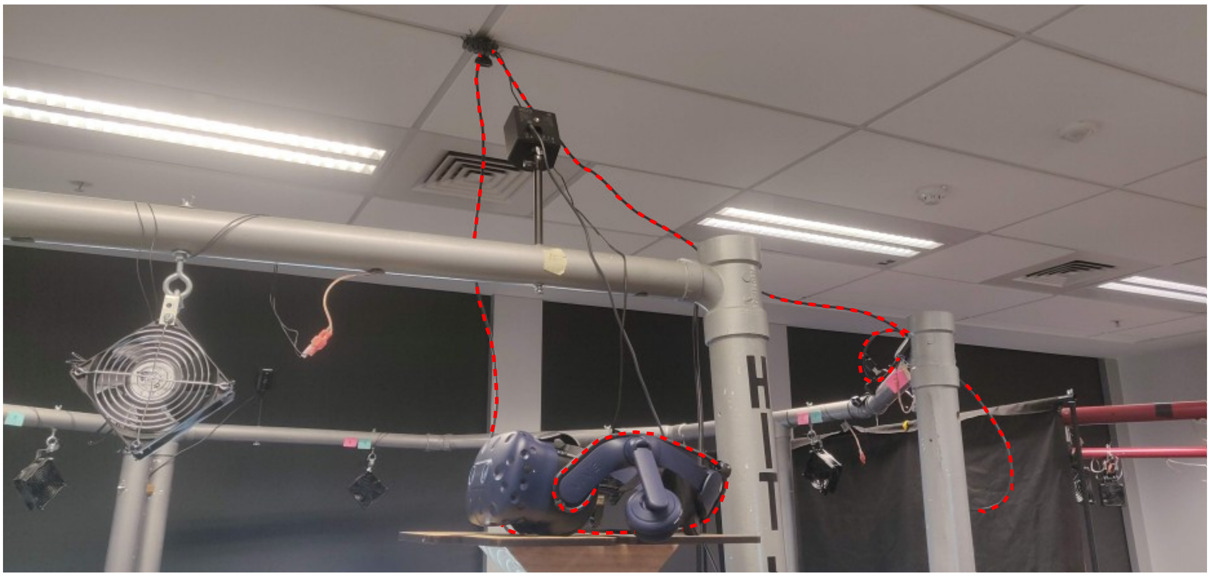


Figure 3.23: The HMD on a stand and cabling routed via the roof.

3.4.5 Application Development

A range of software packages, tools, and assets was used in the development of the VR application. The software used is shown in Table 3.4. As for models, these were downloaded from online sources including 3D Warehouse, Sketchfab, and The Models Resource. Additionally, sound effects and music were sourced online from Mixkit and YouTube.

3.4.6 Data Processing

The tools used for processing the data, running analyses, and plotting are shown in Table 3.5. This includes two programming languages, two Integrated Development Environments (IDEs), the R libraries used, and a specialised statistics tool for running power analyses.

3.5 Participants

To estimate the required sample size for this experiment, an *a priori power analysis* was conducted using the software G*Power [67]. For a one-way ANOVA test across four groups, α was 0.1, power was 0.8 and the effect size was set to 0.4 based on what Cohen classified as a large effect [68]. This test resulted in a required sample size of 60 participants across all

Software		Version
Unity3D		2020.3.20f1 (built-in pipeline)
Sranipal Runtime		1.3.1.1
SteamVR		1.18.6
OBS		27.1.3
obs-websocket		4.9.1
Untity Libraries	MapMagic 2	2.1.8
	Tobii XR	3.0.0
	SRanipal SDK	1.3.3.0
	Final IK	1.7
	Nature Starter Kit 2	1.0
	SteamVR Plugin	2.7.3 (sdk 1.14.15)
	Free HDR Sky	1.0
	WebSocketSharp-netstandard	1.0.1
	NuGetForUnity	3.0.2
	Standard Assets	1.1.6

Table 3.4: The software and versions used in the development of the VR application.

Software		Version
Python		3.10.0
Visual Studio Code		1.63.2
G*Power		3.1
RStudio		1.4.1106
R		4.0.5
R Libraries	ggplot2	3.3.3
	Desctools (Dunnett's test)	0.99.44
	car (Levene's test)	3.0-12
	stats (Shapiro-Wilk test)	4.0.5
	gtrendsR	1.5.0
	effectsize	0.5
	ggResidpanel	0.3.0

Table 3.5: The software and versions used for data processing and analysis.

groups. However, considering that this was a rough approximation relying on assumptions and that time was limited, a target of 40 participants was set for this experiment.

3.5.1 Demographics

Selection criteria for participation in this experiment were devised to maintain the safety of individuals doing it and to protect the equipment. People with vestibular, balance, dizziness, migraine issues or conditions were identified as being a demographic susceptible to extreme CS and therefore high levels of discomfort. This was not seen as appropriate for this experiment so they were screened. A mass restriction was also set to 100 kg to protect the equipment. The product information for the Swopper Stool by Aeris product states that the maximum user weight is 120 kg [69]. Therefore, including a 1.2 factor of safety to account for the modifications, custom additions, and users pitching much more than they would if the stool was not fastened to the ground, 100 kg was chosen. Based on testing, the stool could handle this mass, but there was uncertainty on how it would handle repeated stress. Participants were additionally required to be at least 18 years old. These requirements were indicated on the booking website (Appendix D), the information sheet (Appendix E), and the consent form (Appendix F). Each participant's suitability was determined based on their agreement to participate with the assumption that they were in a sufficient mental and physical state to undertake the experiment.

3.5.2 Recruitment

A variety of advertisement methods were employed to recruit participants for this experiment. This involved posting on the HIT Lab NZ Facebook page (Appendix G.1), putting up posters (Appendix G.2), handing out posters, and sending messages via emailing lists. Potential participants were also made aware of the study by word of mouth. To entice people to sign up and do the experiment a $15 gift card was offered as an incentive. It was expected that the majority of participants would be students at the University of Canterbury due to advertising being primarily targeted at this group.

3.5.3 Booking

Prospective participants were directed to a web page created by the booking platform *bookwhen.com* using a custom URL where they could sign up for the experiment (Appendix D). This page had a list of available 45-minute time slots and had details of the experiment. It also included the eligibility criteria, a brief description of the experiment, the address of the HIT Lab NZ, a link to the advertisement poster, and a link to the information sheet. The sign up required a full name and an email address. After signing up, a confirmation email was automatically sent to the participant and the experimenter, including the time and the details of where to meet.

3.6 Experimental Procedure

For each experiment, 45 minutes was allocated, with 15 minutes between each subsequent session. With the experiment expected to take less time than advertised and the period between sessions, there was almost always a surplus of time. This allowed the experimenter time to write down comments, clean the equipment, check the equipment, fix problems, and organise the storage of the data.

3.6.1 Before the Session

Before each experiment, participants were randomly allocated to a condition and assigned a five-character identification code. These were recorded in an Excel spreadsheet. The information sheet and a consent form were also arranged on a desk with a pen, ready for the participant to look at and sign. To systematically ensure that the experience was working, safe, and consistent between participants a checklist was used. For the first participant of the day, this involved turning on hardware, opening the software, checking the battery charge of devices, and doing a trial run on the mechanical interface with the chosen condition. Between subsequent participants, this process was simplified to doing a trial run of the condition and restarting the Unity application. Problems could therefore be identified and resolved before participants arrived.

3.6.2 During the Session

Once the participant arrived, they were given some time to look through the information sheet and an opportunity to sign the consent form. If the PE condition was allocated, they were given two VIVE Trackers to put on specific hands indicated by labels and advised to double wrap the straps. The trackers were also rotated so the labels faced forward. For all conditions, they were given a fitness band to put on the wrist of their non-dominant hand. After erasing the previously logged data on the phone app, the band was connected and started recording. With the equipment on, the experimenter summarised the key points before asking the participant if they had any questions. Following this, they were directed to enter the TactaCage and take a seat on the travel interface. If the seat height was wrong it was adjusted as much as it could be.

At this point, they were shown where the IPD adjustment knob was, given a VR headset to put on, and helped with adjusting it. The application was then opened, a condition selected and an identifier code was added to the user interface. In the next step, the eye-tracking calibration application was opened where the user was asked to follow instructions via on-screen prompts. This was visible on the computer so the researcher could provide verbal assistance. Finally, with the calibration complete, confirmation was sought from the participant to check that they were ready to begin. If they were, the headphones were snapped down to cover their ears and the experience was started, allowing the player to move in the VE.

During the experience, the stability of the participant on the interface was monitored carefully. If they became unstable, they were supported to ensure they did not fall. Their behaviour and comments were also used to check how they were feeling. To ensure a successful experience, adjustments were also continuously made. These included moving the bean bags to avoid foot obstructions, altering the length of cabling from the roof, fixing fans by pushing the plug contacts together, and reconnecting a button on the breadboard. The participant's virtual experience was visible on the computer screen, including information from the dashboard interface. If they became stuck their position could be reset to the start of the level. To ensure that data was being collected, a small OBS window was kept in the corner of the computer foreground to monitor the recording status (Figure 3.17). HR could also be seen on the phone connected to the fitness band. Additionally, during the experiment comments were recorded in a notebook and the survey was set up, ready for them to do post-exposure if there were no issues.

3.6.3 After the Session

After the experience, they were assisted with taking off the equipment. Questions were then asked on how they were feeling and in some instances behaviours that the researcher noticed. Then they were directed to a separate computer to the one running the experience and were asked to fill out the survey. On completing this, they were given a voucher, thus concluding the experiment.

After the participant had left, the equipment had to be cleaned with wet wipes and the cabling untwisted. To gather all of the data on the computer, HR data was then exported from the phone app and transferred to the computer via USB. Then the VR application data, the transferred HR data, visual recording data from OBS, and the survey results from Qualtrics were collated. They were then placed in a new directory specifically for the participant. Written observations and participant comments were also added to the participant information spreadsheet in a new row. Once the experimentation for a given day was finished, the data was uploaded to OneDrive and the gear was shut down.

The outcomes of conducting the experiment described in this chapter are shown in Chapter 4 (Results).

CHAPTER 4 Results

This chapter summarises the subjective and objective data from the experiment and contains the results of modelling and statistical tests.

4.1 Participant Information

A total of 37 people participated in this study across four conditions. This comprised of ten allocated to CT, nine to GV, nine to PE, and nine to FV. The age distribution of each condition is shown in Figure 4.1. Overall, the minimum age was 18 and the maximum was 36. Of this sample, there were 17 female participants and 20 male participants (Figure 4.2). The distributions of experience with VR and comfort with heights are also shown in Figure 4.3 and Figure 4.4, respectively.

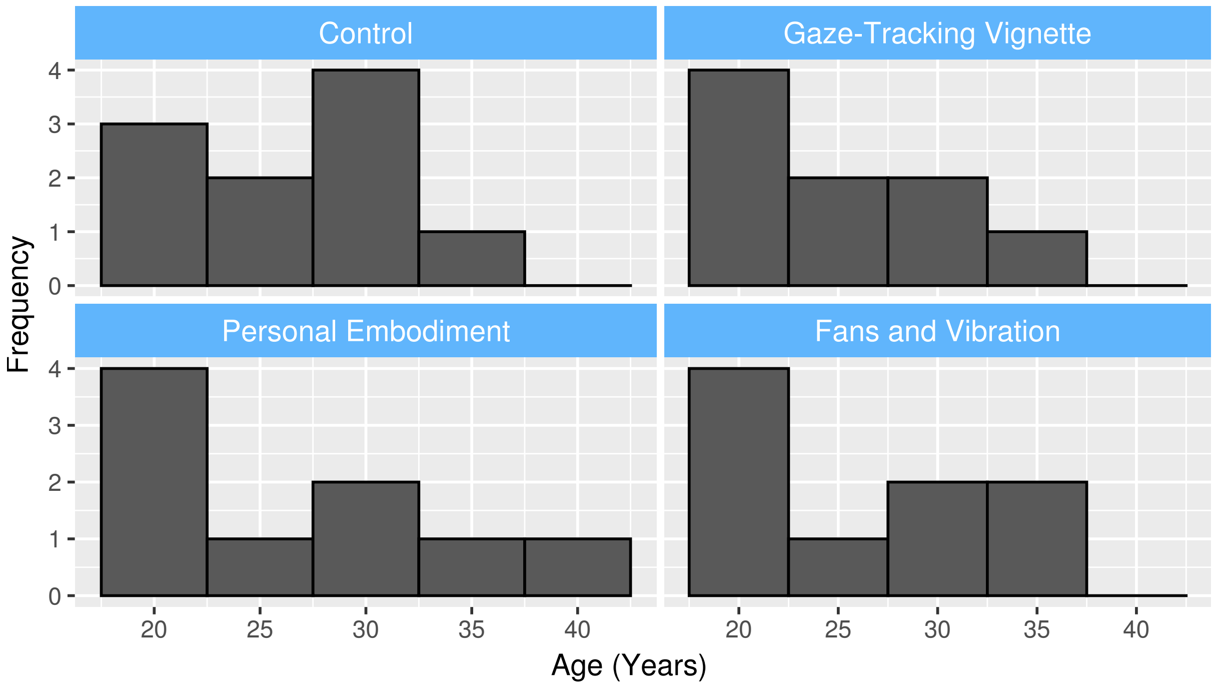


Figure 4.1: The distribution of ages for each condition.

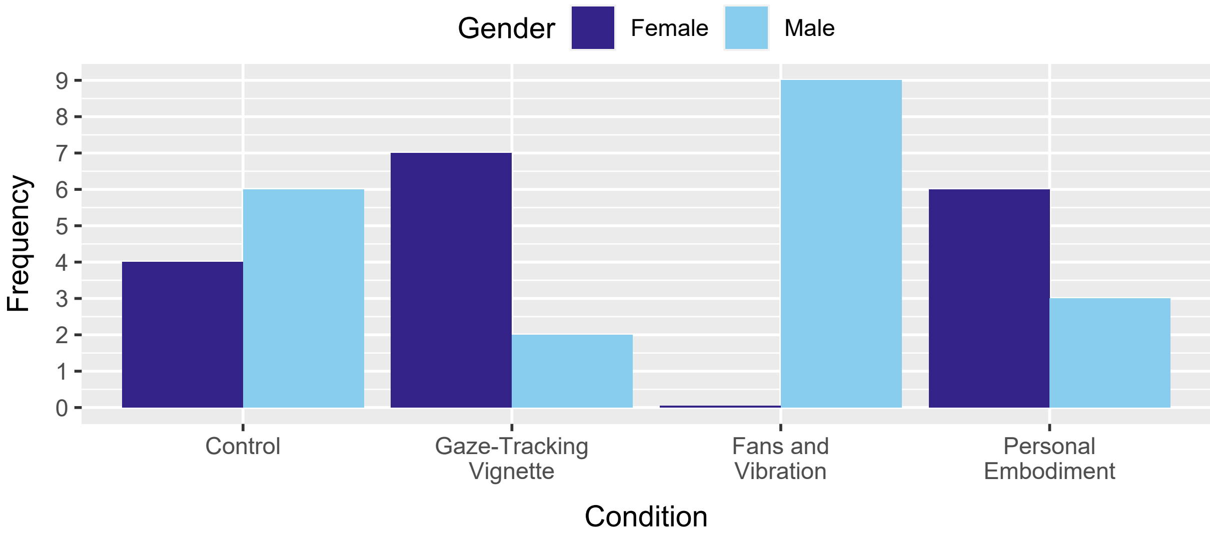


Figure 4.2: The proportions of genders for each condition.

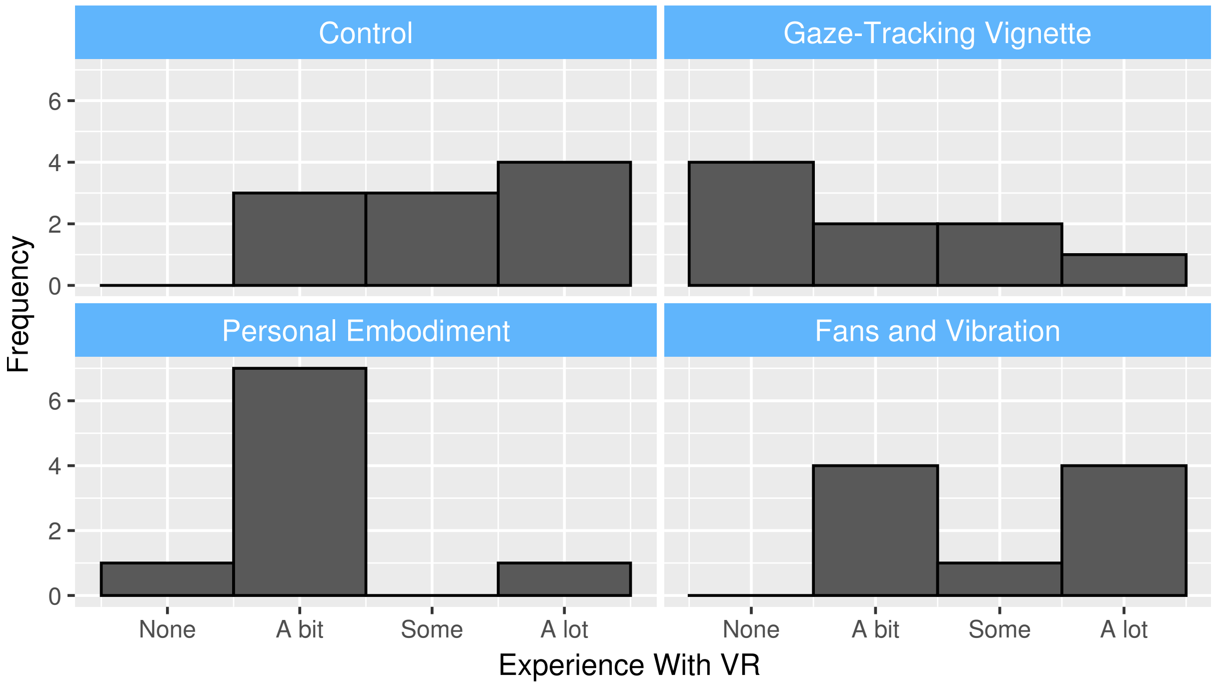


Figure 4.3: The distributions of participants' ratings of experience with VR for each condition.

4.2 Simulator Sickness Questionnaire

The summarised SSQ results for nausea, oculomotor, disorientation, and total severity have been split into the experimental conditions for comparison (Table 4.1). These are also visually compared in Figure 4.5, Figure 4.6, Figure 4.7, and Figure 4.8. For these results, higher

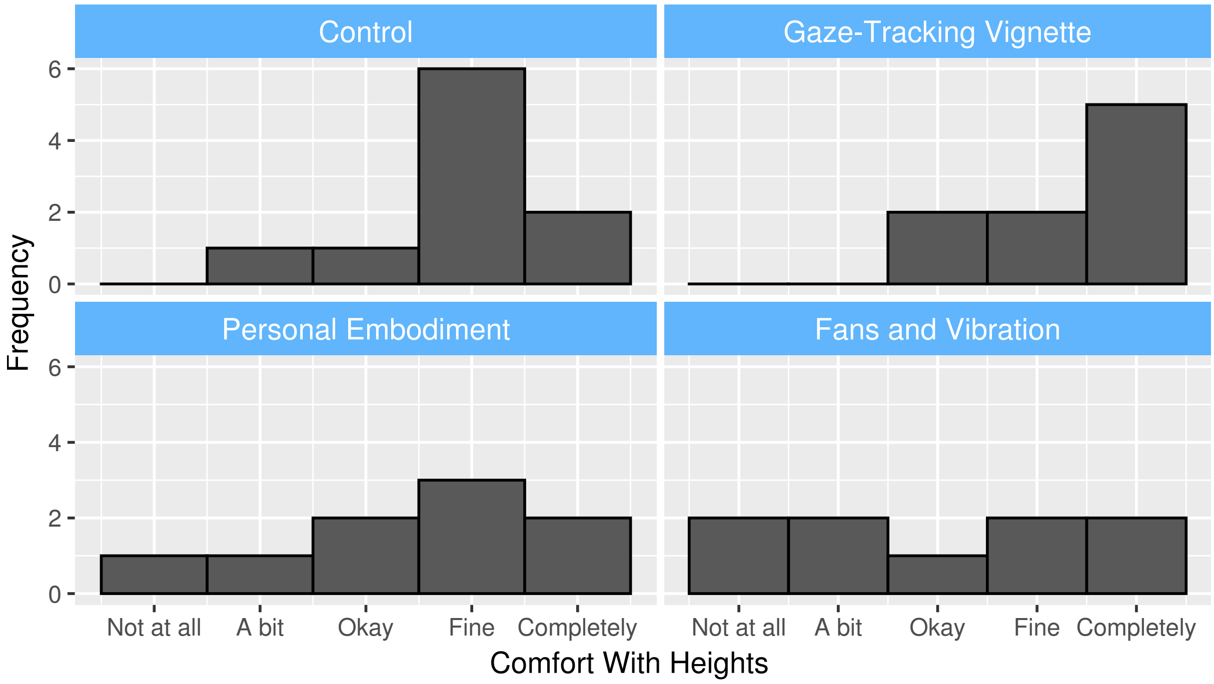


Figure 4.4: The distributions of participants' ratings of comfort with height for each condition.

scores indicate higher levels of experienced SS. Using this data, the effect sizes for each SSQ component were calculated in G*Power [67] using means and pooled standard deviations (Table 4.2).

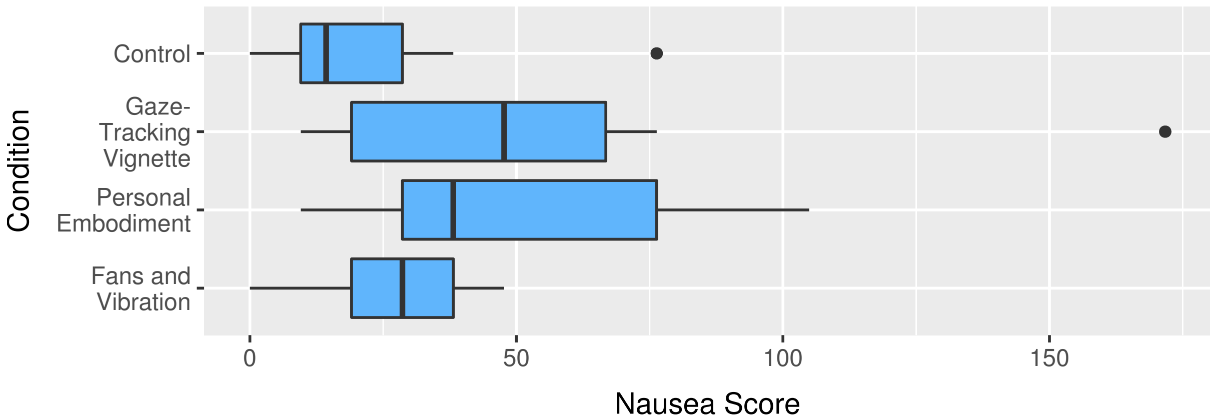


Figure 4.5: A comparison between conditions for the SSQ nausea component scores.

4.2.1 Analysis of Variance

The results of testing to see if an ANOVA could be performed are shown in Table 4.3. Initially, the Shapiro-Wilk test for normality provided significant evidence that seven of the data sets were

SSQ Component	Condition	SSQ Score					
		Mean	SD	Median	IQR	Min	Max
Nausea	Control	21.9	23.0	14.3	19.1	0.0	76.3
	Gaze-Tracking Vignette	53.0	50.5	47.7	47.7	9.5	171.7
	Personal Embodiment	50.9	36.6	38.2	47.7	9.5	104.9
	Fans and Vibration	29.7	15.4	28.6	19.1	0.0	47.7
Oculomotor	Control	19.7	17.6	19.0	13.3	0.0	60.6
	Gaze-Tracking Vignette	46.3	33.1	37.9	15.2	15.2	128.9
	Personal Embodiment	32.8	15.2	37.9	22.7	7.6	53.1
	Fans and Vibration	21.9	10.3	22.7	15.2	0.0	30.3
Disorientation	Control	29.2	38.0	13.9	24.4	0.0	111.0
	Gaze-Tracking Vignette	78.9	53.5	83.5	55.7	27.8	194.9
	Personal Embodiment	61.9	38.2	55.7	27.8	13.9	139.2
	Fans and Vibration	43.3	37.1	41.8	55.7	0.0	111.0
Total Severity	Control	265.0	253.0	182.0	91.8	0.0	786.0
	Gaze-Tracking Vignette	666.0	489.0	658.0	323.0	249.0	1853.0
	Personal Embodiment	545.0	287.0	464.0	233.0	116.0	1004.0
	Fans and Vibration	355.0	207.0	365.0	201.0	0.0	708.0

Table 4.1: A statistical summary of the results from the SSQ.

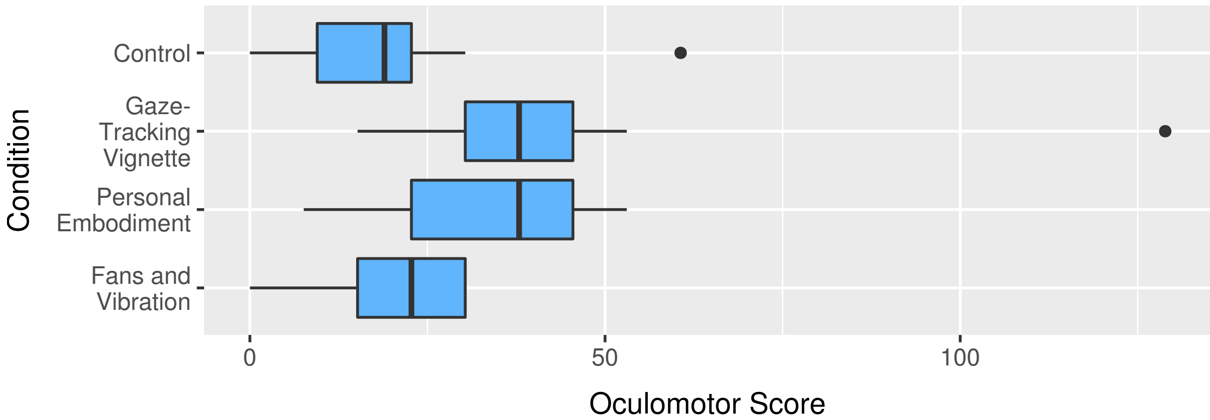


Figure 4.6: A comparison between conditions for the SSQ oculomotor component scores.

SSQ Component	Pooled SD	Effect Size (Cohen's f)
Nausea	38.4620	0.3547
Oculomotor	26.0828	0.4046
Disorientation	45.9075	0.4119
Total Severity	382.7967	0.4131

Table 4.2: The effect sizes of the condition means for each SSQ component using pooled standard deviations.

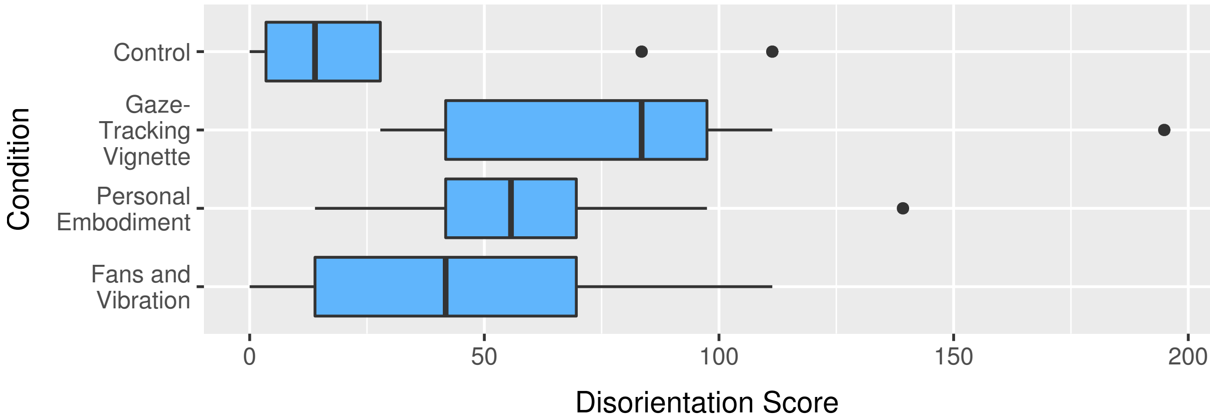


Figure 4.7: A comparison between conditions for the SSQ disorientation component scores.

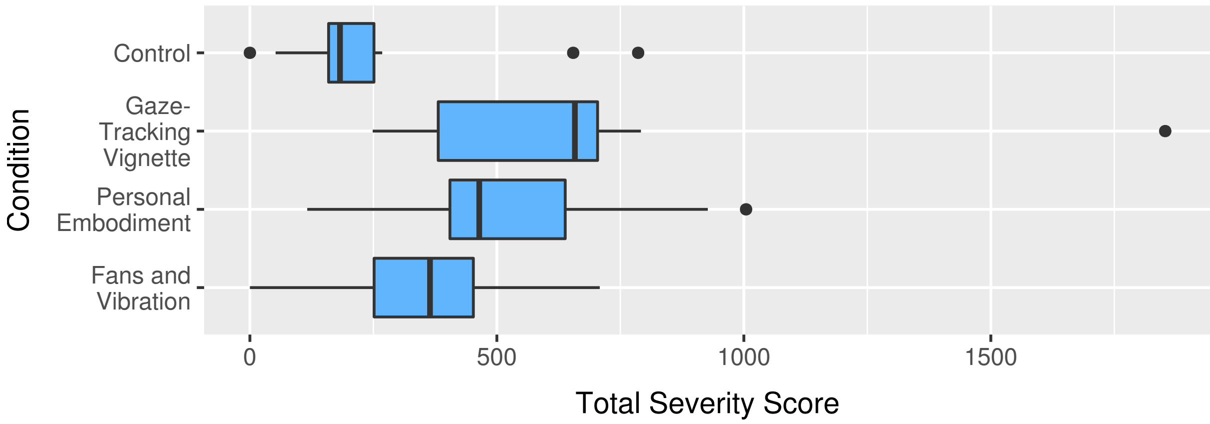


Figure 4.8: A comparison between conditions for the SSQ total severity scores.

not normally distributed. To minimise this issue, a square-root data transformation was applied. This decreased the number that did not pass to three. Additionally, Levene's test provided significant evidence that the variances of all the data sets were equal. In the subsequent ANOVA (Table 4.4), significant evidence of a difference in the means of the conditions for each SSQ component was found.

4.2.2 Post Hoc Analysis

The results of a post hoc Dunnett's test are shown in Table 4.5, comparing each manipulation condition to CT. This found significant evidence for differences due to PE for nausea, disorientation, and total severity. In addition, significant evidence for differences due to GV was found for all components. However, no evidence was found for significant differences due to FV.

SSQ Component	Condition	Shapiro-Wilk Test (P-Value)	Levene's Test (P-Value)
Nausea	Control	0.6020	0.6687
	Gaze-Tracking Vignette	0.4130	
	Personal Embodiment	0.3593	
	Fans and Vibration	**0.0145**	
Oculomotor	Control	0.2812	0.7690
	Gaze-Tracking Vignette	**0.0947**	
	Personal Embodiment	0.3973	
	Fans and Vibration	**0.0011**	
Disorientation	Control	0.1858	0.5835
	Gaze-Tracking Vignette	0.3414	
	Personal Embodiment	0.9847	
	Fans and Vibration	0.3557	
Total Severity	Control	0.3601	0.9798
	Gaze-Tracking Vignette	0.1127	
	Personal Embodiment	0.8658	
	Fans and Vibration	0.1289	

Table 4.3: The results of a Shapiro-Wilk test to check for normality of distributions and Levene's test to check for homogeneity of variances.

SSQ Component	Critical Value	F Ratio	P Value
Nausea	2.2635	2.3090	**0.0945**
Oculomotor	2.2635	3.4710	**0.0270**
Disorientation	2.2635	3.4160	**0.0286**
Total Severity	2.2635	3.4830	**0.0266**

Table 4.4: The results of a one-way ANOVA.

4.3 Objective Measurements

In this section, the results of the impartial data recorded from the VR application and the user are presented. This includes showing the response variation in different MVs for each condition and comparing individual results with different CS responses.

4.3.1 Physiological Response

Measurements to determine the change in HR relative to baselines over time have been compared with MVs in the VE. These include distance travelled, speed, acceleration, and

SSQ Component	Condition Versus Control	Dunnett's Test			
		Mean Difference	Lower CI	Upper CI	P-Value
Nausea	Gaze-Tracking Vignette	2.7109	0.0524	5.3694	**0.0914**
	Personal Embodiment	2.7433	0.0848	5.4019	**0.0867**
	Fans and Vibration	1.1423	-1.5162	3.8008	0.6884
Oculomotor	Gaze-Tracking Vignette	2.6977	0.7429	4.6525	**0.0154**
	Personal Embodiment	1.7423	-0.2125	3.6971	0.1585
	Fans and Vibration	0.5582	-1.3966	2.5130	0.8764
Disorientation	Gaze-Tracking Vignette	4.3161	1.1358	7.4965	**0.0174**
	Personal Embodiment	3.3839	0.2035	6.5642	**0.0749**
	Fans and Vibration	1.4307	-1.7497	4.6110	0.6591
Total Severity	Gaze-Tracking Vignette	10.2033	2.6365	17.7701	**0.0182**
	Personal Embodiment	8.1260	0.5592	15.6927	**0.0716**
	Fans and Vibration	3.0235	-4.5433	10.5902	0.7316

Table 4.5: The results of Dunnett's test.

height above the ground. To assess the difference in conditions for these variables, multiple linear regression models with interactions have been calculated. Statistical tests have also been generated to check the significance of the coefficients. These results are presented in Table 4.6, showing the coefficients of the model, p-values, and multiple r^2 coefficients. The change in HR for each MV and condition has also been plotted with trend lines from the models included. These are shown in Figure 4.9, Figure 4.10, Figure 4.11, and Figure 4.12. The residuals and quantile-quantile plots to check the assumptions of these regression models are included in Appendix H. Additionally, to summarise the changes in HR, the mean changes for each condition are shown in Figure 4.13.

4.3.2 Specific Cases

The distance travelled, speed, acceleration, height above the ground, HR, pupil size, and hoop count are shown for two participants with the most severe cases of CS (A and B) and one with no reported symptoms (C) in Figure 4.14. Participants A and B had the highest SSQ scores of all participants, with the former being 84% higher than the latter. Both of these participants reported symptoms of dizziness, despite also claiming that the experience was fun, and had no prior experience with VR. Participant A, allocated to GV, appears to accelerate much less than the others at the start, maintaining speeds within a certain range. However, for the rest of the experience, there are more fluctuations in acceleration and speed. On average, their HR

Model		Movement Variable (MV)				
		Distance Travelled	Speed	Acceleration	Deceleration	Height Above Ground
Coefficients	Intercept	6.8943 **(P<0.0001)**	6.2299 **(P<0.0001)**	6.3853 **(P<0.0001)**	6.2481 **(P<0.0001)**	6.4287 **(P<0.0001)**
	MV	-0.0104 **(P=0.0702)**	0.0023 (P=0.3782)	0.0014 (P=0.9651)	-0.0357 (P=0.1906)	0.0003 (P=0.8828)
	GV	-0.1805 (P=0.6767)	3.1467 **(P<0.0001)**	2.0023 **(P=0.0002)**	2.5998 **(P<0.0001)**	2.0368 **(P<0.0001)**
	PE	-3.0457 **(P<0.0001)**	-2.0737 **(P<0.0001)**	3.5122 **(P<0.0001)**	3.3259 **(P<0.0001)**	2.9530 **(P<0.0001)**
	FV	-5.5826 **(P<0.0001)**	-7.5022 **(P<0.0001)**	-1.3202 **(P=0.0095)**	-0.4380 (P=0.3851)	-2.9704 **(P<0.0001)**
	GV and MV	0.0517 **(P<0.0001)**	-0.0089 **(P=0.0264)**	-0.0047 (P=0.9250)	0.0205 (P=0.6009)	0.0010 (P=0.7470)
	PE and MV	0.1397 **(P<0.0001)**	0.0475 **(P<0.0001)**	-0.1602 **(P=0.0005)**	0.0809 **(P=0.0327)**	-0.0036 (P=0.2158)
	FV and MV	0.0642 **(P<0.0001)**	0.0395 **(P<0.0001)**	-0.2055 **(P<0.0001)**	0.2013 **(P<0.0001)**	0.0051 **(P=0.0631)**
Multiple r^2		0.0913	0.0808	0.0440	0.0378	0.0347
Overall P-Value		**P<0.0001**	**P<0.0001**	**P<0.0001**	**P<0.0001**	**P<0.0001**
Residual Standard Error		9.7040	9.7590	9.9450	9.9940	10.0000

Table 4.6: Multiple linear regression models with interaction for the change in HR based on numerical MVs and categorical condition variables.

appears to increase despite fluctuating. There are also several sharp but brief drops in pupil size and they manage to fly through the most hoops. Participant B, allocated to PE, chose to finish early and had to stay seated momentarily afterwards to recover. They also rated themselves as *Not at all* comfortable with heights, found the top of the screen blurry, and mentioned that they were not wearing their glasses. This participant's HR seems to increase slightly on average. However, there is a sharp drop in pupil size almost immediately after starting. Compared to Participants A and C, the fluctuations in acceleration and speed are much more aggressive. Participant C, allocated to FV, had more experience with VR than the others and rated their comfort with heights as *Fine*. Interestingly, they change speed and accelerate much more often in the first half of the experience than in the second. Their HR also increases at the beginning and near the end, but drops in between.

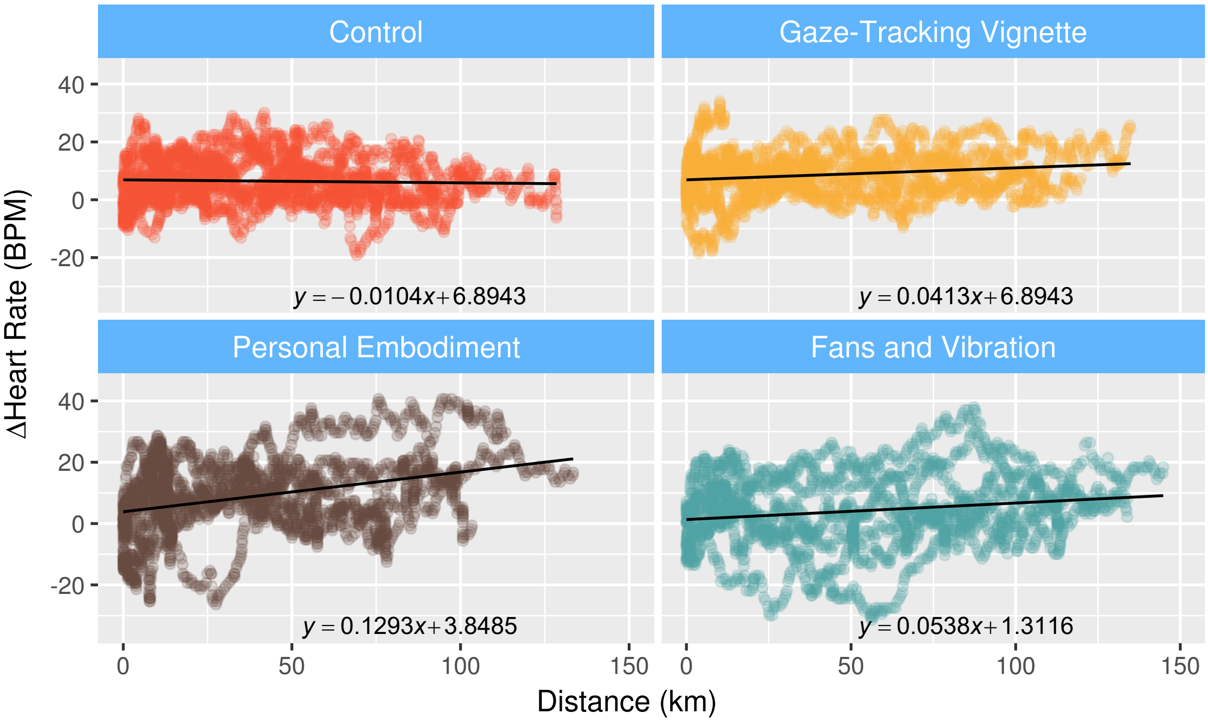


Figure 4.9: A comparison between distance travelled in VR and change in HR relative to a baseline.

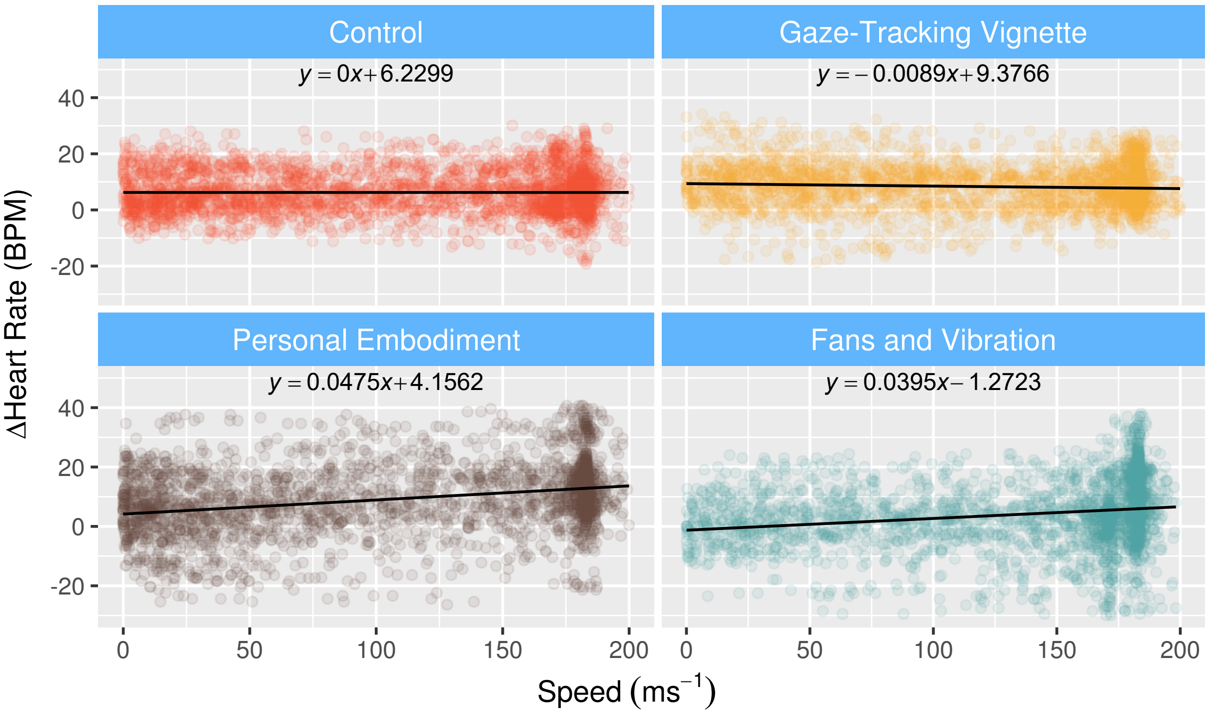


Figure 4.10: A comparison between the speed in VR and change in HR relative to a baseline.

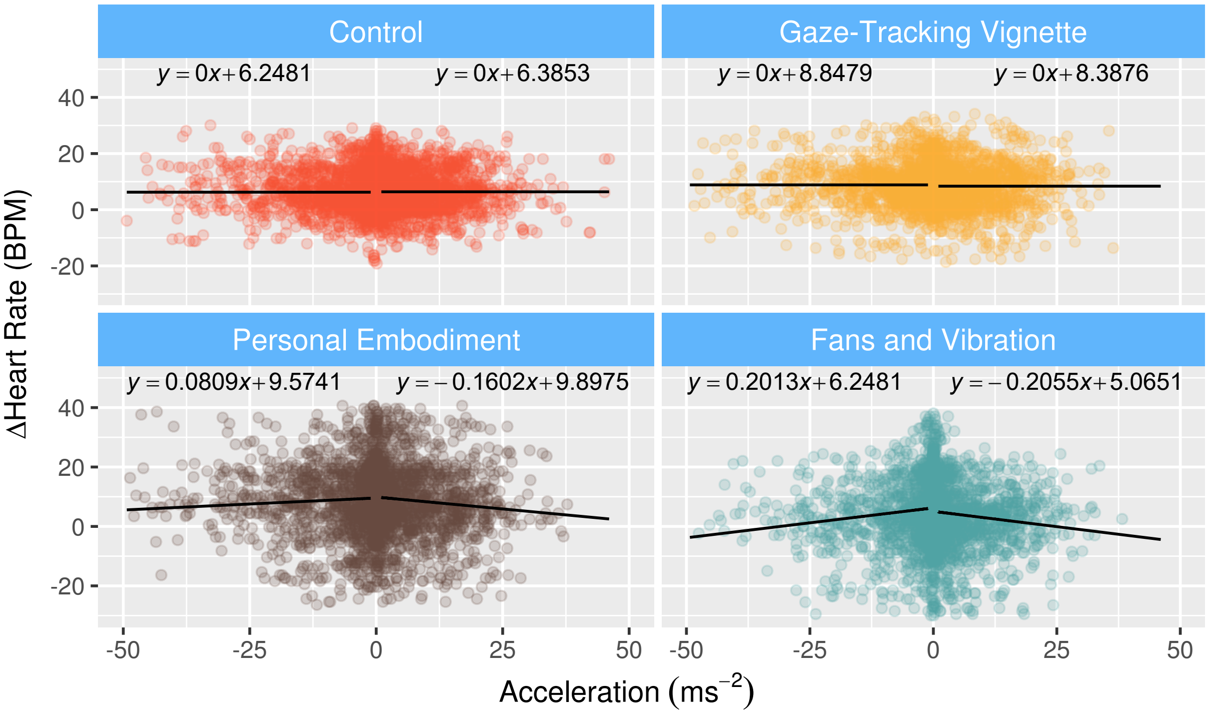


Figure 4.11: A comparison between acceleration in VR and the change in HR relative to a baseline.

4.4 Experimenter Observations

Observations and comments were recorded during the experiment to capture variations across participants or notable events that occurred. This involved noting participant behaviour, ergonomics, control system interaction, interest in the experience, hardware or equipment issues, symptoms, and inconsistencies in the way the experiment was conducted.

Differences in how participants used the interface included sitting positions, how the shaft was gripped, how wide users arranged their feet, techniques for leaning or turning, the amount of physical exertion, and seat height. It was noticed that some seemed to become tired of leaning forward and uncomfortable sitting on the seat. In a few cases, it was noted that the user would switch from using a thumb with both hands gripping the shaft, to one index finger pressing the button to reduce how much they needed to lean forward. Additionally, the seat could only be lowered to a certain point, impacting the ability of some users to place their feet flat on the ground and causing them to be less stable. Overall, there was a mixture in the stability of participants, with a few swaying and almost falling off the seat. Frequently, there appeared to be difficulty leaning forward to aim the broomstick downwards from its initial pitch. This seemed to

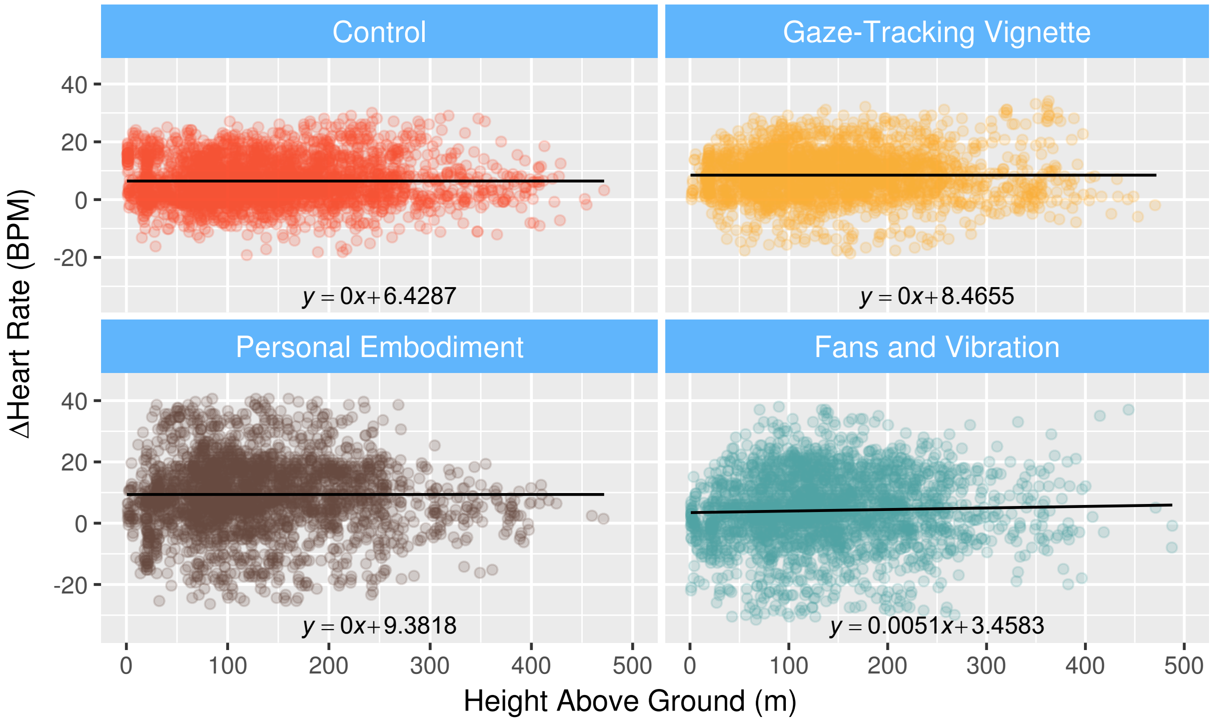


Figure 4.12: A comparison between height above the ground and change in HR relative to a baseline.

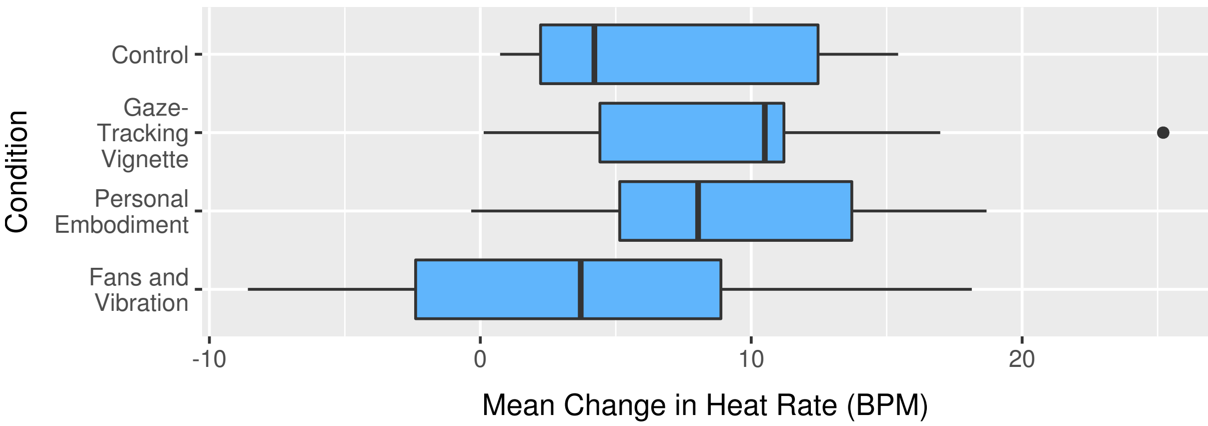


Figure 4.13: The mean change in HR relative to a baseline for each condition.

be related to the limb length of users, how they positioned their feet, and how effectively they were able to shift their centre of mass.

Since the hoops were arranged in a loop on the map, participants tended to only rotate clockwise. This led to the headset cabling, routed via the ceiling, becoming twisted. After this was noticed, the length of the cable was adjusted during the experiment to minimise how much each participant noticed. The bean bags placed around the interface also caused issues by obstructing the foot movement of some users. This was addressed by moving them out slightly. Another issue that happened in one case, was an error with eye-tracking. This caused the eye-tracking calibration to fail and no values to be recorded. There were also two cases where the condition was switched from FV to another condition due to the Unity application failing to connect to the TactaCage server. This was able to be quickly done without restarting the software. Furthermore, two fans did not always work, requiring the electrical contacts in the plugs to be firmly pushed together.

In general, participants rarely used the brake. Since the deceleration from wind resistance was quite aggressive, the extra resistance from braking did not have much additional effect. However, it did seem as if users were reluctant to slow down, with most holding down the acceleration button after they reached maximum speed to maintain it. This ostensibly caused the fingers of two participants to shake afterwards. There were also occasions where the user dislodged a button from the breadboard by pressing it at the wrong angle.

In the level, some users chose to entirely focus on flying through hoops, while others chose to explore the map after initially flying through some hoops. Figure 4.15 shows an approximately normal distribution of the total number of hoops participants flew through with M = 159.97 (SD = 93.82). This equates to M = 5.92 (SD = 3.47) times flying around the course. There were also instances where users explored the edges of the map and even managed to escape through gaps between the terrain and the ceiling. Additionally, some participants stopped for periods before resuming movement, with some using this opportunity to look around. For PE, many appeared to see some of the virtual body. However, most only focused specifically on it briefly. There was also the occasional and brief lag in the software, usually occurring at the start of the experience.

After the experiment, a small number of people had to remain seated on the interface after taking off the headset to recover. It was also common to see people slightly unsteady when they stood up. Another observation was that several people were sweating after the experience. On some days the outdoor temperature was quite high and the room the experiment was being conducted in did not have effective air conditioning. There was also variation in the time it took participants to do the post-experiment survey, with some finishing quickly. Furthermore, some requested clarification on the definitions of certain SSQ symptoms. Interestingly, several participants forgot about the fitness tracker on their wrist, even after doing the survey.

4.5 Participant Survey Comments

In the following, the results from each of the text entry sections in the survey are summarised to ascertain what the experience of participants was like and what they noticed.

4.5.1 Words to Describe the Experience

The adjectives used to describe the experience from the survey were assigned to groups of similar terms and the number of occurrences from each group was counted. This provided an insight into what participants thought of the experience (Figure 4.16). The results show that most of the participants found this to be a compelling and entertaining experience. A high proportion also found it be to convincingly realistic. However, the third most common group accurately reported symptoms of discomfort related to CS and others reported that it was hard, tiring, physically demanding, as well as that it did not provide enough sustained interest.

4.5.2 Feelings About the Experience

Based on survey responses relating to feelings about the experience, participants, in general, were entertained and felt immersed. Having the Harry Potter theme and related assets such as a flying car appealed greatly to certain people and made this experience more interesting. Some found flying through the hoops a challenge but that it did help in the discovery of the world. One participant even noted that they lost track of time.

There were many reports of symptoms related to CS. This included feeling ill, sick, dizzy, disorientated, lightheaded, queasy, nauseous, and motion sick. However, the most common symptom was dizziness. One user attributed their feeling of MS to sharp turns or changes in height. Another attributed their sickness to flying through hoops at high speed. Notably, several participants reported these symptoms increasing towards the end of the experience. In one instance, a participant reported that their vision became increasingly blurred. There was also a case where the user felt fine during the experience, but experienced dizziness and disorientation after taking the headset off. To mitigate discomfort, a user mentioned that they tried focusing on the hoops to avoid being affected by background movement and another admitted that they deliberately slowed down when they felt symptoms. Other responses from the survey included feeling sweaty from overheating, tiredness, pressure from the headset, fear of heights, stiffness from their posture, and unsteadiness.

There were indications that it took time for some participants to familiarise themselves with the controls. In particular, it was mentioned that they struggled to control the flight to pass through the hoops and sudden changes in motion were difficult. However, there was one person who mentioned that they found it easy to control. There were also comments that more to do during the experience could make it more interesting.

4.5.3 Distracting or Annoying Elements

Comments related to the experimental conditions found that for PE some noticed that the virtual hands were not accurately synced to the actual hands, with one person describing them as "almost laggy". Another individual noticed the FOV being decreased with black around the edges.

There were at least four cases where the participant noted that their display or parts of it were blurred. Most of them seemed to think this was due to the headset adjustment, but with one attributing it to not wearing glasses. Users also noted that the experience was impacted by the heat of the day, sweating, feelings of dizziness, stomach sickness, and nausea.

While there were at least five people who reported no distracting or annoying elements, the most frequent comments about elements detracting from the experience were about the control interface. Users found that the acceleration was unresponsive, and did not enjoy having to hold the button down. Participants also mentioned that they had sore hands or fingers from doing this. Additionally, when releasing the button, the deceleration from air resistance was found to be too aggressive. Curiously, some participants thought that the acceleration varied in the experience. Furthermore, pitching forward to aim the interface shaft down was noted as being much less sensitive and more physically demanding than pitching backwards to go up. Turning was described as being hard as well. Specifically, participants had difficulty moving on from objects after collisions.

In the VE, participants reported that the virtual broomstick bobbed, jittered, and rocked from side to side. It was also reported that the scale of objects was too small and movement relative to the ground or stationary objects felt a bit off. The collisions with a flying car and the hoops were also found to be distracting as well as one user who noted that they were able to fly through a wall. Another managed to escape through a gap at the edge of the map and became trapped above the ceiling. Furthermore, a different participant mentioned they would have preferred the hoops to stay lit up to better plan for the path ahead. Overall, several users felt that the virtual space was too small for the given time and more models to explore would have led to more sustained interest. Brief drops in the frame rate were additionally noticed, as well as the limited rendering distance of the camera.

There were some elements of the equipment that users found to be problematic. This included the beans bag obstructing foot movement, the cabling limiting head movement, pressure from the headset, discomfort from the edges of the seat, and the sharp edges of the breadboard pressing on users' hands. In particular, it was noted that with the seat too high for certain participants, it was difficult to maintain stable footing.

The results from this chapter are interpreted and critiqued in Chapter 5 (Discussion) to understand how each manipulation condition impacted participants relative to CT.

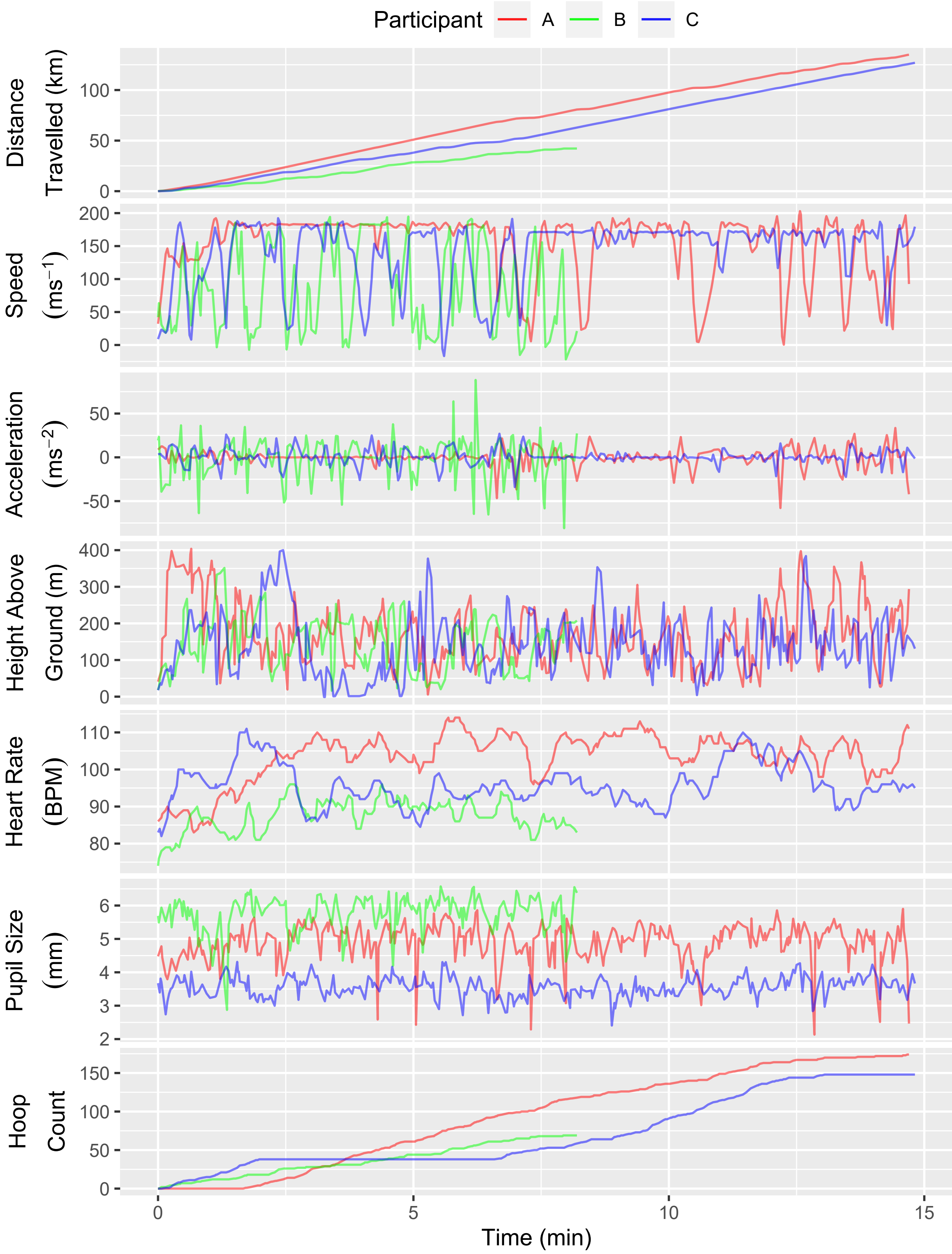


Figure 4.14: A comparison between the objective measurements of three participants.

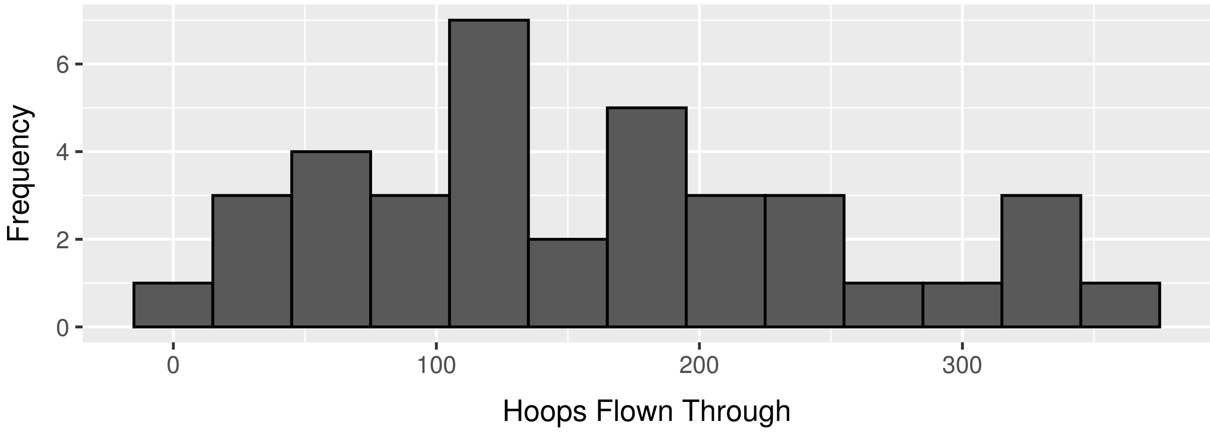


Figure 4.15: The distribution of the total number of hoops participants flew through.

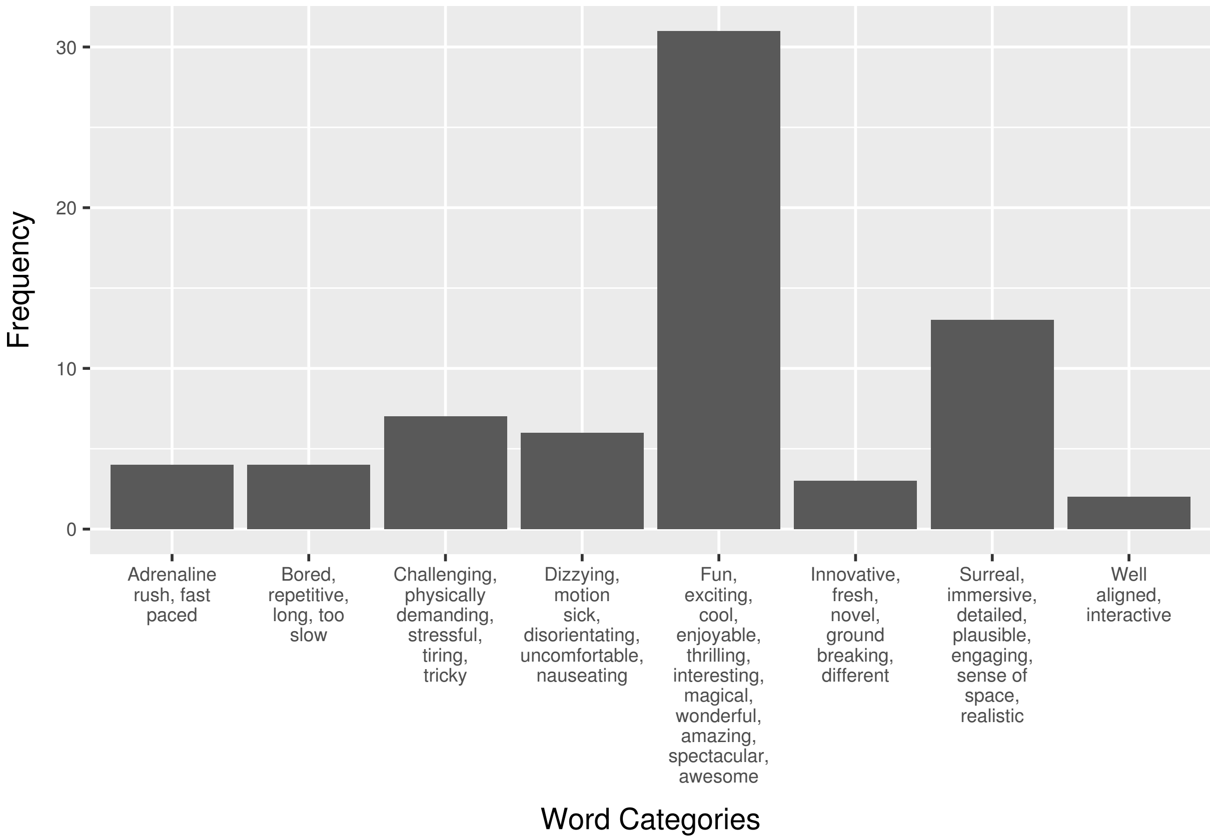


Figure 4.16: Words participants used to describe the experience in the survey.

CHAPTER 5

Discussion

In this chapter, the results are examined critically to understand what happened in the experiment and make judgements on the hypotheses. It explores what the results mean, theories to explain the findings, considers factors that influenced them, and assesses the significance.

5.1 The Experience

The most commonly reported symptom related to CS was dizziness. However, many also reported overheating, which is known to cause dizziness. It therefore cannot be ruled out as affecting the results. Users also felt symptoms consistent with CS increase with the length of exposure to the experience. This could be due to the cumulative player movement, the increasing number of sensory conflicts, and the amount of flicker. Moreover, the travel interface did not suit everyone to use for the entire 15 minutes. It was found to be difficult to tilt to certain angles, unresponsive to button presses, and not particularly comfortable. While it allowed users to have agency over their virtual movements and provided them with the freedom to explore the VE, it could have influenced the results by causing frustration and discomfort unrelated to CS. It was also observed that the perception of speed and acceleration seemed to change with height, which could account for some variation in the results. Overall, it was noted that almost all participants enjoyed the entire experience despite some feeling symptoms, having issues with the control, or finding it a bit repetitive.

5.2 Conditions

The SSQ results showed that across all components each manipulation condition had a higher median score than CT (Table 4.1, Figure 4.5, Figure 4.6, Figure 4.7, Figure 4.8). It was also the case that CT always had the smallest Interquartile Range (IQR). There were also several outliers which, on closer inspection of the data, were in most cases caused by the same group of people across components. These could have introduced some errors in the analysis. Notably, CT had the highest number of outliers across components, whereas FV had none. Additionally, the effect size chosen for the power analysis estimation of a sample size could be compared with the results. By calculating the effect sizes for each SSQ component, it was found that all exceeded the estimation of 0.4 except nausea which was 0.355 (Table 4.2). This confirms that using 0.4 as a large effect was a good choice.

The multiple linear regression models provided insight into how the independent MVs and conditions interact and contribute to changes in HR. Removing all of the coefficients with evidence to suggest they were zero implied that HR changes due to the independent variables were significant. Additionally, it was noticed that all models for CT had positive y-axis intercepts. This suggests that HR increases irrespective of condition, which is not surprising considering the physical manoeuvring required for control. The multiple r^2 coefficients for the models were also low, with a maximum of 9.13% (Table 4.6), indicating that a small amount of variance in the change of HR was explained by the models and that many points were not close to the regression trend lines (Figure 4.9, Figure 4.10, Figure 4.11, Figure 4.12). While many factors which can influence HR were not included in these models, there is assumed to be a correlation between changes in HR and changes in CS in the following analyses.

With regards to the validity of the linear regression, these models appeared to meet the assumptions satisfactorily. Firstly, all HR measurements were independent. From inspection of the diagnostic plots in Appendix H, all quantile-quantile plots, despite minor deviations, appeared to indicate normality of residuals. For the residual plots, distance travelled and speed appeared to be centred around zero across the ranges of fitted values. But while acceleration, deceleration, and height above the ground were centred around zero in regions with high densities of points, there were slight deviations at low densities. In part, this can be explained by the low number of HR values in certain regions being more influenced by random variation. However, it was not enough to be concerned with. There also appeared to be clusters of points in these plots, which can be explained by the categorical condition variables.

As shown in Figure 4.13, the distribution of mean changes in the HR of each participant during exposure for FV had a slightly smaller box plot median than that of CT, whereas PE and FV had higher medians. However, this kind of analysis provides limited insight since means only capture what the users did most of the time and not momentary responses to certain stimuli.

5.2.1 Control

The gradient for distance travelled was slightly negative for CT (Figure 4.9). With increasing distance, it would be expected that participants experience more visual flow, flicker, and sensory conflicts that increase symptoms of CS. However, under the assumption HR directly correlates with CS, this was not the case. It could be a result of users becoming more adapted to the experience or choosing to slow down when they started to feel symptoms. The data also had some dependency on time, as indicated by the clear lines formed by certain data points, and not all participants travelled the same distance. Therefore, while participants travelled through the VE in approximately the same way, the variation could jeopardise the validity of comparisons to the manipulation conditions.

The gradient for speed in CT was zero (Figure 4.10). Assuming HR is solely indicative of CS then this contradicts the research that speed is proportional to CS [22]. This could be due to the limited range of speed or that speed changes were almost always above the ground where there is typically less visual flow and flicker.

Based on the sensory conflict theory, it would be expected that increases in the difference between virtual acceleration and the vestibular response would increase HR. But CT had zero gradients, indicating no change at all with acceleration (Figure 4.11). This could be due to the short time that it took to accelerate to full speed or slow down to a stop, especially if it was due to a collision.

As for height above the ground, HR appeared to be entirely due to the change in condition, with a zero gradient for CT (Figure 4.12). At lower heights, more visual flow or flicker would be expected from proximity to objects, increasing the level of CS. Yet, maybe the user only needs to be slightly off the ground for this effect to be minimised.

5.2.2 Gaze-Tracking Vignette

The results of conducting Dunnett's test found significant evidence that GV increased the total severity of SS when compared to CT (Table 4.5). This test calculated $P = 0.0182$ compared to the significance level $\alpha = 0.1$, providing a high level of certainty that the null hypothesis of this post hoc test should be rejected.

The effect of the GV on HR appeared to be influenced by changes in distance travelled and speed (Figure 4.9, Figure 4.10). Compared to CT, GV had a higher HR gradient that was positive for variation in the distance travelled with the same intercept. It also had a lower HR gradient that was slightly negative for variation in speed with a higher intercept. Additionally, there was a constant increase in HR for acceleration, deceleration, and height above the ground directly due to GV (Figure 4.11, Figure 4.12). Therefore, each GV result for different MVs had the same or a higher intercept and gradients that were either positive or close to zero. Overall, these results suggest that GV causes HR to increase.

These results could be explained by the delay in the vignette introduced by the rolling average of the eye-tracking coordinates or using the incorrect intensity. Due to being out of sync with real-time eye movement, this may have caused users to feel as if their head was moving due to the scope of the FOV change. This kind of involuntary movement could compromise postural stability or cause sensory conflicts leading to CS symptoms. However, only one person noticed their FOV decreasing from the vignette, and no one reported noticing their FOV shifting position. To investigate this further, the delay, size, extent of movement, shape of the scope, and intensity of the vignette could be varied to see what the CS response is and what users notice.

The SSQ provided evidence that GV increased SS and the objective data provided evidence that GV increased HR with the variation of MVs. Overall, this suggests that the GV condition does not mitigate CS, but instead increases it. Therefore, the hypothesis for this condition (H1: Manipulating FOV in VR with a vignette based on speed and eye-gaze direction reduces CS) should be rejected.

5.2.3 Personal Embodiment

Similar to GV, Dunnett's test found significant evidence that PE increased the total severity of SS (Table 4.5). Compared to GV, this condition had a higher p-value of P = 0.0716 for total severity, much closer to the significance level threshold.

The effect of PE on HR appeared to be influenced by changes in distance travelled, speed, acceleration, and deceleration (Figure 4.9, Figure 4.10, Figure 4.11). Compared to CT, PE had higher HR gradients that were positive for variation in distance travelled and speed with lower intercepts. It also had a higher HR gradient that was positive for variation in acceleration with a higher intercept and a lower HR gradient that was negative for variation in deceleration with a higher intercept. Additionally, there was a constant increase in HR for variation height above the ground (Figure 4.12) directly due to PE. This suggests that PE could lead to a lower HR for large absolute accelerations, low speeds, or low distances travelled. However, with users typically moving at or close to maximum speed and not accelerating or decelerating for significant periods most of the time PE is unlikely to be a better alternative to CT.

The evidence could have been influenced by higher user immersion and engagement for this condition. This could have led to participants exerting themselves more, thus leading to higher HR readings. Other factors could be inconsistencies between the features of virtual avatar and reality, a lack of control over movements, latency in responding, or the low resolution of the model. However, this condition is not visually invasive, with users mostly paying little attention to the embodiment, suggesting that discomfort from the straps or the weight of the trackers could have had some impact. To investigate this condition further, evaluating it with the Virtual Embodiment Questionnaire (VEQ) by Roth and Latoschik [70] could provide some insight. Alternatively, more realistic models with better tracking could be used as well as other tracking methods.

The SSQ provided evidence that PE increased SS and the objective data provided evidence that HR was increased most of the time. Overall, this suggests that PE is not an effective strategy to mitigate CS. Therefore, the hypothesis for this condition (H2: Adding personal embodiment to a VR experience reduces CS) should be rejected.

5.2.4 Fans and Vibration

From applying Dunnett's test, no evidence of a significant difference between FV and CT was found for the total severity of SS. This had a p-value of $P = 0.7316$, which is much higher than the other conditions (Table 4.5).

The effect of FV on HR appeared to be influenced by changes in all of the MVs (Figure 4.9, Figure 4.10, Figure 4.11, Figure 4.12). Compared to CT, FV had higher HR gradients that were positive for variation in distance travelled and speed with lower intercepts. It also had a lower HR gradient that was negative for variation in acceleration with a lower intercept and a higher HR gradient that was positive for variation in deceleration with the same intercept. Additionally, FV had a higher HR gradient that was positive for variation in height above the ground with a lower intercept. This suggests that HR begins (at the y-axis intercept) much lower than CT for distance travelled, speed, and height above the ground, but can be become higher at large values. However, while acceleration starts lower and deceleration starts the same as CT, both decrease HR at higher absolute values. This was similar to PE, and was subject to what users spent most of the time doing, but had flatter gradients for distance travelled and speed in addition to lower intercepts for all MVs.

This result could have been impacted by the implementation of this condition. The fans may have been too weak or not reactive enough and users could have been wearing clothes that covered their arms and legs. It could also be the case that the vibration was mismatched with the virtual experience. Activating the vibration based on flying speed and collisions may not have been appropriate for reducing a visual-vestibular sensory conflict from acceleration. It might have been important that participants could relate the feedback to personal experience in the real world. For example, the vibration Jung et al. [32] used to reduce a visual-vestibular conflict was matched with that of a real vehicle.

The SSQ provided no evidence that FV affects the level of SS and the objective results provided evidence that HR is mostly decreased but can be influenced by extreme MVs. Overall, these results are mixed. However, while it is clear that this condition has some impact on HR, more evidence would be needed on its link to CS to overrule the SSQ. Therefore, a judgement on the hypothesis for this condition (H3: Simulating vibration and airflow in a VR experience reduces CS) cannot be made without further investigation.

5.3 Experiment Limitations

There were limitations in this experiment that could have influenced the outcome and the validity of generalising the findings to the wider population. In the following, these are classed as systematic and random errors.

5.3.1 Systematic Errors

While the SSQ is commonly used in research for assessing CS for VR applications, according to Stanney et al. [7] there is a distinction between SS and CS. This may mean the SSQ is not entirely suitable. It also does not consider a user physically interacting with a travel interface. Another consideration is that the SSQ is recommended to be administered post-exposure [7]. However, when electing to run an experiment between subjects, it does not provide an even comparison due to differences between subjects. Something like the Delta-SSQ used by Jung et al. [32] could have been more appropriate, comparing before and after exposure for each participant.

Sources of error could have arisen from the recording of the results, organising the files, the analysis, how participants expressed comments, and how they were interpreted. Biases from the researcher and inconsistencies in the explanations of the instructions could also have had an effect.

A disadvantage of variables independent of time against HR is that an instantaneous HR response is assumed. It could take time for a stimulus to have an effect on the user and for the PPG sensor to register a change. The PPG sensor is also limited in its accuracy and has an approximate sampling rate of every two seconds. This could lead to missing small fluctuations and identifying false relationships between variables.

It could also have been the case that the level of inducement was too low to affect some people. It is possible that increasing the level of inducement could have yielded more significant results from more people. However, this could have caused the small number who are very susceptible to CS more discomfort.

5.3.2 Random Errors

The main source of random error came from the sample of participants that signed up for the study. In such a group, many uncontrolled variables could have influenced the outcome of the experiment and how much the sample represented the entire population. This could include susceptibility to CS, navigation path in the VE, physical exertion, height, gender, age, experience with VR, acuity of eyesight, physique, balance, interest, fatigue, ability to focus, fitness, strength, flexibility, prior consumption of stimulants, prior food consumption, phobias, energy, reaction time, weight, and clothing. Additionally, not everyone has the same change in HR with respect to their baselines for different stimuli. The baselines may also not have been representative of their resting HRs. Participants could have been nervous or exerted themselves before the experiment. Additionally, uncontrolled variables that could have affected the participants include heat, humidity, time of the day, and lags in performance.

The participant data collected in the survey indicated that there was variation in age, gender, experience with VR, and comfort with heights across conditions. This identified some trends in the data which constrains the generalisability of the results. Overall, there was a positive skew towards the younger end of the spectrum (Figure 4.1). Additionally, the gender ratios were not consistent (Figure 4.2), with all of the participants that did FV being male. Furthermore, the majority of people doing this experiment had some prior experience with VR (Figure 4.3).

However, for five people this was their first exposure. Finally, there was a negative skew for CT, GV, and PE towards being completely comfortable with heights (Figure 4.4). However, the distribution of FV appeared uniform.

Another consideration is that participants may have given their answers in the survey insufficient thought or consideration. Also, they may not have understood the questions, prompts, or definitions of symptoms. Some did ask, which suggests that this may have been more of a problem than was evident. Including the definitions of each SSQ symptom in the survey would have helped to solve this issue.

Despite, applying a square root transformation to the data, there remained three data sets from nausea and oculomotor component analyses that did not have significant evidence of normality. This meant that some confidence was lost in the insight of nausea and oculomotor components from the ANOVA and Dunnett's test. However, there was significant evidence that all of the conditions for total severity were normal. Ultimately, this was the most useful metric for summarising and comparing the extent of CS. To make all of the data normal, other transformations would need to be investigated further alongside the removal of outlier values.

The statistical tests, including the Shapiro-Wilk, Levene's test, ANOVA, Dunnett's test, and the multiple linear regressions were susceptible to statistical error. Based on the chosen significance level, there was a 10% probability that the null hypothesis was falsely rejected in a Type I error for each test. There was also a chance that a null hypothesis was failed to be rejected when it should have been in a Type II error.

5.4 Significance of Findings

This thesis offers a novel travel interface that is operated physically to control a virtual counterpart for navigation through a VE. It is one of a growing number of interactive applications which use different types of control to provide users agency of movement in VR with multiple DOF. In particular, this method of travel has relevance to the development of applications that require flying for navigation such as flight simulators and entertainment applications.

Based on feedback in this experiment, when making a control system, some considerations should be made so it does not detract from the experience. The control should not force people into a bad posture or unstable positions. It should also be responsive enough that it does not require the user to make sudden or extreme movements to complete a task, but not cause sudden or jerky movements in VR.

Many looked forward to trying this application and found it enjoyable, exciting, and entertaining. This suggests that creating a convincing experience that is impossible to recreate in reality is valuable and appealing to a wide audience, especially if it is based on popular books or movies people are familiar with.

From this experiment, evidence was found to suggest that a dynamic vignette based on eye-gaze direction and personal embodiment with hand tracking are unsuccessful strategies to reduce CS. This indicates that users are sensitive to visual movements and representations. However, fans coupled with vibration is a promising strategy. While it did not convincingly indicate that it does reduce CS, it did have a significant impact on the experience as indicated by HR. Except for high distances travelled, speeds, and heights above the ground HR was lower than CT. Conversely, at higher absolute accelerations HR was reduced. Additionally, with no manipulation condition applied, speed, acceleration, and height above the ground appeared to not affect HR. Only with increasing distance travelled did HR slightly decrease.

CHAPTER

6 Conclusion

This thesis presents an investigation of strategies that can be used to mitigate CS in VR using a novel travel interface. Three hypotheses for strategies to mitigate CS were devised. These were incorporated into an experiment with three manipulation conditions and a control condition. This involved designing a baseline experience, with a modified stool and a control system to navigate through a VE populated with models by flying. Each Condition was designed and developed to be applied on top of this. During testing physiological, flight data, and camera footage were recorded for analysis. Post-exposure, a survey was also filled out by participants.

From conducting the experiment, the results suggest that GV and PE made SS worse with the HR from PE in most cases higher than CT. However, FV had mixed results. The SSQ found that adding this condition had no effect, yet the HR data was significantly lower for variation in MVs than the other conditions. Ultimately a more focused investigation would be required and further critique of the validity of the measures of CS. In particular, it would be worth investigating what other factors influence HR. Overall, users enjoyed the experience, were entertained by it, and felt immersed in it. However, there remains much that could be improved regarding the usability of the travel interface.

6.1 Future Research

In future research, it would be interesting to see the effect of improving the responsiveness, comfort, and stability of the travel interface based on user feedback. A more focused experiment could also be designed with a higher level of CS inducement where those who have extreme susceptibility to CS are excluded beforehand. This could increase the number of people who experience any symptoms and could remove outliers from the results.

More investigation could be done on FV to determine what causes the changes in HR, whether they are related to CS, and confirm if the SSQ result was correct. This could involve trying other physiological measures such as GSR, EEG, or reaction time. Additionally, surveys for usability, presence, engagement, and embodiment could help to understand the results. The experience could also be altered by increasing the intensity of the fans or by better matching familiar vibration timings and frequencies from the real world that overlap with the virtual experience. Other strategies could also be investigated such as the level of control, manipulating sound, and the effect of using objectives such as flying through hoops to guide users through a level.

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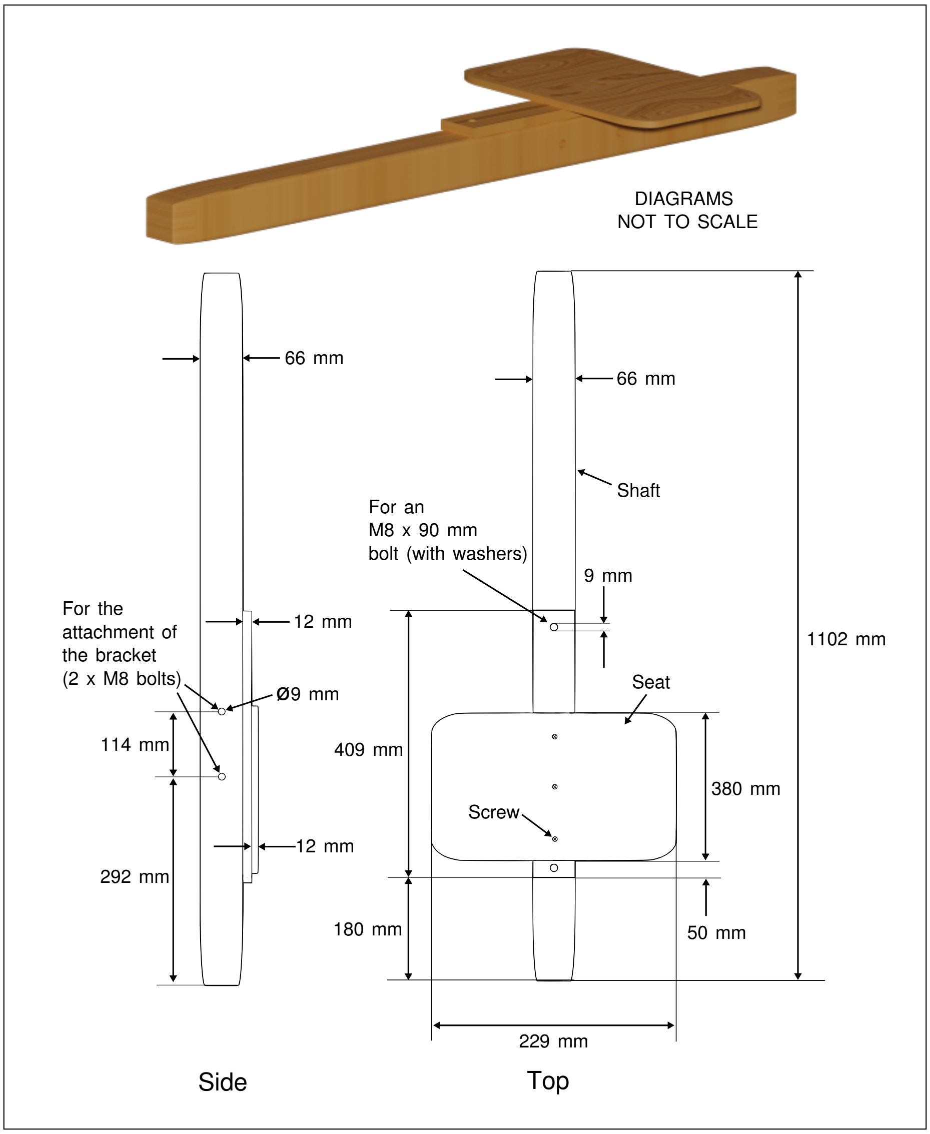
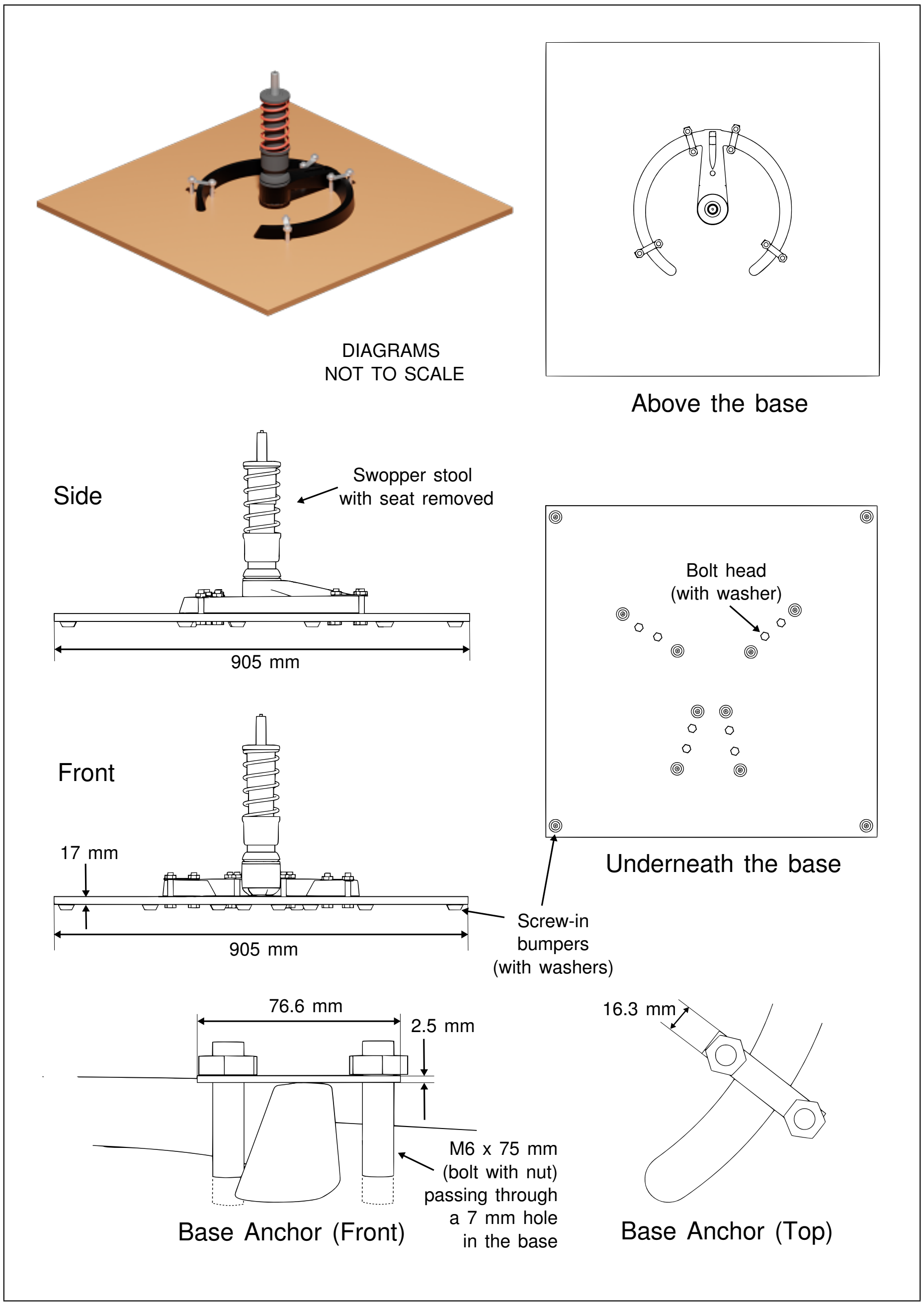
APPENDIX A

Schematics

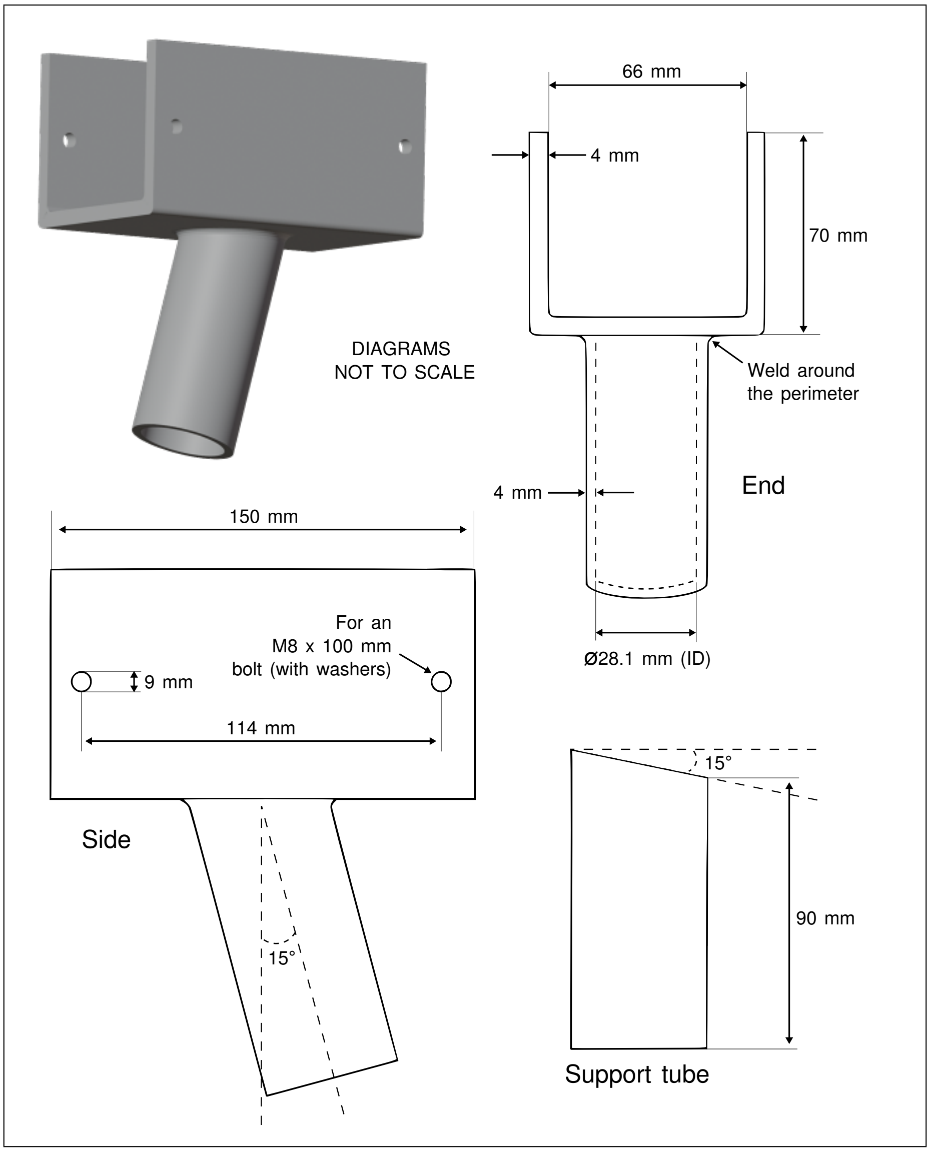
A.1 Shaft and Seat



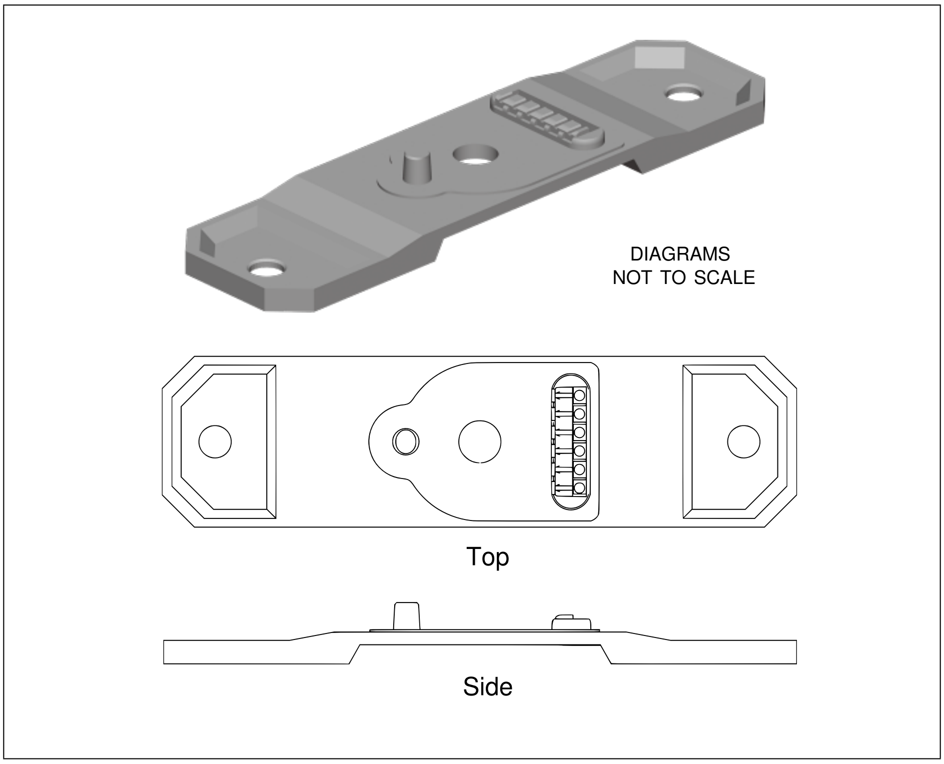
A.2 Base and Stool



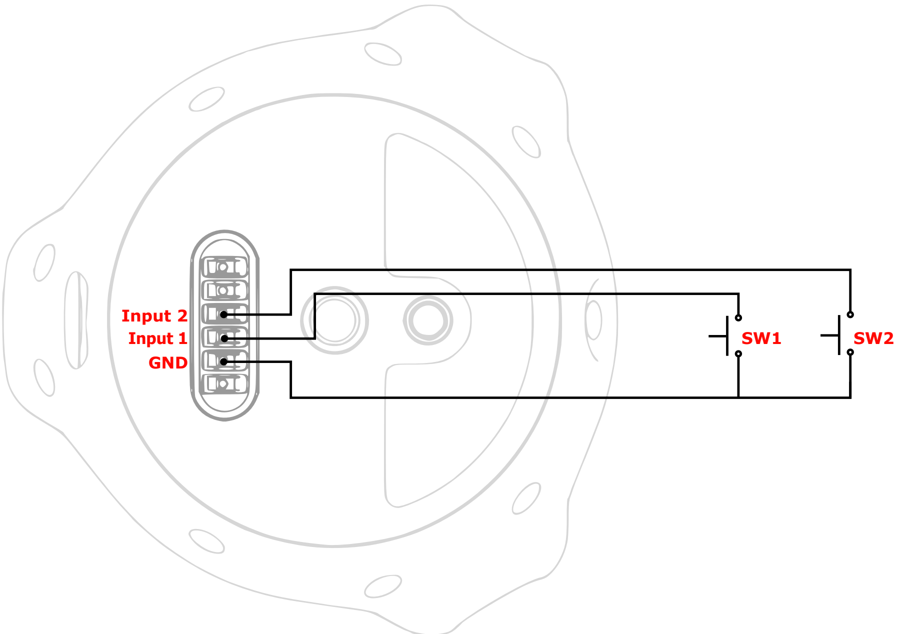
A.3 Stool-Shaft Bracket



A.4 VIVE Tracker Base Plate



A.5 VIVE Tracker Wiring



APPENDIX

B

Ethics Approval

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2021/69/LR

13 September 2021

Daniel Page
HIT Lab NZ
UNIVERSITY OF CANTERBURY

Dear Daniel

Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Identifying Strategies to Mitigate Virtual Reality Sickness Induced by a Flying Broomstick Simulation".

I am pleased to advise that this application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 8th September 2021.

With best wishes for your project.

Yours sincerely

Dr Dean Sutherland
Chair, Human Ethics Committee

University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand. **www.canterbury.ac.nz**

F E S

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2021/69/LR Amendment 1

22 November 2021

Daniel Page
HIT Lab NZ
UNIVERSITY OF CANTERBURY

Dear Daniel

Thank you for your request for an amendment to your research proposal "Identifying Strategies to Mitigate Virtual Reality Sickness Induced by a Flying Broomstick Simulation" as outlined in your email dated 17th November 2021.

I am pleased to advise that this request has been considered and approved by the Human Ethics Committee.

Yours sincerely

Dr Dean Sutherland
Chair, Human Ethics Committee

University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand. **www.canterbury.ac.nz**

F E S

APPENDIX

C Survey

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Participant ID

Preliminary Questions

Age

Gender

Male	Female	Please specify	Prefer not to specify
◯	◯	◯	◯

How much experience have you had using virtual reality headsets (prior to today)?

None	A bit	Some	A lot
◯	◯	◯	◯

To what extent are you comfortable with heights?

Not at all	A bit	Okay	Fine	Completely
◯	◯	◯	◯	◯

What words would you use to describe this experience?

How did the experience make you feel?

Did you notice anything distracting or annoying? If so, what?

Please rate each of the following statements based on your experience.

General discomfort

None ○ Slight ○ Moderate ○ Severe ○

Fatigue

None ○ Slight ○ Moderate ○ Severe ○

Headache

None ○ Slight ○ Moderate ○ Severe ○

Eyestrain

None ○ Slight ○ Moderate ○ Severe ○

Difficulty focusing

None ○ Slight ○ Moderate ○ Severe ○

Increased salivation

None ○ Slight ○ Moderate ○ Severe ○

Sweating

None	Slight	Moderate	Severe
○	○	○	○

Nausea

None	Slight	Moderate	Severe
○	○	○	○

Difficulty concentrating

None	Slight	Moderate	Severe
○	○	○	○

Fullness of head

None	Slight	Moderate	Severe
○	○	○	○

Blurred vision

None	Slight	Moderate	Severe
○	○	○	○

Dizzy (eyes open)

None	Slight	Moderate	Severe
○	○	○	○

Dizzy (eyes closed)

None	Slight	Moderate	Severe
○	○	○	○

Vertigo

None	Slight	Moderate	Severe
○	○	○	○

Stomach awareness

None	Slight	Moderate	Severe
○	○	○	○

Burping

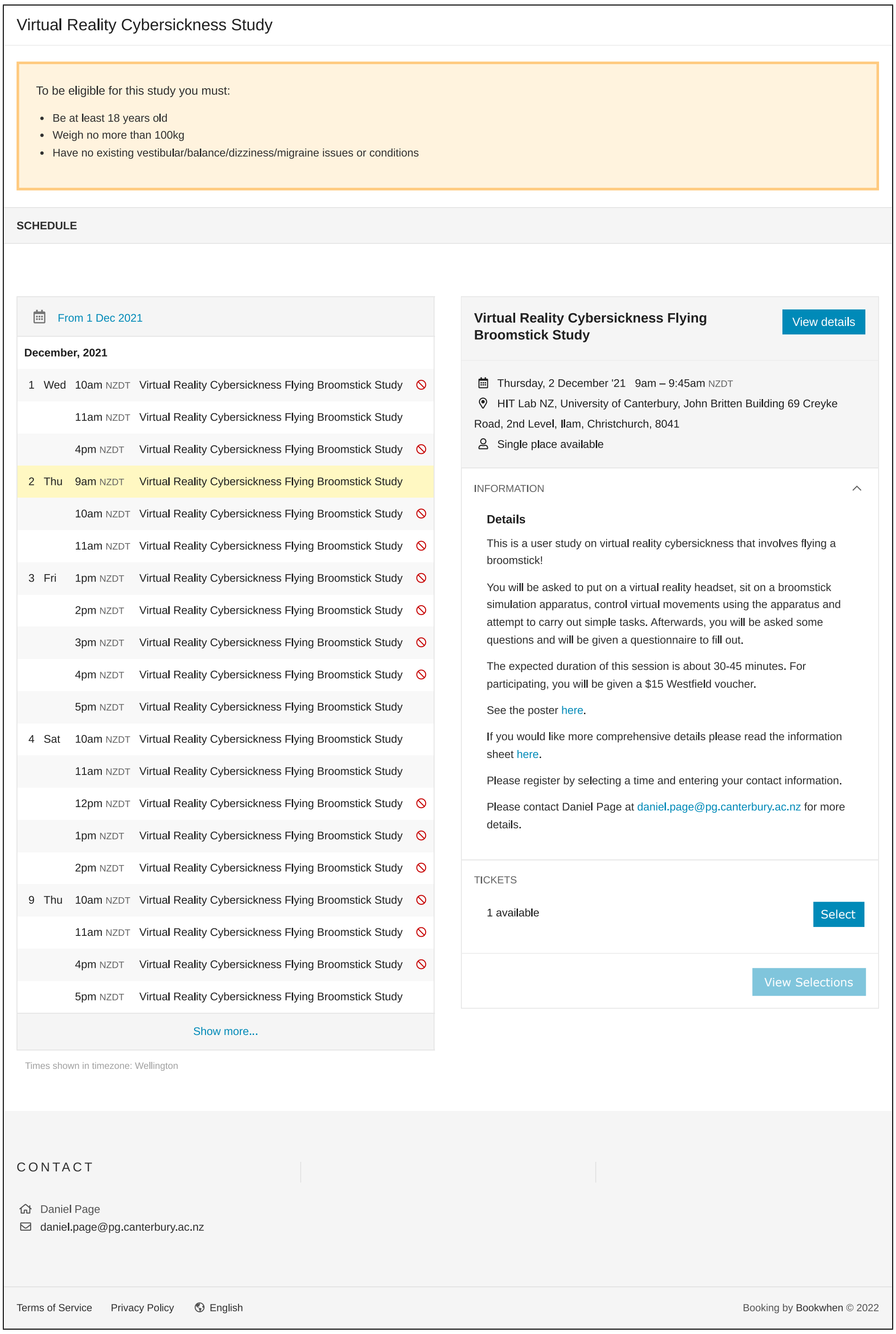
None	Slight	Moderate	Severe
○	○	○	○

→

APPENDIX

D

Booking Website



Virtual Reality Cybersickness Study

To be eligible for this study you must:

- Be at least 18 years old
- Weigh no more than 100kg
- Have no existing vestibular/balance/dizziness/migraine issues or conditions

SCHEDULE

From 1 Dec 2021

December, 2021

1	Wed	10am NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		11am NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		4pm NZDT	Virtual Reality Cybersickness Flying Broomstick Study
2	Thu	9am NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		10am NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		11am NZDT	Virtual Reality Cybersickness Flying Broomstick Study
3	Fri	1pm NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		2pm NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		3pm NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		4pm NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		5pm NZDT	Virtual Reality Cybersickness Flying Broomstick Study
4	Sat	10am NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		11am NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		12pm NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		1pm NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		2pm NZDT	Virtual Reality Cybersickness Flying Broomstick Study
9	Thu	10am NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		11am NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		4pm NZDT	Virtual Reality Cybersickness Flying Broomstick Study
		5pm NZDT	Virtual Reality Cybersickness Flying Broomstick Study

Show more...

Times shown in timezone: Wellington

Virtual Reality Cybersickness Flying Broomstick Study View details

Thursday, 2 December '21 9am – 9:45am NZDT

HIT Lab NZ, University of Canterbury, John Britten Building 69 Creyke Road, 2nd Level, Ilam, Christchurch, 8041

Single place available

INFORMATION

Details

This is a user study on virtual reality cybersickness that involves flying a broomstick!

You will be asked to put on a virtual reality headset, sit on a broomstick simulation apparatus, control virtual movements using the apparatus and attempt to carry out simple tasks. Afterwards, you will be asked some questions and will be given a questionnaire to fill out.

The expected duration of this session is about 30-45 minutes. For participating, you will be given a $15 Westfield voucher.

See the poster here.

If you would like more comprehensive details please read the information sheet here.

Please register by selecting a time and entering your contact information.

Please contact Daniel Page at daniel.page@pg.canterbury.ac.nz for more details.

TICKETS

1 available Select

View Selections

CONTACT

Daniel Page
daniel.page@pg.canterbury.ac.nz

Terms of Service Privacy Policy English

Booking by Bookwhen © 2022

APPENDIX

E Information Sheet

HIT Lab NZ / Human Interface Technology Lab
Phone: +64 3 369 0219
Email: daniel.page@pg.canterbury.ac.nz

HREC Ref: HEC 2021/69/LR Amendment 1

Identifying Strategies to Mitigate Virtual Reality Sickness Induced by a Flying Broomstick Simulation
Information Sheet for Participants

Kia ora,

You are invited to participate in a research study on cybersickness mitigation. This study is being conducted by Daniel Page from the University of Canterbury l Te Whare Wānanga o Waitaha (UC). Other research team members include project supervisors Prof. Rob Lindeman and Prof. Stephan Lukosch. The study is being carried out as a requirement for a Master in Human Interface Technology.

This research aims to make virtual reality more usable. We are interested in finding out whether certain conditions can mitigate the causes and discomforting effects of virtual reality sickness (cybersickness). The information from this study will help to provide guidelines for developers of virtual reality experiences to classify and reduce the discomforting symptoms users experience.

You are invited to participate in this research because you have responded to the advertisement. Your participation is voluntary (your choice). If you decide not to participate, there are no consequences. Your decision will not affect your relationship with me, the University of Canterbury or any member of the research team. After the study, I will provide you with a $15 Westfield Voucher. You will get this even if you withdraw from the study.

If you choose to take part in this research, you will be asked to sit on the broomstick apparatus (a modified 360-degree swivel chair), put on a virtual reality headset, and then move the apparatus to direct the virtual broomstick in the direction of desired travel. Forward acceleration is controlled with two buttons (red for acceleration and white for braking). The objective is to fly through a series of hoops until 15 minutes has elapsed. But feel free to explore the world on the way. If you would like the experience reset to the beginning please let me know. During the experience your heart rate will be recorded using a fitness tracker wristband (on your non-dominant hand) as well as your pupil dilation and eye gaze direction. The visual feed you are seeing, position information, and an external view of your experience (from different angles) will also be recorded. Afterwards, you will be asked to fill out an anonymous questionnaire. Overall, we estimate that your participation will take around 30-45 minutes.

There are possible risks of injury from using the physical apparatus or varying levels of discomfort due to the virtual reality experience. If you weigh over 100kg, have existing vestibular/balance/dizziness/migraine issues/conditions or are not at least 18 years old please notify me immediately. To reduce the risk of injury, bean bags will be placed around the apparatus in case of a fall and you will be closely observed/spotted if necessary. To ensure the cabling is free and clear, all cables will be hung from the ceiling and lead straight to the headset. We also ask that you keep your feet planted on the ground as much as possible and do not make aggressive movements. If it is clear that you are becoming disorientated, unstable or tangled in the headset cabling I will or aim to spot you and/or stop the experience. If you feel too unwell to continue close your eyes and notify me immediately. You can request to stop at any point during the simulation (without any consequence). We will have a sofa nearby where you can recuperate (if necessary). There will also be a bucket in the just in case you start to feel ill. We also strongly recommend you do not drive a car or ride a bike after the experiment for at least an hour.

You are free to withdraw at any time. To do this, please let me know either during the study or after you have

1/2

finished. We will aim to remove any information you have provided up to that point from the data. This may be difficult or impossible after the data is combined and analysed.

All data will be anonymous. We will not be able to identify you or link your identity with any information you provide. We will store all study data in password-protected University of Canterbury computers and lockable cabinets in lockable offices. All data will be destroyed five years after the completion of the study. I will be responsible for making sure that only members of the research team use your data for the purposes mentioned in this information sheet.

The results of this research will be published in a Master's thesis. This thesis will be available to the general public through the UC library. Results may be published in peer-reviewed or academic journals. Results could also be presented during conferences or seminars to wider professional and academic communities. Note that comments or quotes you make and observations of your experience could be published. However, you will not be identifiable in any publication. A summary of results will be sent to all participants who request a copy of these.

If you have any questions about the research, please contact Daniel Page: daniel.page@pg.canterbury.ac.nz. For concerns please contacts Prof. Rob Lindeman: rob.lindeman@canterbury.ac.nz or Prof. Stephan Lukosch: stephan.lukosch@canterbury.ac.nz.

This study has been reviewed and approved by the University of Canterbury Human Research Ethics Committee (HREC). If you have concerns or complaints about this research, please contact the Chair of the HREC at human-ethics@canterbury.ac.nz).

Please review the consent form. If you would like to participate, please fill out the section at the bottom and return the consent form before commencing the experiment.

2/2

APPENDIX

F

Consent Form

HIT Lab NZ / Human Interface Technology Lab
Phone: +64 3 369 0219
Email: daniel.page@pg.canterbury.ac.nz

HREC Ref: HEC 2021/69/LR Amendment 1
Participant ID: _________

Identifying Strategies to Mitigate Virtual Reality Sickness Induced by a Flying Broomstick Simulation
Consent Form

- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time without consequences. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain possible.
- ☐ I understand that comments, quotes and observations from this experiment could be published (in a way that does not identify me).
- ☐ I understand that any information or opinions I provide will be kept confidential to the researcher and supervisors. I understand that any published or reported results will not identify me.
- ☐ I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password-protected electronic form. I understand the data will be destroyed after five years after the end of the project.
- ☐ I understand the risks associated with taking part and how they will be managed.
- ☐ I have read and understood the eligibility criteria for this experiment.
- ☐ Considering all of the information provided, I am in a fit mental/physical state to participate in this experiment.
- ☐ I agree to be recorded (video and audio) during the experience. I understand how these recordings will be stored and used.
- ☐ I understand that I can contact the researcher Daniel Page, supervisor Prof. Rob Lindeman or supervisor Prof. Stephan Lukosch for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Research Ethics Committee, Private Bag 4800, Christchurch.
  Daniel Page: daniel.page@pg.canterbury.ac.nz
  Prof. Rob Lindeman: rob.lindeman@canterbury.ac.nz
  Prof. Stephan Lukosch: stephan.lukosch@canterbury.ac.nz
  HREC Chair: human-ethics@canterbury.ac.nz
- ☐ I would like a summary of the results of the project.

By signing below, I agree to participate in this research project.

Name:______________________Signed:_____________________Date:____________

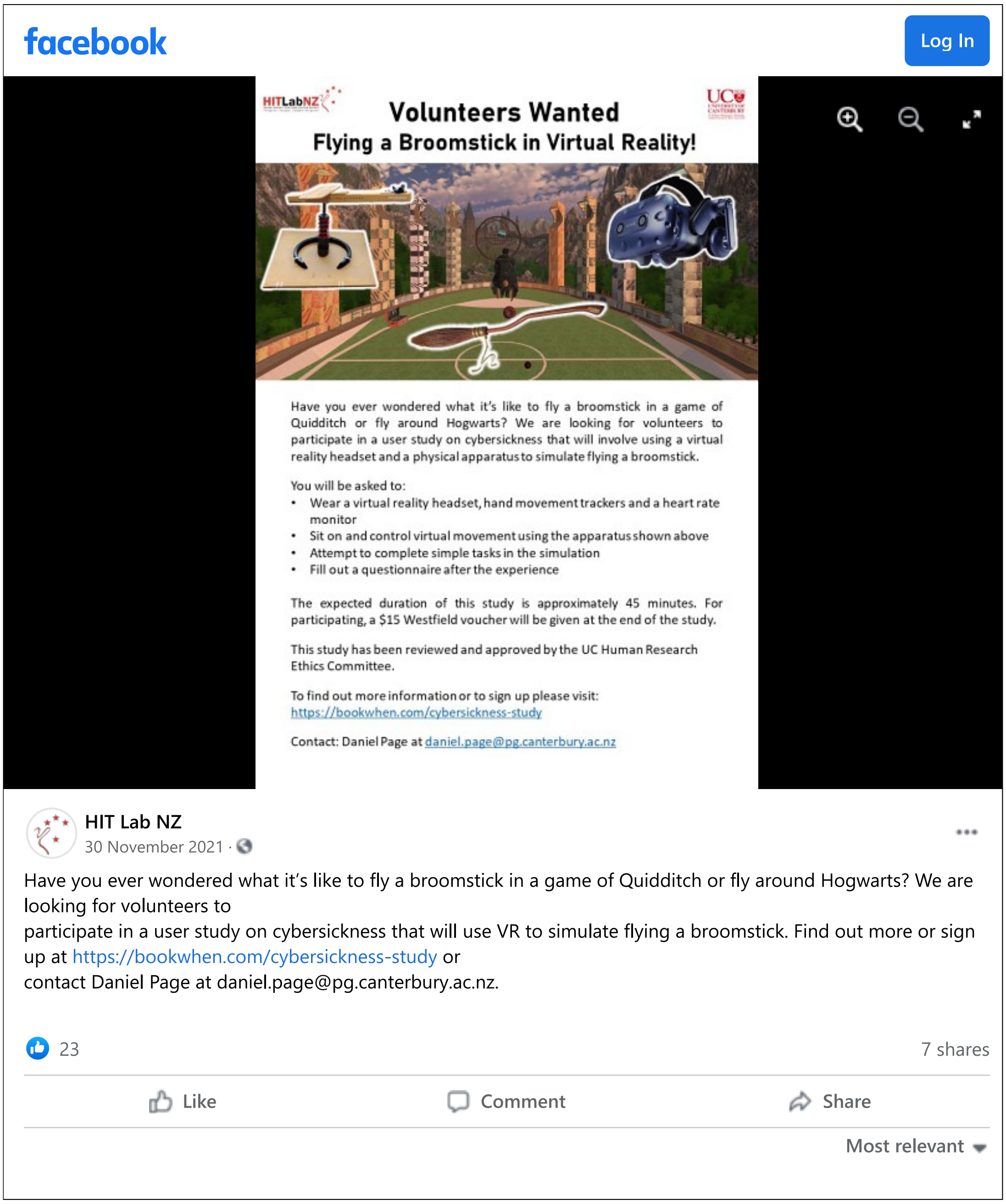
Email address *(for report of findings, if applicable)*:_________________________________

Please return this consent form to the researcher.

APPENDIX G

Advertisements

G.1 Facebook Post



G.2 Poster

Volunteers Wanted

Flying a Broomstick in Virtual Reality!

Have you ever wondered what it's like to fly a broomstick in a game of Quidditch or fly around Hogwarts? We are looking for volunteers to participate in a user study on cybersickness that will involve using a virtual reality headset and a physical apparatus to simulate flying a broomstick.

You will be asked to:

- Wear a virtual reality headset, hand movement trackers and a heart rate monitor
- Sit on and control virtual movement using the apparatus shown above
- Attempt to complete simple tasks in the simulation
- Fill out a questionnaire after the experience

The expected duration of this study is approximately 45 minutes. For participating, a $15 Westfield voucher will be given at the end of the study.

This study has been reviewed and approved by the UC Human Research Ethics Committee.

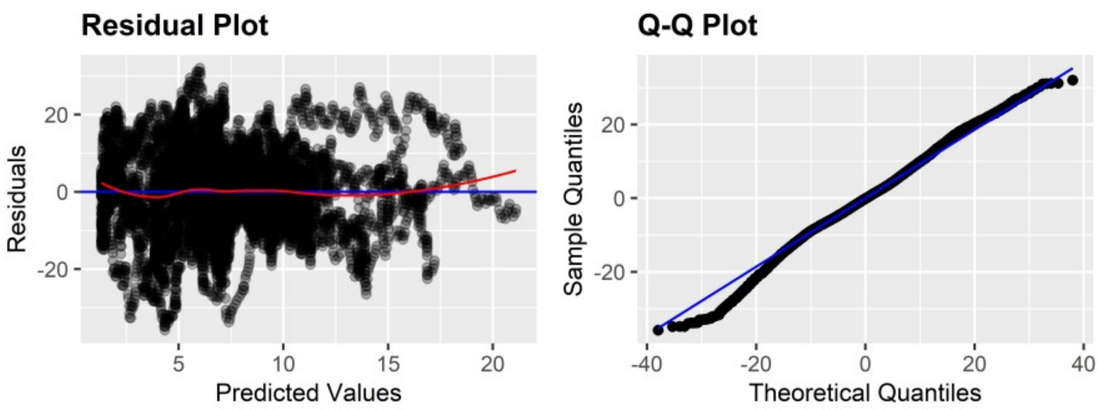
To find out more information or to sign up please visit:
https://bookwhen.com/cybersickness-study

Contact: Daniel Page at daniel.page@pg.canterbury.ac.nz

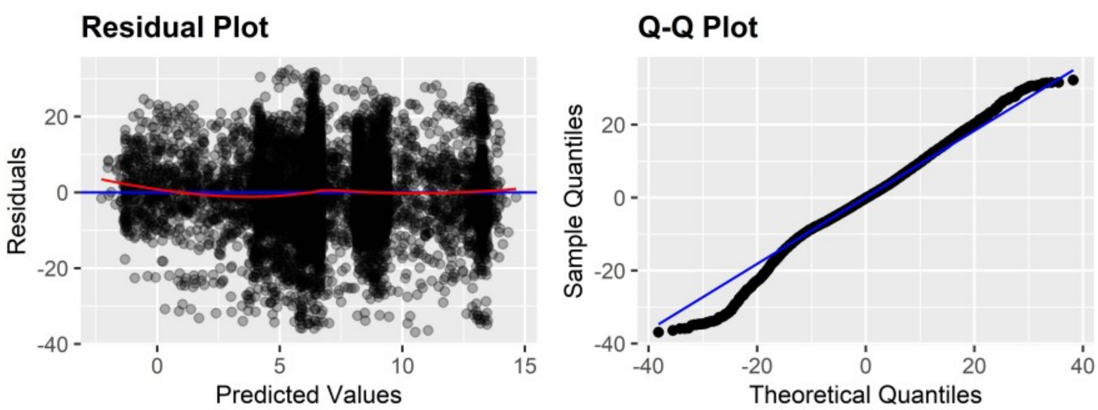
APPENDIX

H Model Diagnostic Plots

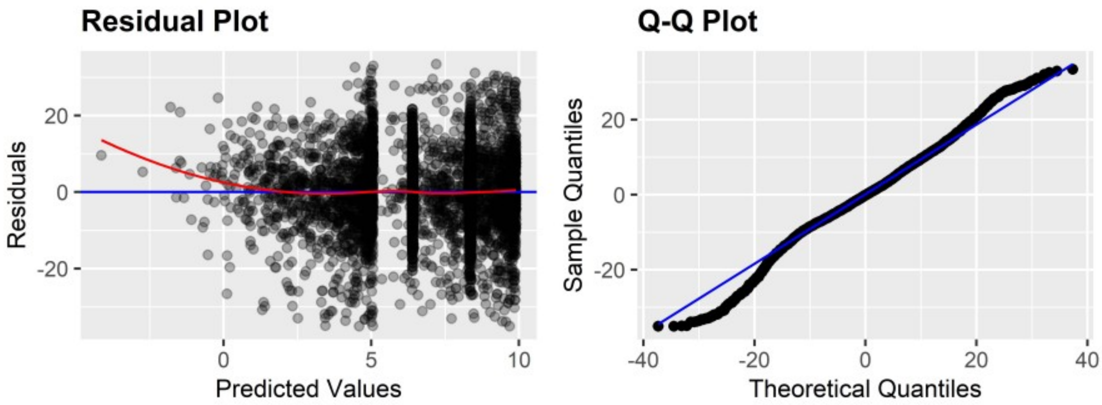
H.1 Distance



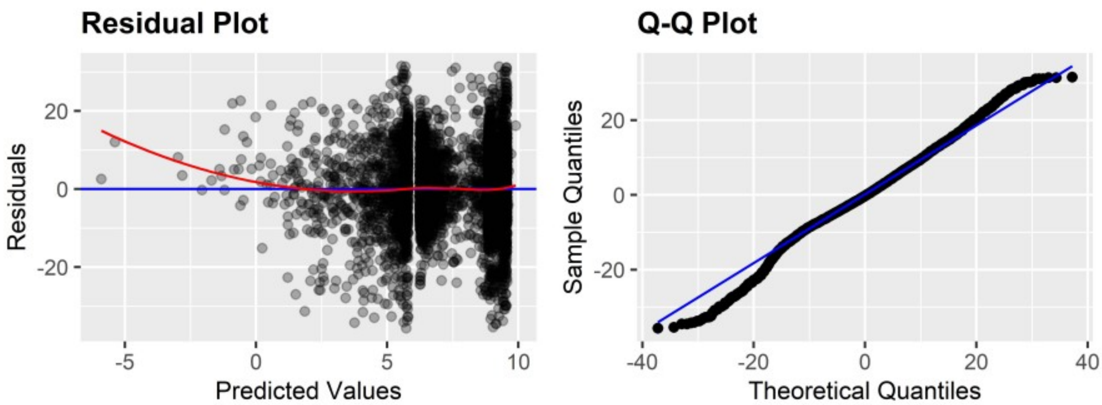
H.2 Speed



H.3 Acceleration



H.4 Deceleration



H.5 Height