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Healing the Cybersick: Utilising Camera Passthrough Technology to Mitigate Motion Sickness in Virtual Reality

Software Engineering
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Abstract:

As virtual reality (VR) technology has become more widely adopted, accessibility issues regarding motion sickness induced by VR have become increasingly apparent. This thesis examines whether camera passthrough, which allows users to view their physical surroundings using cameras integrated into the VR headset, can be used to mitigate virtual reality motion sickness, also known as *cybersickness*. Specifically, the effectiveness of a camera passthrough-based mitigation technique is evaluated against an established approach based on field-of-view reduction, also known as vignette tunneling.

The study is grounded in research on the development of VR, challenges associated with VR application design, and the underlying mechanisms of motion sickness. The experiment conducted for this thesis involved a total of 15 participants traversing a track in virtual reality using both mitigation methods sequentially while reporting their cybersickness symptoms. Participants' self-reported evaluations of the symptoms and their severity were collected both during and after the experiment using two different scales: the Fast Motion Sickness Scale (FMS) and the Simulator Sickness Questionnaire (SSQ).

The results showed that participants consistently reported significantly lower levels of cybersickness when the camera passthrough-based mitigation technique was used in comparison to the vignette tunnelling. These findings suggest that camera passthrough-based strategies are an effective method for mitigating cybersickness, providing a viable alternative to the established techniques involving field-of-view reduction. By providing evidence supporting the effectiveness of camera passthrough as a cybersickness mitigation technique, this thesis contributes to a growing body of research aimed at improving the accessibility and usability of VR technology.

Keywords: VR, virtual reality, cybersickness, VR sickness, motion sickness, camera passthrough

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Tiivistelmä:

Virtuaalitodellisuusteknologian (VR) yleistyessä myös sen käytettävyyteen liittyvät ongelmat, kuten virtuaalitodellisuuden aiheuttama pahoinvointi, ovat tulleet selvemmin esiin. Tässä tutkielmassa tarkastellaan kameran läpivientiä (camera passthrough) mahdollisena VR-pahoinvoinnin eli *kyberpahoinvoinnin* (cybersickness) lieventämismenetelmänä. Kaemran läpivienti mahdollistaa käyttäjän fyysisen ympäristön näkemisen VR-laseihin sisäänrakennettujen kameroiden avulla. Tutkimuksessa arvioidaan läpivientiin perustuvan pahoinvoinnin lievennysmenetelmän tehokkuutta vertaamalla sitä vakiintuneeseen näkökentän kaventamiseen perustuvaan menetelmään, joka tunnetaan myös nimellä vinjettitunnelointi (vignette tunneling).

Tutkielma perustuu VR:n kehitystä, VR-sovellusten suunnitteluun liittyviä haasteita sekä matkapahoinvoinnin taustalla olevia mekanismeja käsittelevään tutkimukseen. Tutkielmaa varten toteutettiin kokeellinen tutkimus, jossa yhteensä 15 osallistujaa kulkivat virtuaalisella radalla käyttäen molempia pahoinvoinnin lievennysmenetelmiä. Osallistujat arvioivat pahoinvoinnin oireitaan ja niiden voimakkuutta sekä kokeen aikana että sen jälkeen käyttämällä kahta mittaria: Fast Motion Sickness Scale (FMS) ja Simulator Sickness Questionnaire (SSQ).

Tulokset osoittivat, että osallistujat raportoivat lievempiä kyberpahoinvoinnin oireita käyttäessään kameran läpivientiin perustuvaa lievennysmenetelmää verrattuna näkökentän kaventamiseen perustuvaan menetelmään. Tulosten perusteella läpivientiin perustuvat menetelmät ovat toimiva tapa lieventää kyberpahoinvointia ja tarjoavat vartenotettavan vaihtoehdon vakiintuneille näkökentän kaventamiseen perustuville menetelmille. Osoittamalla läpiviennin tehokkuutta kyberpahoinvoinnin oireiden lieventämisessä, tämä tutkielma pyrkii edesauttamaan tutkimusta VR-teknologian saavutettavuuden ja käytettävyyden parantamista.

Avainsanat: VR, virtuaalitodellisuus, kyberpahoinvointi, VR pahoinvointi, Matkapahoinvointi, kameran läpivienti

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1 Introduction

Virtual reality (VR) has emerged as a significant field of technology over the past several decades, notable for its immersive qualities enabling users to interact with computer-generated content in virtual environments. Although early research on VR began in the 1950s, developments in computing power, display technologies, and motion tracking systems have enabled its transition from the laboratories of the late 1900s into a widely adopted commercial field of technology. In particular, the increasing availability of affordable high-quality head-mounted displays (HMDs) has accelerated the usage of VR in fields such as entertainment, education, healthcare, and industrial training. [1] Despite these advances in technology, the increased adoption of VR has highlighted numerous new challenges regarding accessibility and the user experience that are actively being researched today.

Among these challenges are the development of efficient interaction interfaces and methods, design principles for VR applications, and user comfort. One especially persistent challenge concerns movement within virtual environments. VR applications frequently employ software-based solutions, such as controller movement through teleportation or continuous forward momentum, as these tend to be cost-efficient and easy to implement. However, due to the discrepancies between the visual and vestibular sensory information, these movement techniques frequently cause an onset of motion sickness in the user. [2] Therefore, researching and developing methods to combat this phenomenon, either through new locomotion techniques, visual modifications, or other means, has become more important as the technology has matured.

1.1 Scope of the Research

This thesis is a mixed-method experimental study primarily focusing on cybersickness, which is a form of *visually induced motion sickness* (VIMS). [3] The study includes the gathering and analysis of qualitative and quantitative data regarding symptoms of cybersickness, alongside post-experiment interviews. For the purposes of this thesis, the motion sickness mitigation strategies are split into the categories of design and rehabilitation, as they differ in their approaches. Design strategies aim to pre-emptively prevent the onset of motion sickness via various

mitigation methods, and rehabilitative strategies aim to build tolerance to motion sickness-inducing stimuli via repeated exposure. Consequently, this thesis is primarily interested in examining potential design strategies for mitigating cybersickness, as their implementation requires less of the end user due to the mitigation being integrated into the software itself. By contrast, rehabilitative strategies would require a potentially significant time and effort investment by the user to build tolerance, thus potentially being less desirable for the average consumer.

Other types of motion sickness, such as carsickness, seasickness, and simulator sickness, are covered briefly, as they are able to provide further context for what makes VIMS, and specifically cybersickness, different and worth researching. A brief historical overview of some of the major milestones in the development of virtual reality, as well as the difficulties inherent in designing and implementing VR applications, is included for further context. Pharmacological solutions to mitigating motion sickness are also covered briefly, although since the primary focus is on design strategies, they are not explored as thoroughly and are mainly included for additional context. The study also does not aim to be a medical examination of physiological changes within the participant's body, thus data such as heart rate, blood pressure, or muscle tension are not gathered. Rather, the study approaches the topic from a software development angle and aims to find ways of developing user interfaces to mitigate the symptoms, thus potentially improving the user experience and technology adoption via increased accessibility. Consequently, as the main focus is on user experience, the experiment uses subjective self-reports on symptoms as the main data points.

The movement mechanics used to induce cybersickness in participants include continuous controller-based forward momentum, as well as moving platforms in the forms of an elevator and a rollercoaster. Therefore, mechanics such as teleportation, redirected walking, flying, floating, swimming, arm swinging, step multiplier, and other methods of movement are not included. The virtual environment is also purposefully designed to induce cybersickness in the participant, therefore the experienced sickness levels may be higher than in a typical use case scenario.

The thesis focuses on comparing two techniques based on visual modification of the user interface: vignette tunnelling (frequently also referred to as field of view reduction) and camera passthrough. Vignette tunnelling has already been established as a functional mitigation technique [4], [5], [6], and it is included as an accessibility option in various VR applications [7], [8]. Conversely, as a relatively new technology, the effects of utilising camera passthrough in a similar manner have not been explored greatly as of yet. Therefore, comparing a new method to a similarly functioning established method may provide valuable information on both the old and the new mitigation technique, as well as offering direction for future research.

These approaches were chosen due to the relative simplicity in implementing them, while also keeping the user experience as close to the experience without mitigation as possible. By contrast, novel control methods frequently used for mitigation, such as redirected walking or step multiplier, require significantly more input from the user, potentially affecting the user experience. Keeping the user experiences consistent between scenarios where mitigation methods are and are not used makes it easier to design VR applications, as the mitigation methods could be included as simple accessibility options that the user could turn on whenever required. Conversely, with more novel approaches, the applications would have to be designed to accommodate the different mitigation strategies. Additionally, vignette tunnelling has already been established as a functional cybersickness mitigation tool, with it even being offered by the Unity engine as a default component [9]. This makes it a good point of comparison for the camera passthrough method designed for this thesis, as they function similarly, and one could be included in every application where the other is also used.

1.2 Research Questions

This thesis aims to find answers to the following research questions:

RQ1 Can camera passthrough be used effectively to mitigate cybersickness?

RQ2 How does camera passthrough compare against vignette tunnelling in reducing symptoms of cybersickness?

RQ1 was addressed through a literature review on motion sickness, the history of its research, its symptoms, causes, various types of motion sickness, and some of the

researched mitigation techniques. RQ2 was examined through an experiment involving a virtual environment with 4 distinct experimental sections of varying stimulation for cybersickness, designed and developed using the Unity engine [10]. Test participants were asked to complete a track in the virtual environment utilising two different cybersickness mitigation methods, and data on their symptoms was collected. The data was then analysed to find answers to the research questions.

For the research questions, the following research hypotheses were formed.

***RH1** Camera passthrough can be used effectively to help mitigate virtual reality sickness*

***RH2** Camera passthrough is more effective than vignette tunnelling in mitigating cybersickness*

The reasoning for RH1 is the assumption that, by displaying parts of the user's physical surroundings during the VR experience, a grounding effect would be created, which would reduce symptoms of cybersickness. The reasoning for RH2 is the assumption that the grounding effect is a stronger method of mitigating symptoms than the field of view (FoV) reduction present in vignette tunnelling. Alongside these research hypotheses, three experimental hypotheses (EH) were also formed for the individual sections in the experiment. These hypotheses are explained in more detail in Section [4.3](#) when discussing the design of the experiment.

1.3 Use of Generative AI

Large language models from OpenAI's GPT-5 series were used solely in a supportive role during the writing process to correct grammar and improve the academic tone, clarity, and readability of the text. During the development process for the virtual environment, the large language models were used as a coding aid in debugging code, fixing errors, and optimising the application to run on the VR device. No AI-generated content was included in the thesis, and all the research is based on the external sources listed in the references. Additionally, no AI tools were used for the interpretation of experimental results, data analysis, or the formulation of conclusions.

1.4 Thesis Structure

This thesis is divided into 7 chapters. Chapter [2](#) gives an overview of virtual reality through its history, definitions of virtual, augmented, and mixed reality, and some challenges designers of VR applications may face. Chapter [3](#) is a literature review on motion sickness that investigates different types of motion sickness, what causes them, what their typical symptoms are, and how to mitigate them. Chapter [4](#) introduces the experiment conducted for this thesis, explains what it is and how it was designed, how data was collected, and the demographics that took part in it. Chapter [5](#) goes over the results of the experiment, while Chapter [6](#) offers a more in-depth analysis of these results. Finally, Chapter [7](#) concludes this thesis.

2 Virtual Reality

Virtual reality, as defined by the Merriam-Webster dictionary, stands for an “artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment” [11]. In a contemporary sense, VR is typically understood to involve the use of a *head-mounted display* (HMD) to allow the user to experience and interact with an immersive virtual world [12], [13]. This Chapter aims to give a background view of the history of VR, as well as contemporary definitions of VR, alongside the closely related concepts of augmented and, on a wider scale, mixed reality. Finally, challenges involved with developing VR applications are discussed as well.

2.1 History of Virtual Reality

The history of virtual reality, as outlined by the Virtual Reality Society [14], can be traced back to 1787 with the creation of the first panorama picture by the painter Robert Barker. These panorama pictures, which were patented in 1787, introduced the concept of immersive 360-degree visual experiences. Specialised buildings were constructed to display panorama pictures. One such building was the London Colosseum, built in 1827. Although panorama buildings declined in popularity throughout the 19th century, eventually being overtaken by cinemas, they laid the conceptual groundwork for immersive visual media, which modern VR technologies continue to build upon. [15]

In 1960, Morton Heilig patented the *Telesphere Mask*, creating the first head-mounted display. Although the Telesphere Mask had a stereoscopic display with an approximately 140-degree field of view and headphones for audio, it did not feature motion tracking, making it functionally a small personal television. [16] Subsequently, in 1962, Heilig patented the *Sensorama Simulator* (invented earlier in the mid-1950s), which was a fully 3D multi-sensory device intended for viewing films. It had a display for both eyes, a moving seat for simulating movement, a binaural audio system, a device to produce a light breeze, and a device to produce odours. [17] Both devices can be seen in Figure [1](#).



Figure 1: The Telesphere Mask (left) and the Sensorama (right), both designed by Morton Heilig. [18]

In 1968, scientist Ivan Sutherland created a prototype for an augmented reality device often referred to as the *Sword of Damocles*, presented in Figure 2. The system itself was originally named the *Head-Mounted Display*, while the nickname referred to the mechanical system holding the device in place. [19] The Head-Mounted Display was created to produce digital images through a stereoscopic display and was capable of tracking and synchronising the visuals with the user's movement. However, it was limited to displaying simple wireframe graphics and required suspension from the ceiling due to its weight, thus making it cumbersome and uncomfortable to use. [20]

In the late 1960s, Myron Krueger developed several experimental projects aimed at creating what he termed "artificial reality". The first of these projects, *Glowflow*, used various technologies to create a room containing visual and auditory effects that responded to human behaviour. Although computer-generated graphics were not used, the project utilised hidden mini-computers, sound synthesisers, and tubes containing phosphorescent coloured fluids to produce the sensory experience. In addition, pressure-sensitive plates were used to interact with the room, generating visual and auditory effects when stepped on by users. [20]

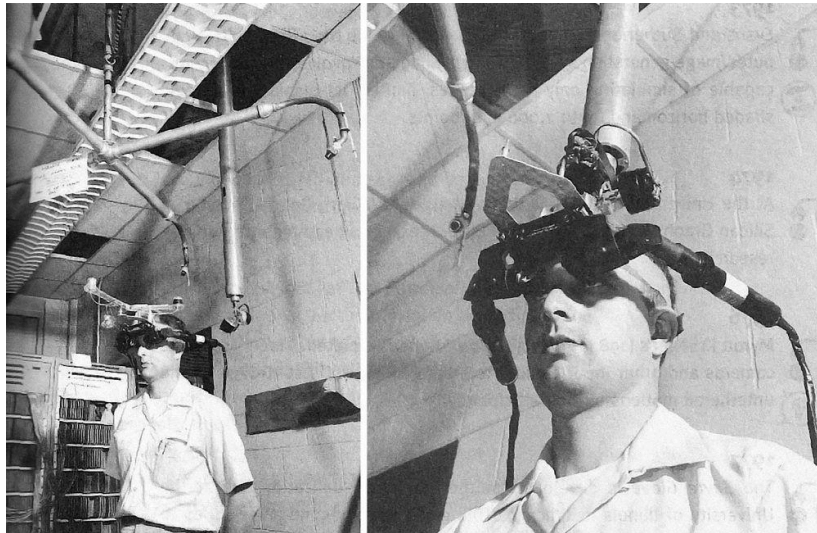


Figure 2: The Sword of Damocles, designed by Ivan Sutherland. [21]

Other projects developed by Krueger include *Metaplay*, which utilised a live camera feed to overlay the user's image onto computer-generated graphics on a screen. The screen was also connected to an unseen facilitator's drawing tablet, allowing them to draw objects for the user to interact with. Another project, *Psychic Space*, used a screen to display a digital maze. The user could attempt to solve it by moving within a defined boundary, with their physical movement controlling a graphical object within the maze. [20]

Krueger's experiments culminated in a project exhibited in 1975 called the *Videoplace*, presented in Figure 3, which is widely considered the first VR platform [14]. It used several video cameras, projectors, mixers, and other specialised hardware in two separate rooms to connect them to each other. Both rooms included a wall-sized screen displaying the silhouettes of the rooms, enabling users to interact with each other remotely. Moreover, the Videoplace was able to detect individual body parts, such as fingers, to enable further interactivity between users. Users could, for example, type on a virtual keyboard or draw on the screen. Building on the Videoplace technology, a project called *Critter* introduced an artificial creature on the screen for users to interact with. The creature could, for example, climb onto a user's shoulder, jump onto their hand, or perform various tricks. [20]

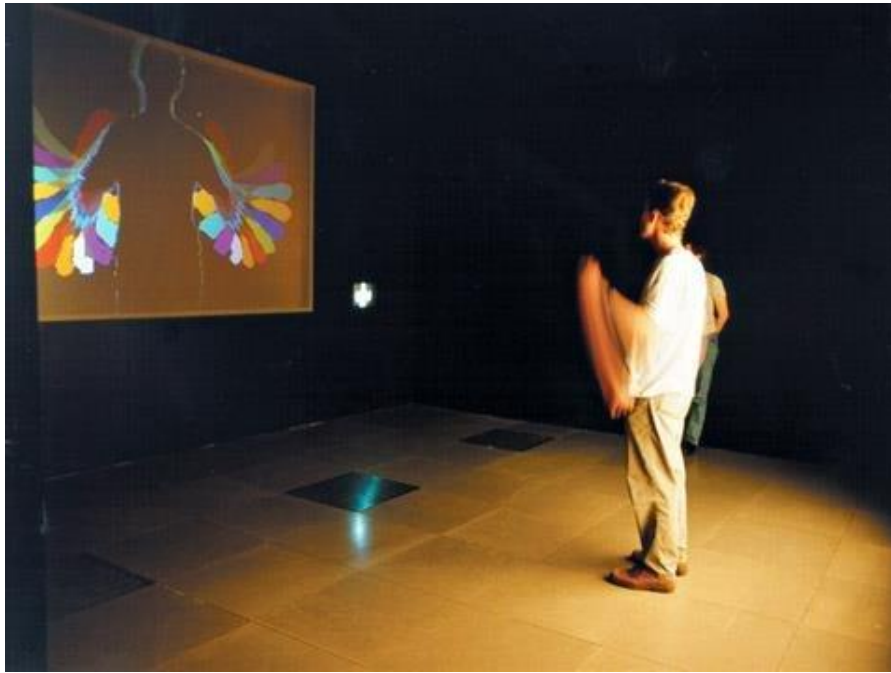


Figure 3: The Videoplace, created by Myron Krueger as the culmination of his series of artificial reality experiments. [22]

These early experiments were focused on creating an interactive artificial reality, as termed by Krueger, which is distinct from the modern concept of virtual reality. A Timeline of Krueger's artificial reality experiments is illustrated in Figure 4. Today, VR is often associated with a head-mounted display (HMD). This technology, however, was absent from these early experiments, with the exception of the Sword of Damocles, whose weight and suspension system made it too cumbersome and inconvenient for any practical use. Although Krueger was more focused on artificial reality experiments, his contemporaries were also interested in developing more usable HMDs. [1]

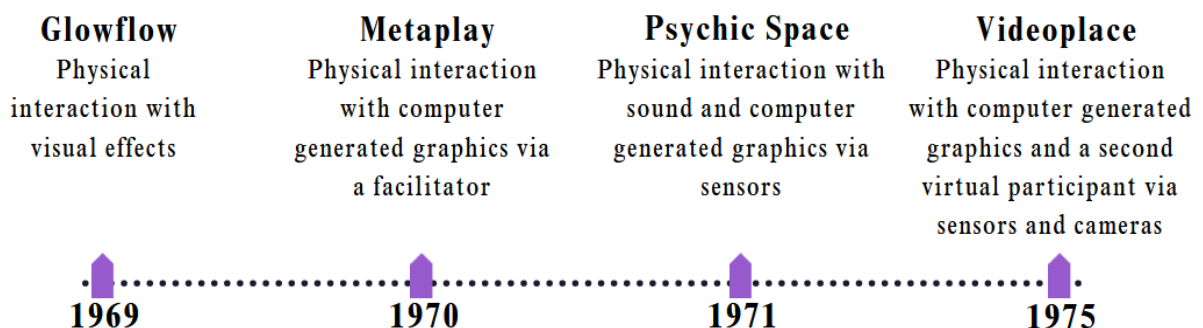


Figure 4: A timeline of Myron Krueger's artificial reality experiments.

Among the early HMDs was the *VITAL helmet* designed by the McDonnell Douglas Corporation for flight simulator training by the United States military, which can be seen in Figure 5. Cathode-ray tubes were used to project images onto beam splitters in front of the pilot's eyes, functioning similarly to the Sword of Damocles by overlaying computer-generated images onto real-world objects. This allowed the pilot to operate the plane's controls while viewing the simulation through the HMD. In contemporary terms, this technology is closer to *Augmented Reality* (AR) than VR. [1] This distinction is discussed in more detail in Section 2.2.

Although the VITAL helmet was functional, it was bulky and inconvenient to use. Notably, operating the control system was awkward and unintuitive, and thus the helmet was never widely adopted. Nonetheless, it served as a proof of concept for the use of HMDs in simulator training, which the United States military continued to research. [1]



Figure 5: The VITAL helmet, designed by the McDonnell Douglas Corporation. [23]

Throughout the 1970s and early 1980s, VR devices were expensive and primarily used for research, training, or as exhibits. A notable step towards the commercialisation of the technology occurred in the mid-1980s with the founding of *VPL Research* by Jaron Lanier. The company is commonly regarded as one of the first to develop and sell VR equipment. Notably, the term “virtual reality” was also coined around this time, with Lanier often credited with popularising it as one of its earliest users. [1], [24], [25]

VPL Research (short for Virtual Programming Language Research) was founded through a collaboration between Lanier and Thomas Zimmerman aimed at developing a virtual programming interface for non-programmers. Prior to this collaboration, Zimmerman had developed a glove that allowed users to control a computer by bending and flexing their finger joints, as well as through hand movement and rotation. Although the glove was initially intended as a tool for creating music using computer-controlled synthesisers, Lanier recognised its potential as a programming interface. This work led to the development of the *DataGlove*, whose underlying technology was later adapted to create the Power Glove for the Nintendo Entertainment System. [1], [25]

VPL initially operated as a supplier of the DataGlove, which was used by NASA as a control device for their HMDs. Conversely, VPL adopted ideas from NASA to develop more systems and software for creating virtual environments. These systems included the *EyePhone*, which was an HMD capable of tracking the user's head position and orientation. Although the device was heavier than modern counterparts, it resembled the HMDs available today. The EyePhone, paired with the DataGlove, were among the first commercially available VR devices. [1], [25] Both devices can be seen in Figure 6.

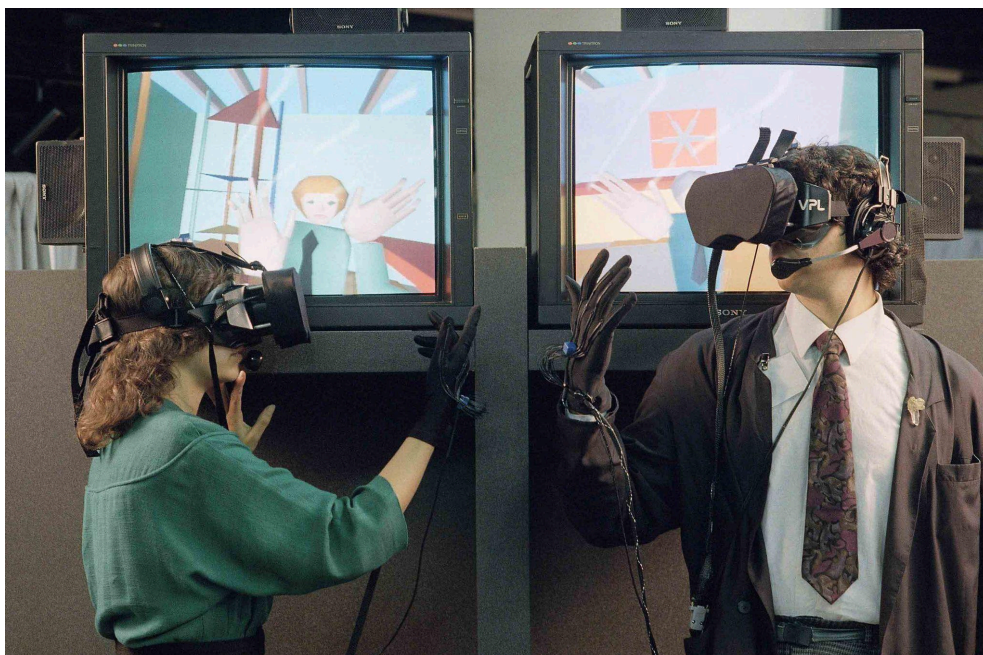


Figure 6: The EyePhone and the DataGlove, both designed by VPL Research. [26]

In 1994, Nintendo, previously known for developing electronic toys and gaming devices, introduced the *Virtual Boy* as its latest gaming console, making it one of the first major companies to invest in the mass production of VR devices. The Virtual Boy, as presented in Figure 7, was a bulky device intended to be mounted on a tripod and played while seated. It was able to display 3D graphics, which was novel for a video game console at the time, and it featured a dual-screen display. [27] The system employed a technique known as the *Scanned Linear Array* (SLA) to display graphics, which enabled lightweight and low-cost design. Using CRT technology would have made the device too heavy and power-hungry, while LCDs would have been too expensive to mass-produce. SLA displays, invented by Allen Backer in the late 1980s, utilised an array of LEDs to display images. Moving the images was done by mirrors oscillating back and forth 50 times per second, resulting in sharp, high-resolution visuals at low cost and weight. However, it was only able to render two colours: black and red. [28]

The inclusion of SLA technology reportedly caused headaches, dizziness, and other uncomfortable side effects among users. The games developed for the system also did not take full advantage of VR, as most of them did not utilise a first-person view. Additionally, the console lacked tracking sensors, instead relying on standard gaming controllers. These limitations, combined with difficulties in developing games for it, contributed to Virtual Boy being a commercial failure, leading to Nintendo phasing it out of production within a year of its release. [27] Although the system itself was a failure, it represents an early effort to introduce VR to a wider consumer audience.



Figure 7: The Nintendo Virtual Boy, created by Nintendo. [29]

The development of VR devices throughout the 2000s was relatively slow compared to earlier decades. However, in the early 2010s, a significant advancement was made with the first *Oculus Rift* prototype developed by Palmer Luckey. The first development kit was released in 2013 and was intended specifically for developers to begin producing applications utilising the technology. The first consumer version of the device, presented in Figure 8, was subsequently released in 2016. The device featured a higher screen resolution than many earlier HMDs, while also utilising a single wide screen split in half, as well as magnifying lenses positioned in front of the eyes. This design allowed for a more compact system at a lower cost compared to earlier devices, which typically employed separate screens for both eyes. [30] .



Figure 8: The first consumer version of the Oculus Rift, designed by Palmer Luckey in 2016. [31]

The Oculus Rift attracted the attention of gaming industry veteran John Carmack, who contributed to its development. The early prototype had issues with image distortion caused by the magnifying lenses, resulting in a fisheye-like effect. Carmack addressed the issue by applying an inverse pre-distortion to the rendered image, compensating for the distortion caused by the lenses. Notably, Carmack demonstrated the Oculus Rift at E3 2012, one of the largest annual gaming events at the time. The increased visibility and positive reception led Luckey to found *Oculus VR Inc.* to continue development, supported in part by a crowdfunding campaign on Kickstarter. [30]

Two years later, in 2014, Facebook (later rebranded to Meta [32]) acquired Oculus VR Inc [33]. During the same year, Sony [34] and Samsung [35] announced their own

consumer VR devices, *Project Morpheus* (later rebranded to PlayStation VR [36]) and *Gear VR*, respectively. In 2015, HTC Corporation introduced its own VR headset called the *HTC Vive* [37] as a collaboration with the video game company Valve. The HTC Vive can be seen in Figure 9. Over the following years, several major technology companies entered the VR market, thus bringing the technology to the mainstream. Consequently, the technology started to become more accessible and usable for consumers.



Figure 9: The HTC Vive, created as a collaboration with the HTC Corporation and Valve. [38]

The technology progressed more rapidly throughout the 2010s compared to earlier decades. In 2018, Facebook Technologies released the Oculus Go, which became the first standalone VR headset, meaning that it did not require connecting to an external computer or sensors to function [39]. The gaming company Valve introduced its VR headset, the *Valve Index*, in 2019 [40], which was notable for its controllers enabling complex finger tracking [41]. The valve index was followed by HP's introduction of the *HP Reverb G2* in 2020 [42], which featured a significantly improved image clarity compared to its contemporaries. During the same year, Facebook established the *Facebook Reality Lab*, aimed at pioneering future VR research and development [43] and announced the *Oculus Quest* [44], which was the first commercial headset to feature hand-tracking technology, enabling a completely controller-free experience [45]. In 2024, Apple introduced the *Apple Vision Pro*, which employs a technology referred to as "spatial computing" intended to blend the virtual and physical worlds together [46]. The Apple Vision Pro can be seen in Figure 10. A similar technology called camera passthrough is utilised by devices such as the Meta

Quest 3 to enable the user to see their physical surroundings through cameras on the headset.

The designs of these newer VR devices have become increasingly standardised, with most utilising wireless handheld controllers alongside a head-mounted display. Some devices, such as the Apple Vision Pro, can also utilise internal cameras to allow interaction through hand gestures. Significant developments have been made in motion-tracking technologies as well. Several earlier devices, such as the HTC Vive and the Oculus Rift, required external sensors to track movement (outside-in tracking). By contrast, newer devices such as the HP Reverb G2 and the Meta Quest 3 use internal cameras to track user movement (inside-out tracking), which increases user convenience and reduces the space required for a VR setup. Additionally, VR devices differ in the degrees of freedom (DoF) they provide. Some systems, such as the Samsung Gear VR, only support rotational movement of the headset (3 DoF). By contrast, devices such as the Oculus Rift and the Meta Quest 3 also support positional movement alongside rotation (6 DoF). A timeline of the major milestones throughout the history of VR is illustrated in Figure [11](#).

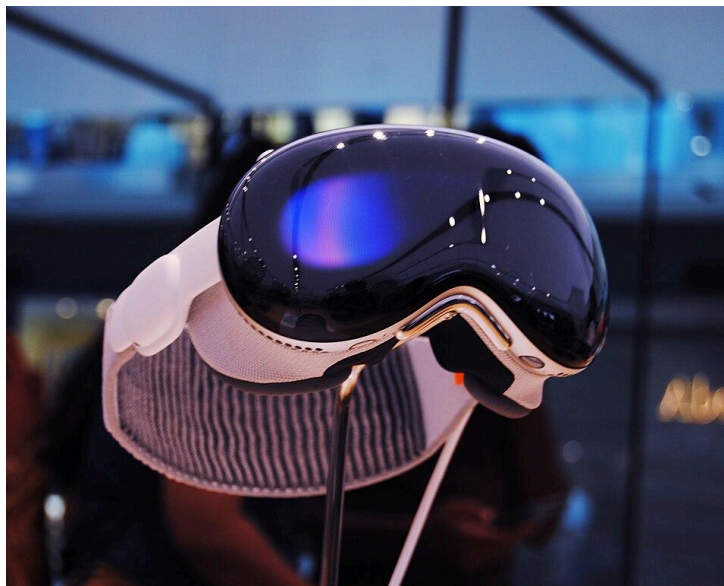


Figure 10: The Apple Vision Pro, created by Apple. [47]

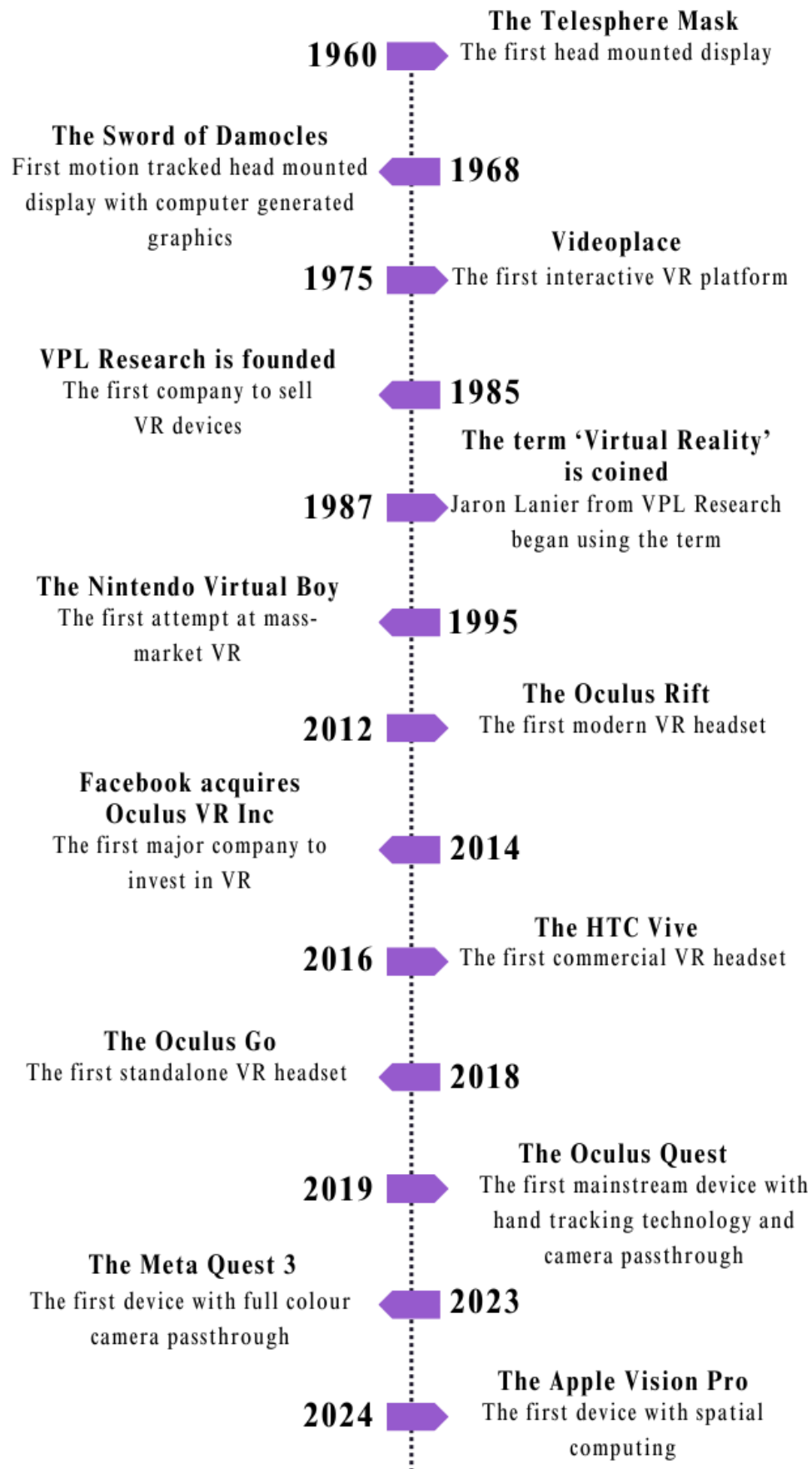


Figure 11: Key milestones in the development of virtual reality.

2.2 Virtual, Augmented, and Mixed Reality

The exact definition of virtual reality has evolved over time, with the term itself only becoming widely adopted in the mid-1980s. Many of the earlier devices can be classified as augmented reality (AR) under contemporary definitions. In addition to virtual reality and augmented reality, mixed reality (MR) is commonly recognised as a distinct but related concept.

These concepts are typically conceptualised with the *Reality-Virtuality Continuum* defined by Paul Milgram in 1994 [48] and illustrated in Figure 12. The continuum describes a spectrum with one end representing the real environment and the other representing a fully virtual environment. Therefore, MR is defined as anything that exists between the real and the virtual, as it is considered a mixture of the two. AR also exists on this continuum, being closer to the real environment than the virtual one. [48]

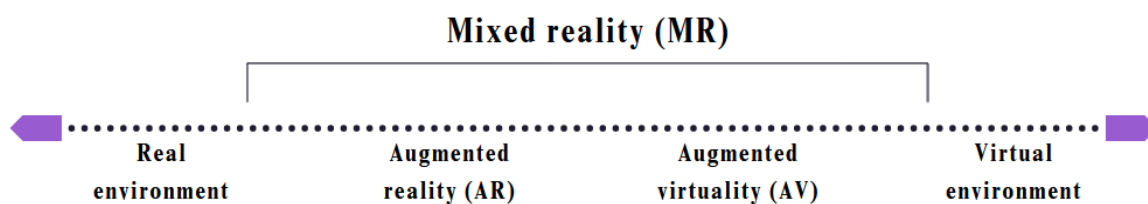


Figure 12: The Reality-Virtuality Continuum as defined by Paul Milgram, illustrated from [48].

The continuum also describes the concept of *Augmented Virtuality (AV)*, situated closer to the virtual end of the spectrum. AV is distinguished from AR in that it refers to a predominantly virtual environment that incorporates elements from the physical world. This could involve using the HMD's cameras to display the user's physical hands in the virtual environment. By contrast, AR is predominantly real-world augmented through virtual means. [48]

To further clarify the differences between virtual, augmented, and mixed reality, Speicher et al. [12] interviewed several experts on the definitions of virtual, augmented, and mixed reality. VR is described in the work of Speicher et al. [12] as a “fully synthetic” and a “fully virtual” view of a “completely constructed reality”. The given definitions also emphasise the necessity of head tracking, a head-mounted display, and full immersion. [12] From the devices listed in Section 2.1, the first to fit

the definitions given in the paper is VPL's EyePhone. Although head-mounted displays existed before, they did not fully meet the given requirements, as some lacked head-tracking (e.g., the Telesphere Mask) while others did not provide an immersive computer-generated environment (e.g., the Sword of Damocles and the VITAL Helmet).

The definitions of AR tend to emphasise the importance of blending the physical and virtual worlds together. It is described as virtual objects and overlays superimposed onto the user's physical surroundings. Unlike VR, which aims to construct a fully virtual environment, the goal of AR is to augment the physical environment through the addition of virtual content. [12] According to these definitions, the Sword of Damocles and the VITAL helmet can be considered as some early examples of AR.

The experts interviewed by Speicher et al. [12] were less consistent in their definitions of MR. Some described it as a combination of virtual and augmented reality, implemented through applications or devices capable of supporting both technologies. This was described as "AR plus full immersion". By contrast, other experts considered MR to be equivalent to AR, with some dismissing the term as "marketing mambo-jumbo". Most definitions of MR depended on AR, with it either being described as a "stronger version of augmented reality", a "mix of augmented and virtual reality", or "synonymous with augmented reality". [12] Because of the unclear definitions, the devices mentioned in Section [2.1](#) cannot be conclusively stated to be examples of MR. However, since AR and MR are strongly related, the devices mentioned in the AR section may also be interpreted as being MR, depending on the chosen definition.

2.3 VR Design and Its Challenges

A key characteristic of VR applications is the user's viewpoint in the virtual environment being intrinsically linked to the position and rotation of the HMD, naturally resulting in a first-person perspective. Consequently, VR applications tend to utilise first-person camera models to maximise immersion. Although there are VR applications that use other camera models, such as video games played in a third-person perspective [49], first-person perspectives remain the conventional approach for immersive VR applications.

As a result, VR presents unique design challenges for designers, particularly in relation to the movement systems. According to a typology proposed by Boletsis in 2017 [2] and illustrated in Figure 13, the movement, or *locomotion*, techniques can be classified under either *physical* (translates the user's physical motion cues into movement in the virtual environment through the use of body tracking) or *artificial* (utilises input devices to control movement in the virtual environment) interaction types. These can be further divided into *continuous* (able to move in the virtual environment uninterrupted) or *non-continuous* (instantaneous and disruptive movement transitions) motion types and *open* (size of the virtual environment surpasses the limits of the user's physical environment) or *limited* (size of the virtual environment is constrained to the user's physical space) interaction spaces. Below is an explanation of the four locomotion types that fit into these classification categories, as identified by Boletsis. [2]

- Motion-based: Physical interaction type, which uses the user's physical movement and translates it into movement in the virtual world. Continuous movement in open virtual spaces is also supported.
- Roomscale-based: Similar to motion-based techniques, in that it is a physical interaction type utilising the user's movement to enable continuous motion in the virtual space. However, roomscale-based methods differ from motion-based methods in that the interaction space is limited, as the size of the virtual space is constrained to a predesignated play area.
- Controller-based: An artificial interaction type utilising handheld controllers to move in an open virtual space in a continuous manner.
- Teleportation-based: Another artificial interaction type also utilising handheld controllers in a non-continuous manner to allow movement in an open virtual space.

Physical interaction types tend to be considered as more intuitive methods of movement, as they more closely resemble real physical movement. Consequently, these locomotion types tend to be studied more, as the literature review by Boletsis showed 47 out of 73 articles utilised some type of physical locomotion. Boletsis stated a more intuitive user response and a reduced cognitive load in movement instructions as reasons why physical interaction types tend to be more utilised. Although free physical movement is more intuitive, it does also create some

limitations, namely through physical exertion, potentially limiting the usability of the applications, as well as requiring more free space in comparison to artificial methods. [2]

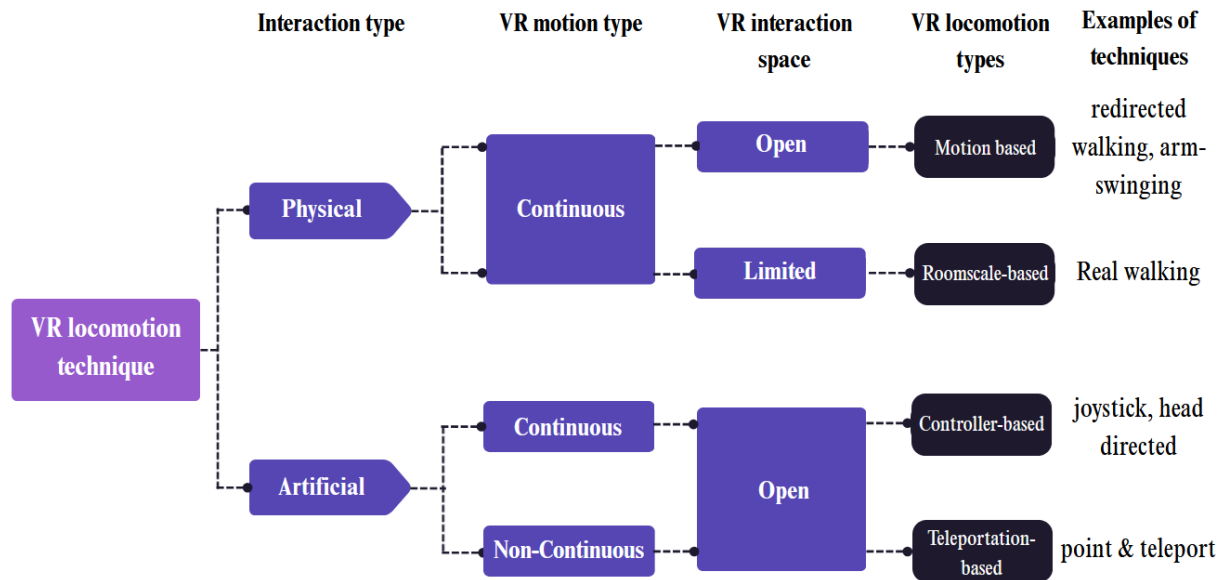


Figure 13: The typology of VR locomotion techniques proposed by Boletsis, illustrated from [2].

A system-specific limitation that may arise in the context of physical interaction types is the requirement for a wireless device. Although a wired system can still support room-scale VR applications, the presence of a cable constrains the user's movement, as it may become entangled around objects or introduce a tripping hazard. Consequently, it limits the potential distance between the user and the host system. Although many current devices are wireless, it is not universally the case. Therefore, VR applications should account for differences in hardware configurations to ensure a consistent user experience across devices. To address these limitations, various software-based locomotion techniques have been developed. Two widely adopted ones are teleportation and joystick-based controller movement. Conversely, an example of a hardware-based solution would be utilising an omnidirectional treadmill as a controller, as seen in Figure 14.

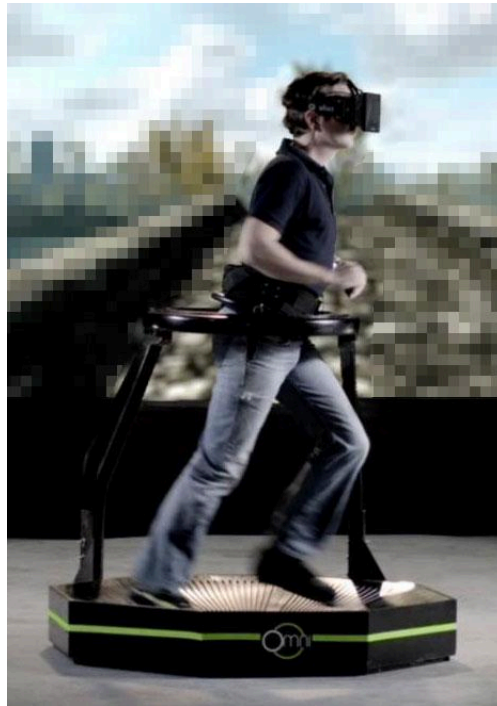


Figure 14: An omnidirectional treadmill -style controller designed by Virtuix. [50]

Teleportation enables movement within a virtual environment by pointing at a target location, typically via ray-casting with a virtual laser pointer, and confirming the action through controller input. Although this technique is commonly implemented due to its simplicity and reduced physical demand, it introduces new limitations. In applications requiring frequent movement, teleportation can become inefficient and disorienting due to its non-continuous motion type. Consequently, it is frequently associated with reduced immersion in users. Therefore, teleportation is often employed in applications where the user is expected to remain stationary or be constrained to a small area. Within the typology of locomotion techniques, teleportation-based methods are classified as artificial, with non-continuous interaction supporting movement in open virtual spaces.

Joystick-based controller movement enables continuous movement in the virtual world using analogue stick input on handheld controllers, resembling common movement systems in many traditional non-VR video games. Within the typology of locomotion techniques, it is classified as artificial with continuous interaction, in contrast to teleportation's non-continuous interaction, while also supporting movement in open virtual spaces. Although this method is frequently perceived as providing smoother and more immersive movement than teleportation, it introduces a

higher risk of motion sickness. This problem arises due to a sensory conflict caused by visually perceived motion in the virtual environment without corresponding vestibular input. This thesis investigates whether camera passthrough can be used effectively to mitigate motion sickness experienced by the user when joystick-based controller movement is employed.

Other methods include arm-swing locomotion, where users move by mimicking running motions with the handheld controllers, and step multiplier, where the user's movement in the physical space is multiplied by a constant and then translated into the virtual environment. These approaches, however, tend to be less common. They also introduce their own challenges, such as increased cost and spatial requirements, especially when utilising controllers such as the omnidirectional treadmill. The complexity in implementation may increase as well, as many of the more novel methods would require additional care so as not to affect the user experience too greatly. Techniques such as the step multiplier may require too much additional input from the user, potentially becoming overwhelming by increasing the cognitive load, thereby negatively affecting the user experience.

3 Motion Sickness

Motion sickness, also referred to as *kinetosis* [51], has been observed throughout human history and remains prevalent to this day. It has been documented as early as ancient Greece, with the earliest written record being from the Greek physician Hippocrates, who stated that “Sailing on the sea shows that motion disorders the body” [52]. Consequently, the historical association of the condition with sea travel becomes apparent from the etymology of the word “nausea”, as it is derived from the Greek word “naus”, meaning ship [53]. With the development of modern transportation systems, such as automobiles, trains, and aircraft, motion sickness continues to be a common phenomenon affecting humans in their daily lives [54].

3.1 What is motion sickness?

Motion sickness is typically understood through the *sensory conflict theory*, which describes the condition as physical discomfort caused by the discrepancy between physical sensations of motion and visually perceived motion. Moreover, it has also become the most widely accepted theory for the fundamental causes of motion sickness. [55] However, motion sickness has also been observed in individuals suffering from blindness [54], suggesting that it is not the visual perception but rather the expectation of some specific movement that creates the discrepancy in the senses. The symptoms most frequently associated with motion sickness include nausea, malaise, and vomiting [56]. Additionally, research also indicates gender-related differences in motion sickness susceptibility, as women have been observed to experience symptoms more frequently. In a study conducted by Lawther and Griffin, interviews with ferry passengers found that female passengers tended to report more severe symptoms more frequently in comparison to their male counterparts. [57] Similar observations have been reported in several other studies [51], [54], [58].

Migraine and motion sickness have been observed to cause an onset of similar symptoms, such as nausea, dizziness, headaches, and general malaise, suggesting a potential link between the conditions [59], [60]. This link is further supported by the observation of migraine being more prevalent in women [60], [61], corresponding with the earlier observation of women being more susceptible to motion sickness [51],

[54], [57], [58]. In addition, both conditions have been reported to intensify during menstruation [59], [60], implying a possible hormonal influence in the development of symptoms. A study conducted by Drummond [62] provided further evidence supporting the link between migraine and motion sickness by experimentally inducing motion sickness in two groups via optokinetic stimulation. One group had a history of migraine, and the other was a control group. Although the stimulation caused headaches in both groups, participants with a history of migraine reported symptoms persisting for up to 30 minutes after exposure, alongside reporting higher levels of nausea. [62]

3.1.1 History of Motion Sickness Research

Although motion sickness has been a documented phenomenon since the ancient Greeks, the term itself was not coined until 1881 by J. A. Irwin in his publication on seasickness, in which Irwin describes motion sickness as a disturbance of the “organs of equilibration”, referring to the canals of the inner ear [63]. Hence, Irwin proposes disturbing the “endolymph in the semicircular canals” or the “viscera in the abdomen” as causes for motion sickness. Irwin also observed that sailors tend to get used to the rocking of a boat and their vestibular system learns to adapt to it. As a result of this adaptation, sailors would then have difficulties balancing on land, as their vestibular system needs to readjust to account for the lack of passive swaying produced by boats. [63]

During the 19th century, technical developments in suspension systems of trains and boats helped advance knowledge of motion sickness by narrowing down the most nauseogenic oscillation frequencies. An example of one such invention is the gimbal-mounted dining saloon intended for ships, invented by Henry Bessemer in 1874. Although the invention proved to be ineffective due to insufficient damping systems in early transportation vehicles, Bessemer’s idea of mitigating motion sickness via suspension systems has been demonstrated in later research. Specifically, resonance frequencies between 1 and 2 Hz have been found to be optimal for passenger comfort. [64]

Seasickness was a major focus for early motion sickness research, particularly during World War II, when the military began to research effective remedies for sailors and downed pilots awaiting rescue. Typical symptoms of motion sickness,

such as nausea, fatigue, and vomiting [3], [65], [66], were deemed detrimental to survival in these situations. Furthermore, the military aimed to reduce dropouts during the air force's basic training, as well as to minimise incapacitation rates among active air force pilots. [64]

In the mid-20th century, during the space race between the United States and the Soviet Union, a new type of motion sickness, referred to as "*Space Motion Sickness*", became a topic of research. Anti-motion sickness medication was carried by crewmembers in the first United States space programs, namely *Mercury* and *Gemini*, although none had been used and no incidences of motion sickness were reported. [67], [68] However, during the *Apollo* program, reports of motion sickness among crewmembers increased substantially. Increased movement in the spacecraft used in later space programs has been theorised as the cause for this increase. [67]

During the *Skylab* program in the 1970s, the performance capabilities of crewmembers decreased substantially as a result of motion sickness, as the anti-motion sickness medications available at the time were found to be ineffective in mitigating symptoms. In response, two means of mitigating space motion sickness became a primary focus of research, namely more effective anti-motion sickness medicine and training techniques for crewmembers designed to better acclimate them to the weightlessness of space. [67]

To advance research on space motion sickness, the *National Aeronautics and Space Administration* sponsored research programs in the United States to determine the causes, prediction, prevention, and treatment of space motion sickness. Researchers were able to identify effective drug combinations for the treatment of motion sickness. [67] Notably, *promethazine* was determined to be highly effective, particularly when administered in combination with *ephedrine*. Consequently, this combination is frequently used to treat motion sickness in the modern day [67], [68], [69].

3.1.2 Causes of Motion Sickness

Although researchers have been able to determine the underlying mechanisms behind motion sickness, there is still uncertainty as to why humans have evolved a susceptibility to the condition [51], [54], [65]. In a publication by John F. Golding [54],

two hypotheses are presented as possible evolutionary explanations: *the toxin detector* and the *vestibular-cardiovascular reflex*.

The toxin detector hypothesis explains motion sickness as resulting from an accidental activation of a toxin detection system in the human body. Detected derangements in expected visual, vestibular, and kinaesthetic patterns trigger a vomit response, as unexpected changes in these systems could be caused by the presence of ingested toxins. This mechanism functions as a backup to the main toxin detection system in the chemoreceptors of the nervous system and the brainstem. Motion sickness has also been observed in non-human species, supporting the hypothesis of the toxin detector as an evolutionary survival mechanism. Additionally, increased susceptibility to motion sickness correlates with a higher sensitivity to toxins. [54]

The vestibular-cardiovascular reflex hypothesis proposes that motion sickness is caused by inappropriate activations of vestibular-cardiovascular reflexes, which provoke pressor responses such as increased blood pressure and cardiac output. This hypothesis is based on the observation that these specific pressor responses are provoked by the neural pathways that get activated by motion-sickness-inducing stimuli. [54]

Genetic factors have also been shown to influence sensitivity to motion sickness. A survey by Hromatka et al. [70] collected data from over 80 000 customers of 23andMe, which was analysed to identify genes with correlation to increased susceptibility to motion sickness. As a result, 35 single-nucleotide polymorphisms (SNPs) with genome-wide-significant associations for motion sickness were identified. Notably, the SNPs associated with eye and ear development had the largest correlation with motion sickness. In addition, genes involved in cranial development, SNPs associated with glucose and insulin homeostasis, body mass index, and hypoxia-inducible genes were also found to correlate with motion sickness. [70]

The aforementioned survey by Hromatka et al. [70] exhibited a significant bias toward individuals of European ancestry, however, as participants from other populations were not included. A study by Stern et al. [71] found a significant association between ancestry and motion sickness, notably with individuals of Asian descent

being hypersusceptible to the condition. The study was conducted in three parts: first compared Chinese women to European-American and African-American women, second compared American-born Asian individuals to the same groups as the first part, and third compared Chinese men and women. Motion sickness was induced in the participants via an optokinetic drum. As a result, Asian participants in the first and second parts exhibited more severe symptoms of motion sickness, and in the third part, their average nausea scores were significantly higher than those of European-American or African-American participants. Furthermore, the study noted that Asian individuals have a higher sensitivity to various drugs compared to European-Americans [71], supporting the aforementioned toxin detector hypothesis [54].

Associations between dietary intake and motion sickness have been observed as well. In a study by Glenda and Paul Lindseth [72], correlations between certain foods and incidences of airsickness among airline pilots were identified through pre-flight health assessments before their first flight and post-flight interviews after each flight. Additionally, the pilots reported their dietary intake within the last 24 hours before each flight. As a result, consumption of dairy products, such as milk and cheese, was found to correlate with a higher rate of motion sickness. Notably, the condition was found to decrease after consuming food rich in carbohydrates, such as bread and cereal. The study also referenced previous research supporting these findings, as well as another that observed increased rates of motion sickness in participants who had not eaten at all. [72]

3.1.3 Symptoms of Motion Sickness

The most typical symptoms of motion sickness are nausea and vomiting, with other frequently reported symptoms including sweating, salivation, apathy, fatigue, stomach awareness, disorientation, dizziness, and incapacitation. Physiological signs, such as changes in cardiovascular, respiratory, gastrointestinal, biochemical, and thermoregulatory functions, are also commonly mentioned in reports. [3], [65], [66]

The symptoms can be broadly categorised into three groups: *nausea*, *oculomotor*, and *disorientation* [3], [65]. The nausea-related category encompasses symptoms of gastrointestinal discomfort, such as nausea, stomach awareness, salivation, and burping. Oculomotor symptoms involve visual disturbances such as difficulty

focusing, blurred vision, and headaches. Disorientation-related symptoms are associated with vestibular disturbances such as dizziness and vertigo. [3] A chart of some of the prominent symptoms is illustrated in Figure 15, with a more thorough list presented in Section 5.2.

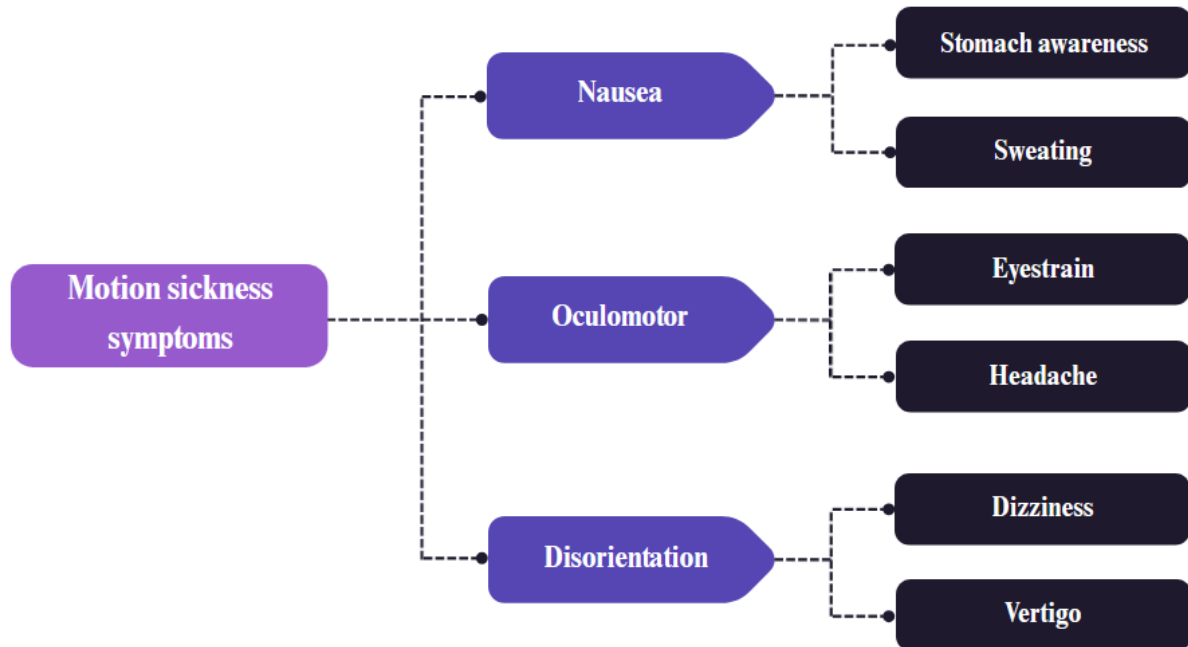


Figure 15: Some of the prominent symptoms of motion sickness associated with the different symptom types.

A lesser-known symptom of motion sickness, referred to as *sopite syndrome*, was first described by Graybiel and Knepton in 1976 [73]. It derives its name from the Latin word “sopire”, meaning “to put to sleep”. The symptom is associated with an increase in drowsiness, lethargy, yawning, apathy, and decreased concentration. Sopite syndrome has been reported both as the sole symptom of motion sickness, as well as in combination with symptoms discussed previously [3], [73]. Additionally, it has been typically observed to occur before the onset of nausea and may also persist after it. Consequently, sopite syndrome has been theorised as a possible explanation for the commonly observed phenomenon of rocking a baby to sleep. [73]

3.1.4 Measuring Motion Sickness

Motion sickness is commonly assessed using self-reported questionnaires designed to quantify a person’s susceptibility to the condition [51], [56], [3]. Several different types of questionnaires have been developed, including the *Pensacola Motion*

History Questionnaire from 1965 and the *Motion Sickness Questionnaire* from 1968. The latter was later used to derive a shorter *Motion Sickness Susceptibility Questionnaire* (MSSQ), which remains one of the most widely used types in the modern day. [51]

Self-reported measurement systems are, however, prone to varying types of biases. Although self-reports are frequently utilised in medical research due to their convenience and low cost, self-reporting biases are an inherent flaw of these methods. Furthermore, data gathered via these methods has been argued to lead to unreliable or misleading results, thereby threatening the validity of research [74]. As these methods are not flawless, it is important to understand the ways in which self-reports may distort data collection, particularly during data analysis. In an article on information bias in health research, Alaa Althubaiti identifies two types of self-reporting bias: *social desirability bias* and *recall bias*. [74]

The first type of bias is the social desirability bias, which can be observed in studies concerning sensitive topics, such as diet, income, or social standing. This may lead the participant to provide inaccurate data in an effort to present themselves more favourably. For example, the participant could underestimate their alcohol usage or overstate their social status. Overcoming social desirability bias can be accomplished either via internal or external methods. In the case of the participant underestimating their alcohol usage, an internal approach could be measuring their blood alcohol level, and an external method could be verifying their claims through friends or family. However, such validation checks may be challenging and time-consuming when dealing with large sample sizes. [74]

Measurement scales have been created specifically to address the social desirability bias, such as the *Marlowe-Crowne Social Desirability Scale* and the *Martin-Larsen Approval Motivation Score* [74]. For this study in particular, social desirability bias may have had an effect on the results, as a possible effect of social desirability bias would be participants reporting results they feel would be beneficial for the research being conducted. Additionally, as discussed previously in Section [3.1](#), women have frequently been observed to report higher incidences of motion sickness in comparison to men [51], [54], [58]. One explanation for this discrepancy could be the social desirability bias, as social pressure may lead men to downplay the severity of

their symptoms. However, motion sickness has also been observed to cause women to vomit more frequently than men [57], supporting the claim of an objective difference. Although social desirability bias is unlikely to be the primary cause of the discrepancy, it may still be a contributing factor.

The other type of self-reporting bias discussed in Althubati's article [74] is recall bias, which affects studies requiring participants to recall past events and may lead to inaccurate data, as a person's memories are seldom perfectly reliable. Recall bias is more common in medical research than social desirability bias, and it is especially common in dietary surveys where participants are required to recall past dietary intake. Negating recall bias may be accomplished by shortening recall periods, as it is easier to remember recent events, or by instructing participants to keep a diary of required information. [74] For this study, recall bias should not have an effect on the results, as the questionnaire is filled immediately after testing has been concluded. In addition to the post-experimental questionnaire, data about the symptoms are collected during testing as well.

The aforementioned reasons may suggest that self-reported data is unreliable, but it is nevertheless accurate enough to be useful when researching motion sickness. Consequently, self-reports remain the standard way to gather information in such research [51], [56]. Laboratory-based testing is also frequently used in motion sickness research, and it often takes advantage of a cross-coupling effect arising from a combination of passive rotation and head movement. Common laboratory tests include the *Coriolis Sickness Susceptibility Index test* and the *Staircase Velocity Motion test* [51]. A rotating chair capable of motion on one or more axes may also be used alongside these, as it is an effective method of inducing motion sickness. Military organisations and space agencies in particular utilise such chairs in their training [67], [68], [75], with motion sickness measured by the duration of movement until severe symptoms, such as vomiting, occur [51]. This method of data collection can be used to create a cumulative group rating, representing the percentage of participants who vomited, known as the *Motion Sickness Incidence* (MSI). [76]

A similar scale that may also be used is the Misery scale (MISC), which rates the participants' subjective misery throughout the experiment, rather than relying solely on the MSI. The MISC ranges from 0 to 10, with each number between the extremes

representing a different symptom. 1 represents uneasiness, 2-5 represent different severities for the milder symptoms (dizziness, warmth, headache, etc.), 6-9 represent different severities of nausea, and 10 represents vomiting. The primary benefits of using MISC over MSI as a measuring method are the ability to chart the severity of symptoms over time, as well as being able to measure sickness without requiring participants to vomit, as vomiting may not always occur. [76] However, this does not mean that MISC is a superior method to MSI, as MSI can still be effective as a cumulative group rating if the objective is to measure the rate of vomiting, for example. Furthermore, these methods are not mutually exclusive, and they can be used together. MISC does also have disadvantages, such as requiring participants to be able to recall which symptom each of the 10 numbers represents, which may take time to memorise.

If the misery scale is determined to be too complicated to implement, but a real-time scale for symptoms is still desired, the *Fast Motion Sickness scale* (FMS) may be employed. The FMS ranges from 0 to 20, with 0 representing no symptoms at all and 20 representing severe motion sickness, and the participants are asked to rate the severity of their symptoms every minute. [77] Because the FMS is easy to implement, it is advantageous to use it alongside post-experiment questionnaires whenever possible, helping to maximise the accuracy of data.

3.2 Types of Motion Sickness

Motion sickness is frequently categorised into several types based on its underlying causes, such as car sickness, sea sickness, or simulator sickness. [51], [54], [66]. For this thesis, however, the condition is divided into two primary categories according to the nature of inciting stimuli: *traditional motion sickness* and *visually induced motion sickness*. This division is deemed necessary because the underlying mechanics of these two forms differ enough to warrant a distinction. Consequently, this thesis is primarily concerned with visually induced motion sickness.

3.2.1 Traditional Motion Sickness

Traditional motion sickness refers to forms of motion sickness that arise from passive movement of the human body. It includes conditions such as car sickness, seasickness, airsickness, space motion sickness, and other forms where the affected

individual's vestibular system detects movement that is inconsistent with either their visual perception or their expectation of movement.

Induction of motion sickness is strongly influenced by the oscillation frequency. In a laboratory-based experiment conducted by O'Hanlon and McCauley [78], a cabin attached to vertical tracks on a 9-meter-tall tower was used to induce motion sickness. The cabin oscillated up and down at frequencies ranging from 0.083 to 0.500 Hz and an acceleration range of 0.025 to 0.40 g. Over 300 subjects were exposed to oscillatory motion for up to two hours, or until vomiting occurred. The results demonstrated that MSI peaked at 0.167 Hz and decreased as the frequency increased beyond this point. The highest rate of vomiting occurred at this frequency with an acceleration of 0.20 g. [78]

A low frequency at approximately 0.2 Hz, one full movement cycle per five seconds, has been cited in other publications as the peak of nauseogenicity [54], [56], [79]. This frequency coincides with the motion frequency of various modes of transportation, such as ships, planes, coaches, and camels, all of which commonly induce motion sickness. These findings suggest that motion sickness is more strongly influenced by the periodicity of movement, rather than the magnitude of acceleration. [79] Notably, being preoccupied with other activities, such as reading, increases the risk of motion sickness occurring [56], [66], [80].

While the oscillation frequencies discussed above are a dominant factor in air- and seasickness, the motion sickness induced by land vehicles is also influenced by frequent changes in acceleration, as well as stops, starts, and sharp turns. As a result, the passenger experiences varying degrees of lateral and vertical sway, which can further increase the severity of motion sickness. [79] Additionally, motion sickness in land vehicles has been noted to primarily affect passengers [56], [66], [81], [82]. As demonstrated by the previous experiment [78], as well as other literature [54], [56], [79], oscillation frequencies below 1 Hz are particularly nauseogenic. Consequently, suspension systems in land vehicles are commonly designed to create a resonant frequency between 1 and 2 Hz. Moreover, managing an upper limit for the frequency is important, as higher frequencies may result in increased ride discomfort. [79]

3.2.2 Visually Induced Motion Sickness

Visually Induced Motion Sickness (VIMS) differs from traditional motion sickness in terms of its underlying mechanisms. In contrast to traditional motion sickness, VIMS occurs primarily through visual stimuli that indicate movement but are not sensed by the vestibular system. In essence, traditional motion sickness involves movement that is sensed but not seen, whereas VIMS involves movement that is seen but not physically experienced. Common examples of VIMS include simulator sickness and cybersickness, also known as VR sickness. [3]

Although the given examples of VIMS are a result of relatively recent inventions, such as VR devices, VIMS has been observed since at least the late 1800s. An example of early research in VIMS comes from an article published by R. W. Wood in 1895 [83], where he described an optical illusion known as the “Haunted Swing”. The Haunted Swing consists of a cubic room with a swing in the middle where the participants are seated. Upon being seated, the surrounding room starts to rotate with increasing velocity, eventually completing a full rotation while the swing itself remains motionless. This creates an optical illusion of movement for the participants. [83]

Wood reported a feeling of leaning inwards during the backward swing, and involuntarily clutching the seat to prevent himself from falling off. Although Wood did not suffer from dizziness, other participants reported dizziness and nausea [83]. Notably, Wood noted that despite being fully aware of the mechanics of the Haunted Swing, it did not reduce his immersion in the illusion. He noted that repeated attendance while trying to reason against the illusion did not decrease the effect in a substantial way. [83] This observation suggests that the immersive effect behind VIMS is involuntary and is not substantially reduced by awareness of the mechanics behind the illusion.

This type of illusory sense of self-motion is also known as *vection*, and it is frequently associated with VIMS, although VIMS is not a necessity to experiencevection [84]. A typical example of a non-VIMS-relatedvection is the experience of sitting in an unmoving train and seeing an adjacent train start to move, causing a sensation of self-motion. An experiment conducted by Keshavarz et al. [85] aimed to investigate characteristics of visual motion stimuli and their relation tovection and VIMS. The

three characteristics of stimuli being investigated were speed, density, and axis of rotation. [85]

The experiment involved using a stereoscopic projection of a starfield, consisting of white dots of varying sizes on a black background. Two sections were included, with the first one involving linear forward movement in the starfield, and the second one incorporating rotations in yaw, pitch, or roll alongside the forward momentum. Data from a total of 20 participants was collected, of which 12 were men and 8 were women. Data collection for VIMS was done during the experiment with the FMS and after the experiment with the SSQ. Data on vection were collected with three measures: the onset time, intensity, and duration. [85]

The first experimental section found no significant effect on vection onset time caused by either stimulation speed or density. However, the results indicated a significant increase in vection duration with higher stimulus speed, regardless of stimulation density, which did not exhibit significant effects on vection duration. For vection intensity, both higher density and speed correlated significantly with a stronger sense of vection. FMS scores resulted in higher average scores with faster speeds, with fast speed and high density resulting in the highest sickness scores. However, SSQ scores were the highest with slow speed and high density, with high speed and high density resulting in the second highest SSQ scores. Calculating Pearson correlations between vection measures and VIMS resulted in non-significant correlations. [85]

Data from a total of 21 new participants with an age range of 18-36 were gathered for the second section. A significant effect on vection onset time was found, with rotation resulting in a faster onset. Out of the three rotation types (yaw, pitch, and roll), pitch exhibited the most significant effect on vection onset time. For vection intensity, both pitch and roll resulted in a significantly higher intensity in comparison to yaw and no rotation, which showed no substantial effects. Notably, the data did not indicate a substantial effect on vection duration by any of the rotation types. [85]

All rotation types showed a significant effect on FMS scores, with pitch rotation exhibiting the highest average score. Similarly, pitch rotation also resulted in the highest SSQ scores, with roll rotation being the second highest in both the FMS and the SSQ. No significant relationship between vection and sickness scores was found

in the second section either, as the parameters associated with an increase in vection were not found to substantially affect VIMS. [85] Prior research has indicated both a correlation [86], [87], [88], [89] and a lack of correlation between vection and VIMS [84], [90], [91], [92], suggesting a complex relationship between the two conditions. Figure 16 presents the two primary motion sickness categories and some of the prominent types of motion sickness associated with them.

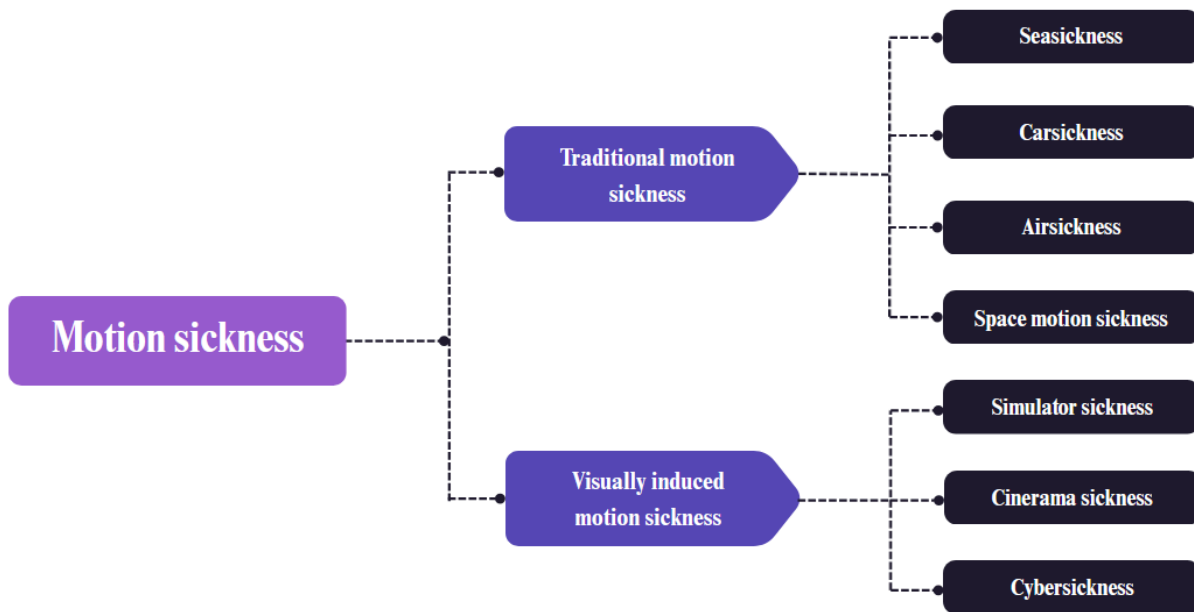


Figure 16: Some of the prominent types of motion sickness in the two main categories.

3.3 Mitigating Motion Sickness

Treatment of motion sickness is frequently divided into two primary categories: *behavioural* and *pharmacological* [54], [65], [93]. Each approach has advantages and disadvantages, such as behavioural therapy being more successful long term and lacking side effects, but requiring significantly more time for desensitisation to take effect [54], [93]. This thesis is mainly concerned with behavioural therapy, which, for the purposes of this thesis, has been further split into two categories: design and rehabilitation. The design category involves design strategies for motion sickness-inducing devices that help prevent the condition from occurring. Rehabilitation strategies encompass methods to increase tolerance towards motion sickness-inducing stimuli, such as exposure therapy. Pharmacological solutions are covered briefly, although they are not the focus of this thesis.

3.3.1 Designing for Mitigation

As a result of a rising interest in self-driving cars, research on traditional motion sickness has increased as well [66], [80]. Since drivers of conventional vehicles are in control of the motion, they typically exhibit fewer symptoms of motion sickness than passengers [56], [66], [81], [82]. With self-driving cars, however, the driver's control is reduced or entirely absent, thus making them more susceptible to the condition, much like the passengers in traditional vehicles. Furthermore, a key advantage of self-driving cars is allowing the driver to focus on other activities, such as work or entertainment, which has been shown to further increase susceptibility to motion sickness [56], [66], [80].

Alongside increased susceptibility arising from the ability to engage in external activities during movement, motion profiles have also been cited as a contributor to motion sickness [51], [66], [81]. As discussed in Section [3.2.1](#), motion sickness induced by land vehicles is associated with frequent changes in acceleration, as well as stops, starts, and sharp turns. [79] The lateral and vertical swaying caused by an individual's driving style has been shown to correlate with a higher rate of motion sickness, particularly in aggressive driving styles with sudden changes between accelerating and braking [66]. Due to self-driving cars being fully automated, removing unexpected sharp motions inherent in human driving styles is a key aspect of optimising the motion profiles to better account for motion sickness. Motion profiles should therefore aim to reduce lateral swaying and ensure smoother acceleration and braking patterns.

In addition, vehicle components such as the chassis and suspension system, as well as roads with frequent sharp turns at high velocities, further contribute to motion sickness by exposing the driver and passengers to the nauseogenic oscillation frequencies, lateral swaying, and frequent changes in acceleration discussed in Section [3.2.1](#). Therefore, another aspect of accommodating people with a susceptibility to motion sickness is by designing car components enabling a smoother passenger experience, which also applies to traditional cars as much as self-driving ones. The lateral swaying and the acceleration patterns caused by turns on the road may also be accounted for with the car's motion profiles by optimising for smoothness in turning, deceleration, and acceleration. This is a more reliable method

of mitigation for self-driving cars in comparison to traditional cars, due to automation removing human error in the driving style.

Alongside modifying oscillation and acceleration frequencies of the motion profile, as discussed in Section [3.2.1](#), another potential mitigation strategy is the use of anticipatory audio cues. As discussed in Section [3.1](#), motion sickness can arise from a discrepancy between sensed and expected motion. This observation suggests that the ability to accurately anticipate movement would reduce the occurrence of motion sickness. In a study on anticipatory audio cues in self-driving cars, Kuiper et al. [81] used a moving apparatus mounted on a 40-meter rail track, which moved back and forth while changing directions at unpredictable intervals. The moving platform had an enclosed cabin with a rally car seat and speakers inside. The participants were divided into two groups: one heard anticipatory audio cues 1 second before a change in motion, the other heard the same cues 2-6 seconds after the change. Of these two groups, the former reported significantly lower levels of motion sickness. [81]

Another study investigating the use of audio to mitigate motion sickness was conducted by Keshavarz and Hecht [65], who examined whether pleasant music could reduce VIMS. In their experiment, a video of a bicycle ride was used to induce motion sickness, while participants listened to music of different genres. Four groups were included, each of which listened to a different genre of music. Group A listened to relaxing instrumental music, group B listened to neutral pop music, group C listened to stressful electronic music, and group D was a control group that did not listen to music. The experiment used the fast motion sickness scale to get verbal measurements of symptom strengths every minute. The study observed groups A and B reporting significantly lower levels of VIMS in comparison to group D, with group C reporting levels higher than A and B but lower than D. [65]

The researchers proposed several explanations for these findings, noting that the results do not serve as definite proof that music works as a cure. One explanation is that the music distracted the participants enough to cause them to experience reduced levels of VIMS. By contrast, with regard to carsickness, engaging in distracting activities was found to increase symptoms [56], [66], [80], highlighting another key difference between traditional motion sickness and visually induced motion sickness. The difference is likely a result of the different mechanisms at the

root of the conditions, as traditional motion sickness includes physical movement, where possible distractions serve to exacerbate the visual-vestibular conflict. Conversely, physical movement is not a part of VIMS, as the induction of symptoms occurs primarily visually. Therefore, distractions would reduce symptoms by reducing the individual's exposure to the inducing stimuli.

Another explanation for the results of the aforementioned experiment is that pleasant music improved the participants' mood, potentially counteracting sopite syndrome. Although the exact cause of the results remains unclear, the results indicate that specific types of music help mitigate symptoms of VIMS more than others. [65]

3.3.2 Rehabilitation Therapy

Rehabilitation therapy for motion sickness primarily relies on repeated exposure [54], which has been shown to be an accessible and cost-effective method of mitigating the condition [66], [75], [94], [95], [96]. Such therapy can be implemented with either long-term or short-term strategies [54]. Long-term strategies typically involve rehabilitation programs used to train an individual's tolerance to motion sickness, and such programs are commonly employed by military organisations and space agencies during pilot training [67], [68], [75]. In contrast, short-term strategies involve smaller changes in behaviour, such as reducing head movement and keeping a stable view of the horizon. These strategies are easy to implement, as they do not require long habituation periods to be effective, although they are generally not as effective at reducing symptoms as long-term strategies. [54]

A significant advantage of rehabilitation therapy over anti-motion sickness medicine is the absence of side effects [54]. In contrast, anti-motion sickness medication has been reported to induce side effects such as drowsiness [54], [65], [66], [68], which may impair the performance of pilots if experienced mid-flight. However, long-term Rehabilitation therapy requires a significant time and effort investment, as tolerance to the condition develops gradually. Therefore, these strategies are less suitable for the general population, as their benefits are most apparent for individuals working in motion sickness-inducing environments.

As an example of a rehabilitation program for military pilots, a report released by Lucertini et al. [75] showcases the results of a program developed by the Italian Air

Force. The program's goal is to rehabilitate pilots at risk of dropping out of the pilot course as a consequence of their incapacitating airsickness. The report compares the results of military pilots requiring rehabilitation with pilots whose airsickness symptoms were either non-existent or small enough to be inconsequential.

This rehabilitation program uses a rotating chair to induce motion sickness in the participant, with the duration of exposure increasing on each subsequent session, up to 20 minutes. The participants are instructed to keep their eyes closed during movement in order to enhance the effectiveness of the induction method.

Furthermore, the Misery Scale is employed to continuously monitor the participant's symptoms and their severity. Sessions are held two to four times per day, depending on the participant's needs, and the program in total typically lasts for two weeks. [75]

The program has been effective in treating motion sickness, with 85% of the participants continuing and completing the flight program following rehabilitation. This aligns with the 86% success rate for the same flight program among pilots who did not require rehabilitation due to their lack of severe symptoms. Notably, the effects of the program appear to be long-lasting, with participants remaining less susceptible to motion sickness up to 8 years after the conclusion of the rehabilitation. [75]

3.3.3 Pharmacological solutions

As discussed in Section [3.1.1](#), much of the early research on mitigating motion sickness focused on identifying and developing pharmacological treatments [64], [67]. The medication can be divided into three categories: *antimuscarinics*, *H1 antihistamines*, and *sympathomimetics* [54], [93]. Although medications are generally effective, they typically carry the risk of side effects, such as drowsiness [54], [65], [66], [68]. However, side effects do not always occur, and their type and severity vary between individuals. Therefore, when considering anti-motion sickness medicine, it is important to weigh the potential impairments from side effects against the severity of the motion sickness symptoms.

Several naturally occurring herbs and spices have also been shown to reduce symptoms, such as *Zingiber officinale*, more commonly known as ginger [93], [97]. It has been used in traditional Chinese medicine to treat various conditions, such as asthma, constipation, and osteoarthritis. Furthermore, it possesses antiemetic

properties, making it an effective medicine for nausea and vomiting, as well as motion sickness. [93]

Alongside the symptoms listed earlier, motion sickness also inhibits gastric emptying [54], [69], which makes pharmacological solutions to the condition more challenging. Inhibited gastric emptying makes it more difficult for the body to absorb medication, especially when administered orally. This effect can be reduced by taking medication in advance, but it is not always possible to anticipate the onset of the condition. Moreover, anti-motion sickness medications can also inhibit gastric emptying, further limiting their effectiveness.

An experimental study conducted by Stewart et al. [69] investigated whether erythromycin, a prokinetic agent intended to facilitate gastric emptying, could be used to reverse the gastrostatic effect induced by motion sickness. The experiment included three groups taking different anti-motion sickness medications, after which motion sickness was induced in participants from each group with a rotating chair and a blindfold. Gastric emptying of the participants was assessed with nuclear medicine techniques. The results demonstrated that erythromycin reversed the gastrostatic effect of the anti-motion sickness medicine specifically, while being unsuccessful at reversing the gastrostatic effect when it was caused by motion sickness instead. This finding suggests that the effect has different underlying mechanisms depending on its cause. [69]

3.4 Introduction to Cybersickness

Cybersickness, also known as VR sickness, is a type of motion sickness specifically induced by VR devices. It typically falls under the category of VIMS, as it is primarily caused by visual stimuli, rather than physical movement. As it is a form of VIMS, it is closely related to simulator sickness. Therefore, the *Simulator Sickness Questionnaire* (SSQ) is typically used to assess symptoms in cybersickness studies. In a paper published by Chang et al. [98], it was found that in the 77 studies on cybersickness conducted between 1992 and 2019, 58 of them used the SSQ as a measurement scale. The second most used scale was the FMS, used in 6 articles. As the questionnaire is subjectively self-reported, the self-reporting biases mentioned in Section [3.1.4](#) may have an effect on the result. Other, more objective, ways to measure cybersickness include tracking physiological changes, such as heart rate,

blink rate, changes in skin temperature, and EEG power bands. SSQ does, however, remain the primary method of measuring symptoms due to it being much easier and cheaper to implement in comparison to more objective measuring systems.

Cybersickness is a big factor limiting the wider adoption of the technology, as between 20% to 80% of users experience symptoms similar to traditional motion sickness [99], thereby reducing user enjoyment, making them potentially less likely to use VR in the future [100]. Furthermore, symptoms caused by cybersickness tend to be more severe than those of other motion sickness types [101], likely as a result of VR being relatively inaccessible to the average person. As discussed in Section [3.3.2](#), rehabilitation therapy and repeated exposure are effective ways of treating motion sickness through building an immunity to the condition. Because the average person is less likely to have extensive experience with VR, they are also less likely to have developed any tolerance to cybersickness. Moreover, cybersickness symptoms tend to have a shorter exposure time in comparison to other forms of motion sickness [100], likely for similar reasons.

The symptom profiles of cybersickness also tend to differ from other types of motion sickness [99], [101]. The SSQ is typically divided into the three symptom categories mentioned in Section [3.1.3](#): nausea, disorientation, and oculomotor. Studies on cybersickness tend to report a symptom profile of $D > N > O$, meaning that disorientation is more severe and frequent than nausea, and nausea is more severe and frequent than oculomotor [99], [100], [101], [102]. Other forms of motion sickness tend to have differing symptom profiles, such as simulator sickness with $O > N > D$, seasickness with $N > O > D$, and space sickness with $N > D > O$ [99]. Moreover, symptoms caused by cybersickness may last for several hours after exposure, thereby limiting the individual's ability to perform other tasks [99], [100].

3.5 Research on Mitigating Cybersickness

Strategies for mitigating cybersickness tend to fall under the category of designing for mitigation, discussed in Section [3.3.1](#). Techniques such as novel software-based control schemes and visual effects manipulations, are frequently used. In addition, new types of controllers, such as an omnidirectional treadmill or a full-body tracking suit. One software-based solution is a technique called *Redirected Walking* (RDW), which enables the usage of much larger virtual spaces in comparison to the physical

play space. This is achieved by manipulating the virtual environment, causing the user to adjust their physical orientation. An implementation could, for example, involve the user manually pressing and holding a button on a handheld controller, locking the rotation of their virtual avatar in place. The user can then rotate physically to reorient themselves in the physical space while keeping their virtual self facing in one direction. This enables the user to keep walking endlessly in one direction in the virtual environment, while being constrained to a limited physical play area, as they are able to rotate physically whenever they reach the limit of their play space without affecting their orientation in the virtual environment. [2], [103], [104], [105]

The technique can be used either in an *imperceptible* (virtual environment is adjusted automatically during locomotion in an unnoticeable way) or a *perceptible* (adjustments are noticeable to the user) way. Imperceptible manipulation is generally considered more immersive and thus more desirable. [103] Furthermore, RDW technology can also be categorised based on the manipulated object, which can be either *perceptual manipulation* (manipulation focuses primarily on visual elements during locomotion) or *virtual space manipulation* (adjusting the virtual environment around the player). [103], [105]

An experiment conducted by Tang et al. [103] investigated the usage of perceptible perceptual manipulation to mitigate cybersickness. The following three controller design schemes were used in the experiment, with continuous forward momentum via handheld controllers being utilised for locomotion in each control scheme. [103]

1. Adjusting the angle of the user's view either upwards or downwards based on their acceleration or deceleration speed.
2. Similar to design scheme 1, but also incorporates the Field of View (FoV) adjustment during acceleration and deceleration.
3. Requires the user to physically accelerate their body to adjust acceleration speed in the virtual environment.

These three schemes are used alongside two basic control schemes, where one involves simple continuous forward momentum, and the other extends the functionality to include an acceleration period before reaching maximum speed. By comparison, the first method achieves maximum speed instantaneously. The

participants were required to progress through a virtual track using each control scheme, with SSQ being used to track symptoms. [103]

A total of 30 participants, with an equal distribution of 15 men and 15 women, took part in the experiment. The experiment found that adjusting the user's view downwards during acceleration and upwards during deceleration resulted in the lowest sickness score, while the inverse (upwards during acceleration, downwards during deceleration) was found to slightly increase symptoms. Furthermore, increasing FoV during acceleration and decreasing it during deceleration was also found to lower sickness scores, while the inverse again resulted in the highest sickness scores of any mitigation method. Finally, in the third control scheme, the results indicated that requiring a physical head movement forward to accelerate resulted in a slightly decreased sickness score, while requiring a similar movement in the opposite direction resulted in a slightly increased sickness score. Of the two basic control schemes not involving visual manipulation, the first one not involving an acceleration time resulted in slightly higher sickness scores, while an additional acceleration time slightly reduced symptoms. [103] A summary of the findings is presented in Table [1](#).

In the analysis section, imitation of passive running leans was presented as a possible reason for reduced symptoms with a downward slanting camera view during acceleration. The aim of the design scheme was that the visual manipulation of the camera would result in the user subconsciously adjusting their head rotation, causing a similar head movement to accelerating while running. This was then theorised to reduce the sensory conflict, thereby reducing symptoms of cybersickness. Similarly, increasing the FoV during acceleration was found to decrease discomfort by reducing perceived visual acceleration. The difficulty adjusting to the control scheme was given as a possible reason for the less effective third control scheme, which required physical head movement to accelerate in the virtual environment. [92]

Method	Scenario 1	Scenario 2
View angle adjustment	Downwards during acceleration Upwards during deceleration Resulted in decreased symptoms	Upwards during acceleration Downwards during deceleration Resulted in increased symptoms
Dynamic FoV adjustment	Increased during acceleration Decreased during deceleration Resulted in decreased symptoms	Decreased during acceleration Decreased during deceleration Resulted in increased symptoms
Physical head movement to accelerate	Forward movement Resulted in decreased symptoms	Backwards head Resulted in increased symptoms
Controller-based locomotion with no visual modification	Acceleration time before reaching maximum velocity Resulted in decreased symptoms	No acceleration time, with maximum speed reached instantaneously Resulted in increased symptoms

Table 1: A summary of the findings in the RDW experiment by Tang et al. [103]

Alongside novel control methods, visual manipulations are another software-based solution to design applications against motion sickness. These visual manipulations frequently involve modifying the user's peripheral view to include different effects, such as a *circle effect* and a *dot effect*, as labelled by Buhler et al. [106] in their experiment on reducing cybersickness through peripheral visual effects. The experiment aimed to compare two different visual modifications and their effect on cybersickness. The first of these modification methods was the circle effect, where, when movement begins, the user's camera view is split into two: The outer peripheral camera, which stood still and was locked into showing the view from when the user was standing still, and the inner camera, which displayed the actual movement in a circular camera view. When the user stopped moving, the outer camera view faded

into the inner one. Both cybersickness mitigation techniques can be seen in Figure [17](#). [106]



Figure 17: The circle effect (left) and the dot effect (right) used in the experiment by Buhler et al. [106]

The second modification was called the dot effect, which displayed a starfield-like dot pattern superimposed on the user's peripheral view during movement. The movement of the dots was designed to counteract the motion in the user's peripheral view to cancel out the optical flow, thereby reducing the sensory conflict as the user's peripheral appeared to involve zero motion. [106]

The experiment involved 18 participants being exposed to both the visual modifications, as well as a control condition with no visual modifications, for 5 minutes at a time. The objective in the virtual environment was to collect 20 sequentially ordered boxes, with symptom data being collected using the FMS. The outcome of the experiment indicated that both the circle effect and dot effect were able to reduce symptoms in comparison to the control effect, but the difference was too small to be statistically significant. Of the two visual modifications, the circle method was more effective at reducing symptoms. A potential reason for the circle effect being more effective is that it was more effective at reducing motion in the user's peripheral view, as it involved a completely still-standing camera view, whereas the dot-effect still showed motion but with a counteracting secondary motion effect superimposed over it. [106]

Another experiment involving peripheral visual modifications was conducted by Groth et al. [4] to compare the effectiveness of two methods based on eye tracking and virtual movement to manipulate the peripheral view. The first mitigation method, called *peripheral blurring*, gradually blurred the user's peripheral view in a circular shape. The diameter of the blur circle was affected by the user's velocity, whereas the intensity of the blur was modified with the eye tracking technology, with a higher intensity whenever the user was looking further away in the virtual environment. The second method, called *field of view reduction*, simply greyed out the peripheral view in a similar circular shape as the peripheral blur, with the diameter again being controlled by the user's movement. Both mitigation methods can be seen in Figure 18. A control condition with no visual modifications was also included. [4]

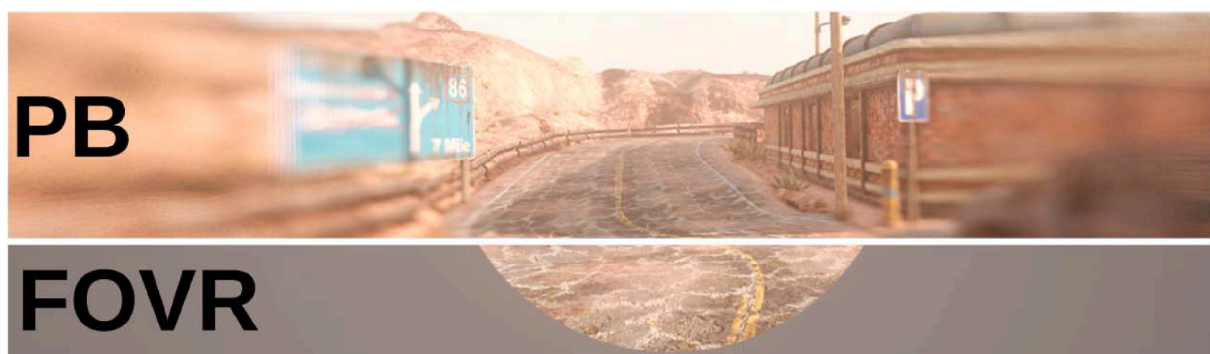


Figure 18: Peripheral blurring (above) and field of view reduction (below), used in the experiment by Groth et al. [4]

A total of 19 participants took part in the experiment, with symptom data being collected using the SSQ. The results indicated that both methods were able to reduce symptoms of cybersickness, with the field of view reduction being more effective of the two. Similar to the earlier experiment conducted by Buhler et al. [106], the method involving blocking out all peripheral motion was found to be more effective, as peripheral blurring still displays some motion, although the blurring makes it more ambiguous. [4] Taken together, the results of both experiments suggest peripheral motion to be a key factor in exacerbating the sensory conflict causing cybersickness, therefore limiting the peripheral view would be a simple way to reduce the sensory conflict. A summary of the different visual modification techniques can be seen in Table 2.

Name	Description
Circle effect	The peripheral shows a different still-standing camera during movement. When movement stops, the still camera fades into the centre camera.
Dot effect	Added artificial motion in the peripheral view, counteracting the virtual motion.
Peripheral blurring	Gradually blurs the peripheral view during movement based on the distance to the eye-tracked viewing point.
Field of view reduction	Blocks out the peripheral view with a grey circle during movement.

Table 2: The visual modification techniques for cybersickness mitigation used in the experiments by Buhler et al. [106] and Groth et al. [4]

While the above experiments investigated a software-based solution, hardware-based ones tend to utilise novel controller technology to reduce the sensory conflict. In an experiment conducted by Dopsaj et al. [107], a neurodigital interface known as *C-Infinity*, seen in Figure 19, was compared against a traditional gaming controller to determine its effectiveness in alleviating symptoms of cybersickness. The interface enables multisensory inputs with a full-body control scheme by utilising motion sensors and haptic feedback in a standing position. The interface is operated by standing on a platform and utilising controllers built into the handrests on both sides of the user. Rotational upper-body movement may also be used for further control in the virtual environment. The *C-Infinity* is compared against a traditional Xbox 360 video game controller. [107]

The experiment included 12 participants, all of whom were male. They were instructed to travel through a virtual underground parking garage, designed to guide them through an optimal route. The participants were allowed to move in whichever way felt the most pleasant for them, and each session was limited to 3 minutes, as this was determined by the researchers to be the length of exposure required to

cause a potential onset of cybersickness. Objective data were collected on general muscle isometric strength potential through hand grip testing, and cardiovascular and metabolic effects through lactate concentration measurement from capillary blood, as well as heart rate monitoring. Data on nausea were collected through a more subjective self-reported nausea assessment questionnaire. Data was measured both before and after each session with both the C-Infinity interface and the Xbox 360 gamepad. [107]



Figure 19: The C-Infinity neurodigital interface, created by NeuroSync Laboratories. [108]

The subjective self-reports of nausea after each session were primarily used to measure three aspects of cybersickness: the duration, intensity, and quantity of the symptoms and sensations of nausea. Comparing the C-Infinity against the gamepad, the C-Infinity exhibited a 47.9% improvement in duration of nausea, measured by requesting the participant to state a measurement of nausea on a scale of 1 (minimal symptoms) to 5 (maximal symptoms) in 30-second intervals after the experiment. A 27.4% improvement in the intensity of nausea was reported, which was measured using the highest value of the 1 to 5 scale, with 0.5 point increments. Lastly, a 36.2% improvement was reported in the quantity of nausea, measured by multiplying the intensity by duration. [107]

The results indicate that novel controller technology requiring more physical movement from the user to operate the VR device may be effective at mitigating cybersickness. This may be due to a reduction in the sensory conflict, as the physical

movements by the user would more closely match the visual input from the HMD. Thus, there is a decrease in the mismatch between the visual and the vestibular systems. However, the 3-minute-long duration of exposure to the VR environment was significantly shorter than is usual for experiments on motion sickness, which tend to range from approximately 10 to 30 minutes [3], [51], [75], [109], [110], therefore the data may not be fully reliable. A chart of the different cybersickness mitigation techniques discussed in this Section is presented in Figure 20.

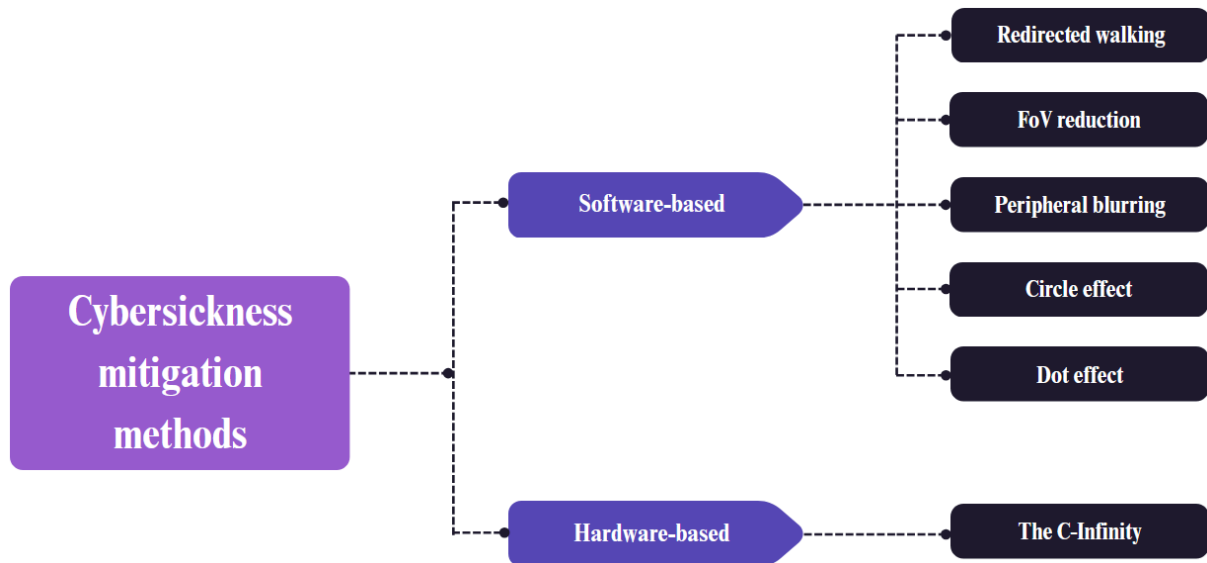


Figure 20: Some examples of cybersickness mitigation techniques with a focus on software-based approaches.

The distinct symptom profile, the relative severity of symptoms in comparison to other forms of motion sickness, and being a limiting factor in a wider adoption of VR technology all serve to highlight the importance of developing effective mitigation strategies for cybersickness. While previous research has been able to identify factors contributing to the condition, further research is still needed in order to identify more effective methods of mitigation.

The advancement of VR technology has enabled new potential ways to help individuals with a susceptibility to cybersickness. One of these developments is camera passthrough, which enables the device to use its internal cameras to display the user's physical surroundings while using the device. This technology allows the user to maintain awareness of their physical environment while wearing the VR headset. An experiment was conducted for this thesis to investigate a software-based solution utilising camera passthrough, and whether the technology

could be used effectively to mitigate cybersickness. The following Chapter describes the design and the implementation of the experiment.

4 Experiment Design and Implementation

The goal of the experiment was to compare the effectiveness of two motion sickness mitigation methods based on peripheral visual modifications. As indicated by the experiments conducted by Buhler et al. [106] and Groth et al. [4], fully blocking out the user's peripheral view during movement appeared more effective than more subtle visual modifications. Therefore, both of the mitigation methods used in this experiment involve blocking out the user's peripheral view with different techniques.

The first method utilised camera passthrough to display the user's physical surroundings in their peripheral view during movement, as can be seen in Figure [21](#).

The size of the passthrough area was dynamically adjusted based on the user's velocity in the virtual environment, with faster velocity resulting in a smaller field of view and increased visibility of their physical surroundings. Dynamic adjustment based on velocity was chosen because higher velocity results in a greater optical flow, potentially leading to stronger stimulation for motion sickness. Therefore, it stands to reason that stronger mitigation should be used with higher velocity.

Furthermore, the experiment conducted by Tang et al. [92] indicated positive results for dynamic FoV adjustment. Another way of implementing these mitigation methods would be a static implementation, in which the methods would remain at the same size regardless of locomotion speed. However, to limit the number of variables, comparisons between static and dynamic variations of each mitigation method were not done, although some sections of the experiment resemble static mitigation.

The underlying hypothesis for this mitigation method was that providing the user with a visual of their physical surroundings during movement would create a grounding effect, thereby reducing the sensory conflict caused by movement in a virtual environment. This approach is a software-based solution that falls under the category of "designing for mitigation", as discussed in Section [3.3.1](#).



Figure 21: Camera passthrough at maximum strength. The Meta Quest 3 screenshots are taken from the point of view of the left eye, therefore the image appears slightly offset from the centre.

The second mitigation method involved the use of a black vignette to reduce the user's field of view during movement, as illustrated in Figure [22](#). The black colour for the method was chosen due to it blending better with the user's physical peripheral view of the insides of the VR device, which appears black due to the lack of lights. Similar to the passthrough approach, the size of the vignette was dynamically adjusted based on the user's velocity, with a higher velocity resulting in a narrower field of view. This method is functionally similar to the field of view reduction method used in the experiment by Groth et al. [4], with the main difference being the colour, as this experiment uses a black circle while Groth et al. [4] used a grey circle. In addition, the edges of this black vignette are blurred slightly to better blend it with the main view, whereas the grey field of view reduction technique utilises sharper transitions between the camera and the circle.

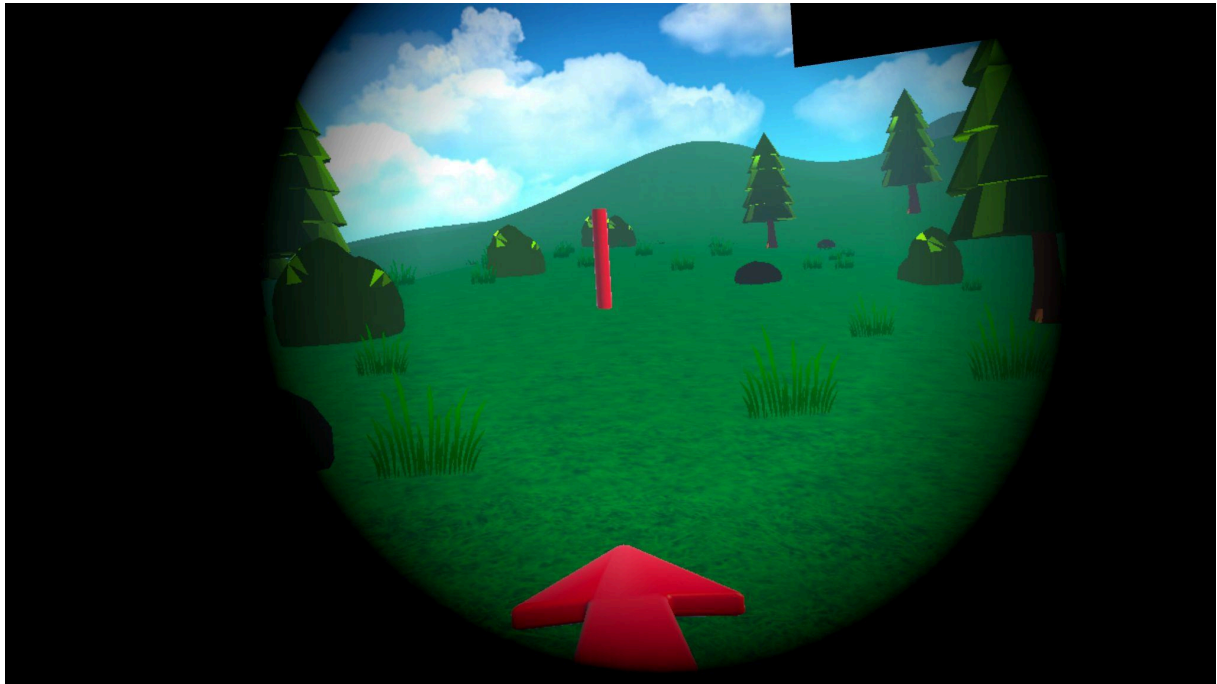


Figure 22: Vignette tunnelling at maximum strength.

This type of strategy is commonly offered as an accessibility option in some applications [7], [8], therefore it was deemed a good point of comparison, as the passthrough method used in this experiment closely resembles it in shape and functionality. Furthermore, Unity provides a tunnelling vignette as a default component in the *XR Interaction Toolkit* [111]. However, to ensure consistency with the passthrough approach, a modified vignette controller was implemented for this experiment. The default vignette controller's size does not scale with the user's velocity, instead utilising a simpler binary logic in which the vignette activates during movement and deactivates when movement stops, resulting in a constant maximum vignette size during movement. The modification was applied to the vignette in order for it to also be dynamically adjusted based on velocity.

The reasoning for using vignette tunnelling as a point of comparison is due to the similarities in how they function. Both methods activate during movement and fill an equal amount of screen space in a similar circular shape. While vignette tunnelling is an already established method for mitigating motion sickness [4], [5], [6], due to developments in passthrough technology, it is now possible to implement similar circular FoV tunnelling techniques using passthrough, therefore it is worth researching whether it could be more efficient over earlier methods.

4.1 Virtual Reality Environment

The VR environment used in the experiment consisted of four experimental sections (ES) with progressively varying levels of motion sickness-inducing stimuli. The gradual increase in intensity was deliberately chosen so as not to overwhelm the participant immediately, and to also get a more accurate view of the more basic stimuli. If the experience had started with the most intense ES first, it may have had a large effect on the results of the low-intensity ES, thus it was determined that a gradual increase would likely offer the most accurate symptom results for each ES. The track was also purposefully designed to induce cybersickness in the participants, therefore the symptom severities may be stronger than in a typical use-case scenario.

ES1 involved the participant walking through a forest at ground level, following a path marked by red poles. The path formed a zigzag pattern, requiring the participant to turn frequently. This ES provided a basic low-intensity VR experience. Furthermore, continuous controller-based forward momentum is one of the more common methods of movement in VR, thus combining it with a nature-themed VR scenario created a familiar and easy-to-understand use-case for VR. A screenshot from ES1 can be seen in Figure [23](#).



Figure 23: The end point of the ground-level walking section (ES1). The ES2 starting point is visible in the distance.

ES2 required the participant to ascend via an elevator, presented in Figure 24, to a platform located at high elevation on top of a mountain. The elevator provided variation in both the movement mechanics and the activation of the mitigation method in comparison to ES1. The difference in movement came from the moving platform affecting the participant's position in the virtual environment. The goal was to see whether symptoms of cybersickness would be different if primary movement happens passively outside the participant's control. The participant was also able to move within the boundaries of the moving platform, functioning as secondary movement, as this movement was inconsequential to whether the participant was able to reach the end of the ES. Because the mitigation methods were activated automatically as controlled by the participant's velocity, the methods were active during the entire elevator ride regardless of how much controller movement was utilised. Therefore, the experience was similar to a static variation of the method.

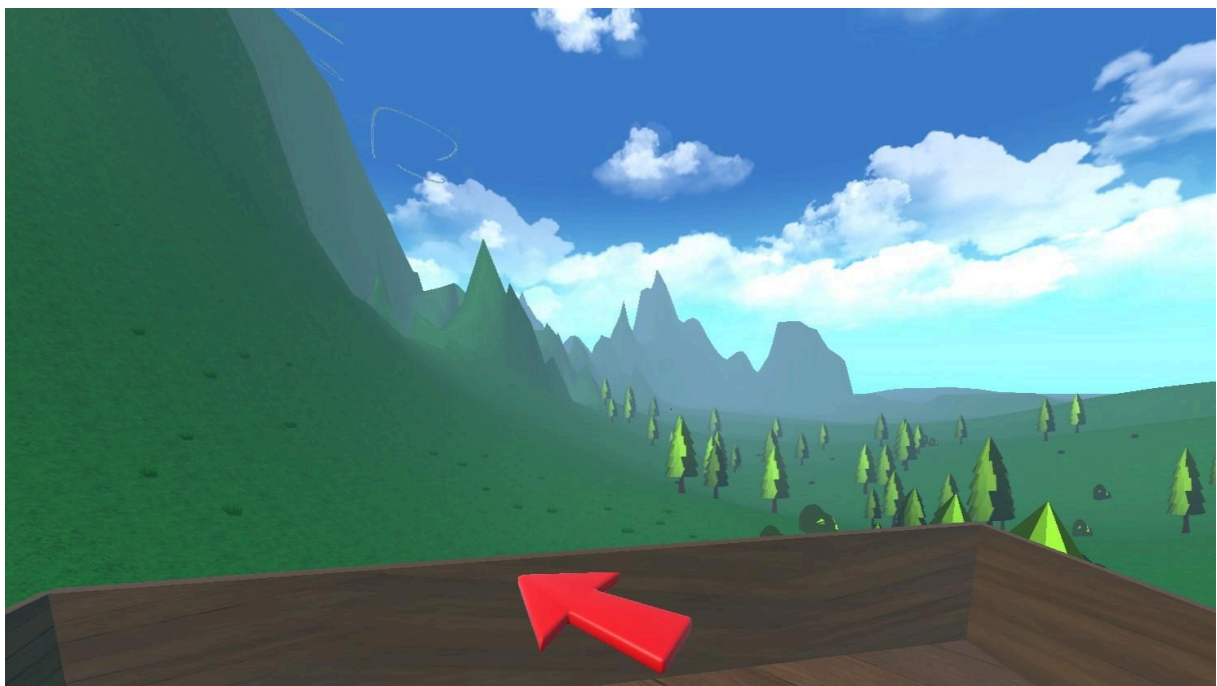


Figure 24: Standing on the moving elevator during ES2.

ES3 involved traversing across bridges in a mountainous environment, as well as a fall to a lower platform, followed by a short elevator transition to the final ES. This ES provided a more intense variation of a basic movement scenario in comparison to ES1. The aim was to evoke a sense of tension through high elevation, narrow bridges, and a drop from high elevation to see whether the increased tension has an effect on symptoms of cybersickness. Furthermore, prior research has suggested

that virtual environments associated with a higher heart rate and blood pressure, such as horror games, correlate with higher levels of motion sickness [112]. Therefore, including an ES with a heightened sense of tension, which might increase the participant's heart rate and blood pressure, was deemed important, as it helps cover a wider range of use cases, although heart rate and blood pressure were not being measured during the experiment. A screenshot from ES3 is presented in Figure 25.

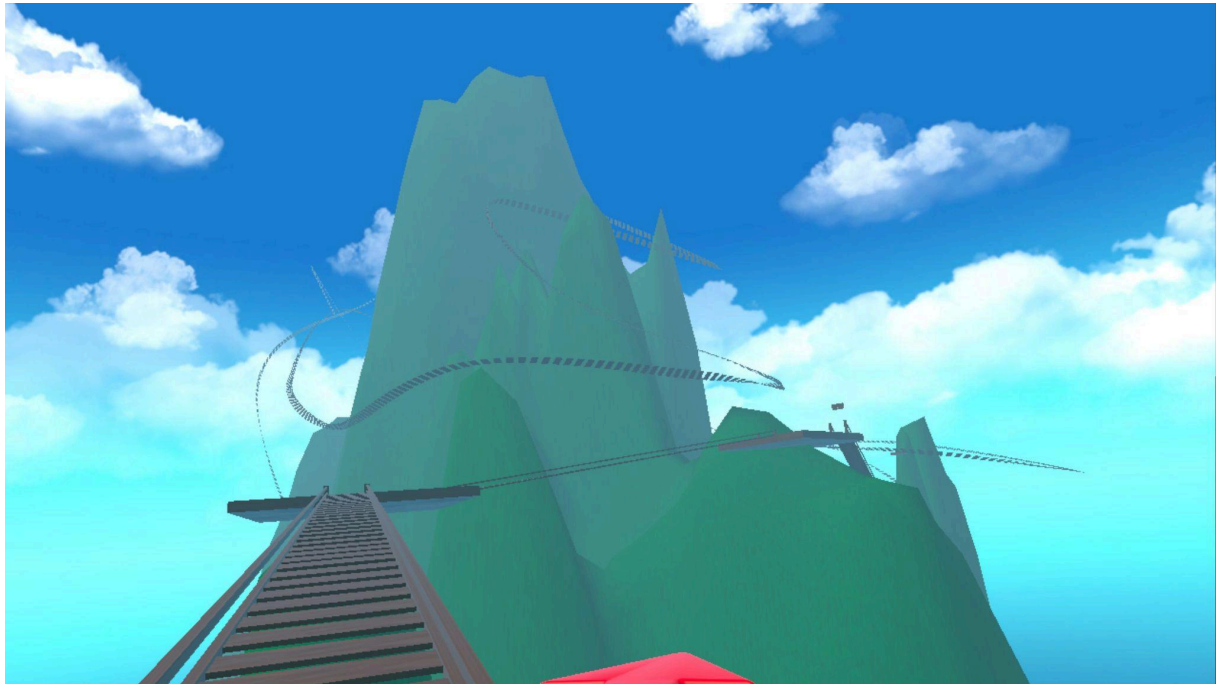


Figure 25: Walking across the mountains during ES3.

ES4 consisted of a rollercoaster ride, as illustrated in Figure 26, intended to induce a high level of motion sickness. The rollercoaster is among the classic VR experiences frequently used to showcase the capabilities of a device, the level of immersion VR is able to evoke, as well as to induce cybersickness in experiments [113], [114], [115], [116], [117]. Due to its high velocity combined with sharp turns and spins, it is an effective method to induce a high level of motion sickness in the participant.

Therefore, it stands to reason that a rollercoaster section was included as the most intense ES of the experiment. In addition, for this ES, the mitigation methods had to be activated manually instead of being activated automatically during movement. The methods were activated by pushing the controller joysticks forward, similarly to the movement controls. The reason for this was to determine whether, and at what strength, the participants tended to use mitigation if it was voluntary.

Each ES was completed twice before proceeding to the next one, once with each MS mitigation method. This was to keep the MS induction method, as well as the intensity level of the experience, consistent between each mitigation method. If the participant had completed the entire track with one method before switching to the other, it is likely that the ES4 from mitigation A would have affected the ES1 with mitigation B, providing inaccurate sickness scores. ES4 was completed three times, with the final completion conducted without any mitigation methods. This served as a control condition to determine whether the sickness scores with mitigation were notably lower than those without mitigation.

Furthermore, implementing a round without mitigation only with the most intense ES functions as a check for potential cybersickness immunity in case a participant exhibits no symptoms in any prior ES. If the participant does not exhibit any symptoms in the ES4 round lacking mitigation, then it is possible they may have developed a significant tolerance to cybersickness. If it is the only ES where they exhibit symptoms, then it indicates that the mitigation methods were effective. In addition, a control group was included in which participants completed each ES multiple times without any mitigation methods. Completing each ES multiple times was deemed necessary in order for control groups to be exposed to VR for comparable amounts of time to the mitigation groups.

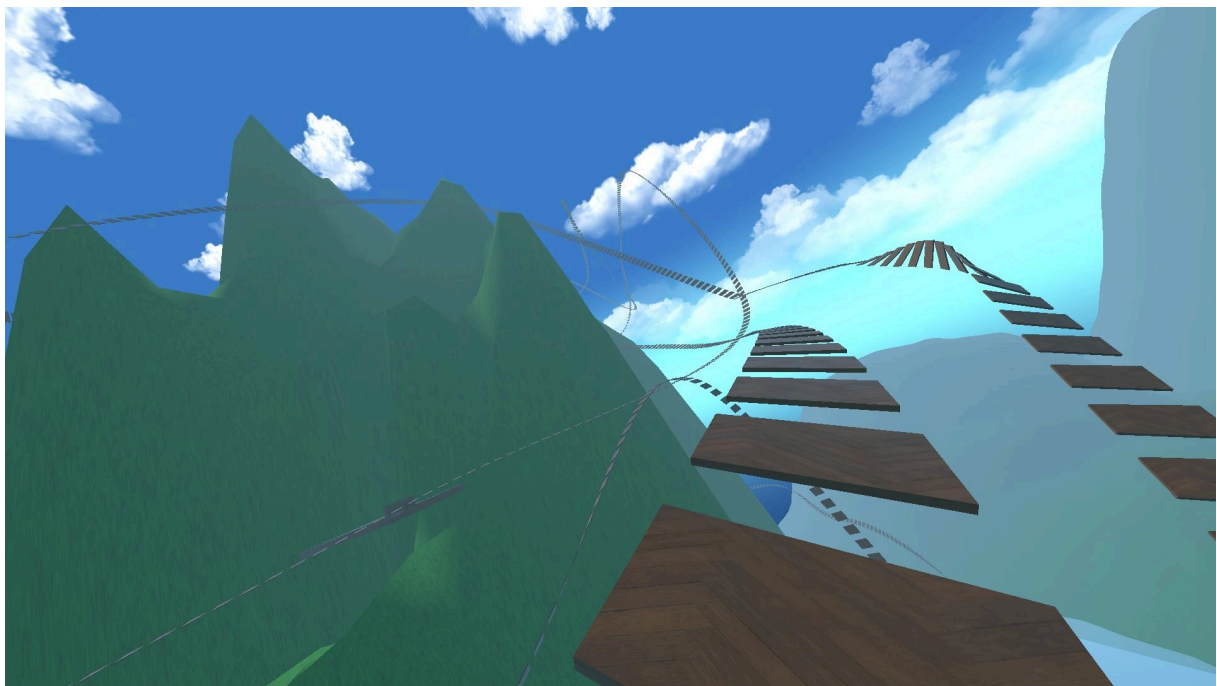


Figure 26: Riding a rollercoaster during ES4.

The VR environment was developed using Unity due to its compatibility with a wide range of VR devices. As a result of its popularity among VR developers, Unity provides extensive documentation and ready-made developer packages. Specifically, the Unity version 2022.3.56f1 [118] was used due to previous familiarity with the version. The environment was developed specifically with the capabilities of the Meta Quest 3 in mind, which was also used in the experiment. The device was selected for the experiment due to its camera passthrough capabilities, which support a full range of colours. In comparison, the passthrough in the earlier Meta Quest 2 is limited to greyscale, leading to a potentially less immersive passthrough image.

The virtual environment was made to resemble a forested area surrounding a mountain. A naturalistic environment was chosen both for its simplicity and to achieve an immersive feeling in the user. The environment offers fewer distractions in comparison to, for example, an urban environment, therefore enabling the participant to be more focused on the movement mechanics and their effect on the participant. Consequently, the environment would more closely resemble a typical VR experience in comparison to other simple environments, such as a textureless environment only utilising Unity's default gameobjects, therefore giving a more accurate view of symptoms in a typical use case. Moreover, a natural environment would create more immersion, thus engaging the participant and making them more present in the experience. The different sections of the experiment, such as the mountain and rollercoaster sections, rely heavily on immersion due to their aim of evoking a fear of heights alongside motion sickness. Thus, a natural and immersive environment is ideal. The paths and the approximate locations of the different experimental sections are presented in Figure [27](#).

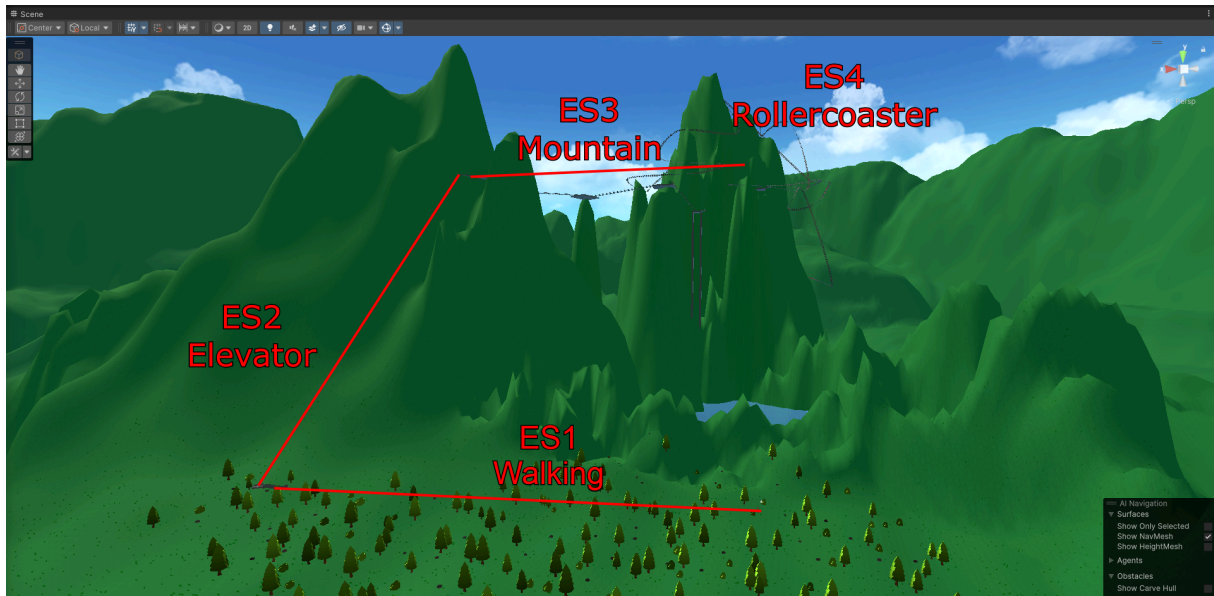


Figure 27: Direct paths across each experimental section showcasing the locations and their relation to each other. ES1 was a low-intensity walking section on ground level across a forested area. ES2 was an elevator section ascending to the top of a mountain. ES3 was a walking section across a mountain environment involving a drop from a high elevation. ES4 was a rollercoaster section. Both ES1 and ES3 utilised controller-directed forward momentum as the primary locomotion method, whereas ES2 and ES4 utilised a moving platform instead.

The movement system implemented in the experiment was continuous controller-based movement (see Section 2.2), using the *XR Origin* [119] with the *ContinuousMoveProvider* [120] and the *ContinuousTurnProvider* [121] scripts, all offered by Unity. Participants used two handheld controllers, one for each hand, each of which was equipped with an analogue joystick. The virtual avatar's movement was controlled by pushing forward or backwards on either one or both joysticks. Simultaneous use of both joysticks increased the avatar's velocity up to double that of a single joystick. Both controllers could also be used to rotate the avatar by pushing the joysticks sideways.

The *OVRCameraRig* [122] offered by Meta was used to create the passthrough functionality. It involved creating a flat plane in Blender with a hole in the middle, and positioning the plane in front of the camera, as shown in Figure 28. The size of the plane is scaled based on the user's velocity. The *OVRCameraRig* includes a script called *OVRPassthroughLayer* [123], which can be applied to a gameobject, in this case the flat plane, to enable camera passthrough on the object.

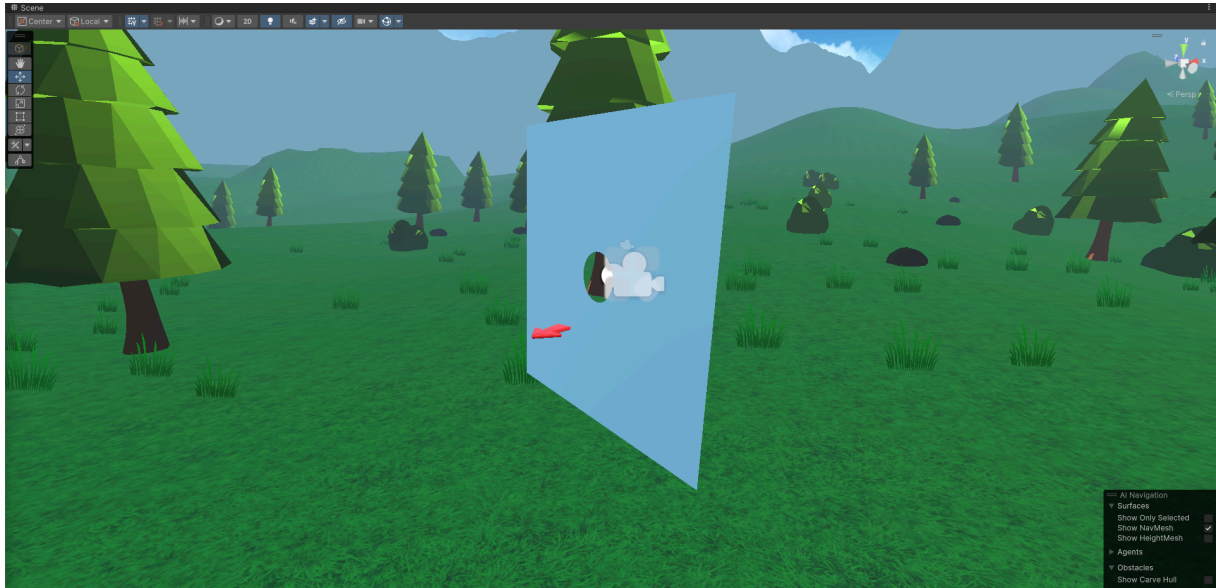


Figure 28: Screenshot from the Unity scene view showing how the passthrough plane was implemented before passthrough functionality was added to the plane.

In the initial design, only the left controller could be used for movement while the right controller was reserved for turning. However, preliminary testing indicated that enabling movement with both controllers, doubling velocity when both are used, allowed for greater flexibility in controlling the avatar's movement. Furthermore, it resulted in a more consistent control scheme for both left- and right-handed users.

As discussed in Section [3.3.1](#), prior research has suggested that pleasant music may reduce motion sickness, possibly by offering a distraction or by positively influencing the participant's mood. To minimise potential confounding variables affecting the experimental outcome, both the audio design and the user interface were kept to a minimum in order to reduce cognitive load. Therefore, the virtual environment does not include any music or other non-essential sounds. The user interface is limited to a compass-like directional arrow superimposed on the participant's field of view, which serves as a navigation aid throughout the course.

4.2 Experiment Environment

The experiment was conducted in the mixed reality laboratory at the University of Turku. The laboratory contains approximately 9 m² of unobstructed testing space, with adjustable lighting. The Meta Quest 3 was used for the experiment, alongside its 2 native controllers. The headset features passthrough capabilities with a full range of colours using 2 18 pixels-per-degree passthrough cameras, 6 DoF inside-out

tracking via 4 internal cameras, 2064x2208 pixels per eye at 72-120 Hz refresh rate, 110° horizontal and 96° vertical FoV. [124] Figure 29 shows a picture from the laboratory alongside the VR device used in the experiment.

For the virtual environment, *Low Poly Trees Pack Lite - Free Stylized Nature & Environment Assets* by Hiroba Games [125] was used to add trees, rocks, and bushes to the scenery, with additional grass details from *Low Poly Environment - Nature Free - LOWPOLY MEDIEVAL FANTASY SERIES* by Polytope Studio [126]. The elevators and the rope bridges in the mountain section were built using several of the default cube gameobjects in Unity, with the *Free Parquet Texture* by Eustace [127] applied to them to make them more aesthetically pleasing. Furthermore, the cube objects with the same texture were also used to create the rollercoaster track, which utilised Unity's *Spline* feature to connect them together into a smoothly functioning track. *Fantasy Skybox FREE* by Render Knight [128] was used to add a clear blue sky to the environment.

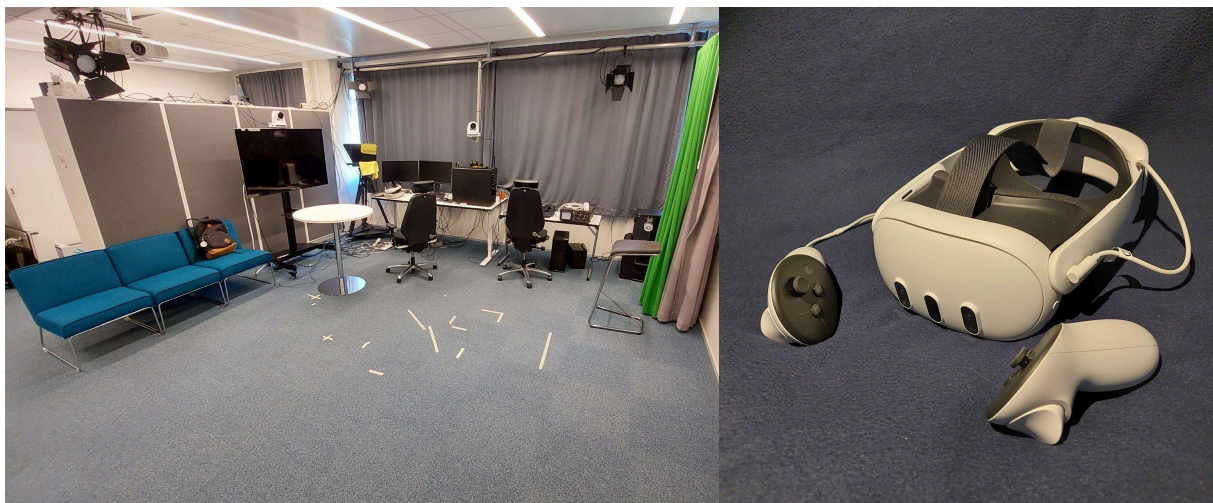


Figure 29: The mixed reality laboratory (left) and the Meta Quest 3 used in the experiment (right).

4.3 Overview of the Process

The experiment began with the participant signing a consent form, after which they completed a short questionnaire regarding their prior experience with VR. The information was used to examine whether prior VR experience correlates with lower levels of cybersickness, as repeated exposure to motion sickness-inducing stimuli has been shown to reduce susceptibility (see Section 3.3.2). Following the

questionnaire, the participants were provided with instructions on the control scheme and on how to proceed in the VR environment. The full experimental process can be seen in Figure 30.

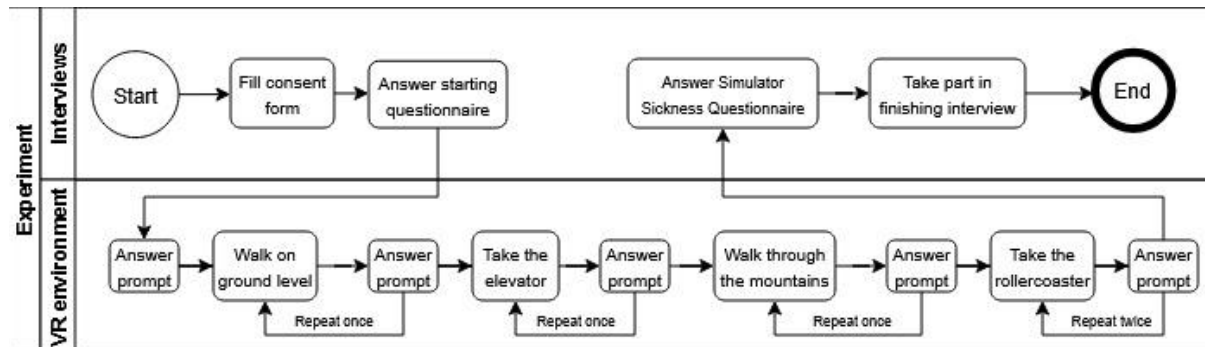


Figure 30: The experimental process from start to finish.

The VR experience began with a short tutorial on the control scheme, which the participants were required to complete before they could move their avatar. Participants were instructed to rotate in the VR environment to locate a prompt behind them, as illustrated in Figure 31. The prompt requested participants to report the severity of their motion sickness symptoms using a slider controller. These prompts served as an applied form of the *Fast Motion Sickness Scale* (see Section 3.1.4), which ranges from 0 to 20. Consequently, the prompts appeared frequently, requesting an input each time an ES was completed with either mitigation method. The experiment included four experimental sections, each completed twice (with the exception of the rollercoaster, which was completed three times). Therefore, a total of nine prompts were to be filled throughout the experiment, not including the tutorial prompt.

The experimental sections involved different forms of movement and variations in the activation of the mitigation methods (see Section 4.1 for a description of the experimental sections). The goal of ES1 was to investigate whether the mitigation methods alleviate symptoms caused by continuous controller-based forward momentum in VR. As ES1 provided the most basic form of stimulation for cybersickness, it served as a baseline for comparison when designing the other experimental sections.



Figure 31: The prompt used for sickness scoring throughout the VR experience.

The goal of ES2 was to investigate whether motion sickness induced by a moving platform differs significantly from symptoms induced by walking. Because the platforms resembled elevators and the participants were likely familiar with them, the experimental hypothesis (EH1) was that symptoms of cybersickness would be reduced compared to ES1. This prior familiarity was expected to reduce the sensory conflict caused by standing on a moving platform. Furthermore, the mitigation methods remained static at maximum strength during this ES, due to the movement of the elevator, regardless of how much the participant moved using the controllers.

ES3, taking place in a mountainous environment, investigated whether walking across bridges at high elevation creates a different form of stimulation compared to walking on ground level. The EH2 was that the increased tension associated with the high-altitude environment would result in stronger stimulation for cybersickness due to heightened fear and anxiety.

ES4, consisting entirely of a rollercoaster ride, aimed to investigate how being seated on a moving platform that rapidly changes direction and rotation affects symptoms of cybersickness. The EH3 was that the rollercoaster would elicit the strongest symptoms of cybersickness due to its high velocity and rotational movement. Unlike prior experimental sections, where the mitigation methods activated automatically,

here the participants were required to manually control the mitigation methods during movement. The goal was to investigate how much and for how long the participants would use the mitigation methods. Each ES, alongside the experimental hypothesis corresponding to the ES, can be seen in Table 3.

Section name	Section content	Hypothesis name	Hypothesis
ES1	Ground-level walking section	No hypothesis	The section was used as a base level of comparison for symptom scores due to its low intensity
ES2	Elevator section	EH1	Reduced symptoms compared to ES1 due to assumed familiarity with elevators, potentially reducing sensory conflict
ES3	Mountain walking section	EH2	Increased symptoms compared to ES1 due to increased tension caused by high elevation
ES4	Rollercoaster section	EH3	Strongest symptoms due to the fast velocity, rotational movement, and sharp turns

Table 3: The experimental sections and their corresponding hypotheses.

During the preparation phase, the participants were made aware that they were allowed to terminate the experiment at any moment and withdraw both their participation and their consent for data usage with no repercussions. This was to ensure that they did not feel pressured to complete the experiment if they started to feel too uncomfortable or motion sick. Consequently, the participants were being monitored closely throughout the experiment so that they could get help immediately if they felt their symptoms getting too severe.

Although the experiment was intended to be completed standing up, the participants were made aware that they were also allowed to sit down at any point in the experiment if they felt a loss of balance or if their symptoms got too strong. This was

to minimise the risk of falling, as well as to enable the participants to continue with the experiment if they would otherwise have wished to terminate it. Additionally, a bucket was kept nearby in case the participant was in danger of vomiting.

4.4 Data collection

Data was collected before, during, and after the experiment. Before the experiment, the participant filled out a short questionnaire about their prior experience with VR, as well as their age, sex, and an evaluation of their susceptibility to motion sickness. Prior to the experiment, each participant was also assigned an ID based on their sequential order in the experiment (i.e. first participant was 1, second was 2, etc.), and the participant's data was handled using their ID instead of any personally identifiable information. During the experiment, data were collected using the FMS, as well as data logging from the VR device. The virtual environment logged the participant's time, walking speed, FMS results, mitigation strength in the rollercoaster, amount of time the mitigation was used at different strength levels, and average frames-per-second for the application. Furthermore, the participant was also observed during the experience to see whether the virtual environment had any noticeable effects on, for example, their balance.

After the experiment, more data were collected using the SSQ, as well as a semi-structured interview. The SSQ listed symptoms associated with simulator sickness and asked the participant to rate their severity on a scale of *none*, *slight*, *moderate*, and *severe*. The goal of the interview was to investigate what the participants thought of the experiment, whether they liked it, which part of the experiment felt the worst, which part felt the best, whether symptom types differed during different experimental sections, whether they preferred either mitigation type over the other, and if there were any notable or weird feelings associated with any part of the experiment.

4.5 Questionnaire

The SSQ scores can be used to calculate total scores for the different symptom categories, as well as for the total sickness. The 4-point scaling system (*none*, *slight*, *moderate*, *severe*) is converted into numerical values in the range of 0-3, which are then summed together based on which category the symptom is associated with. The

results of these are then multiplied by a scalar value specific to the category. Below are the equations for each category, presenting the specific symptoms associated with the categories, as well as for the total score. [129]

$$\text{Nausea} = \text{General discomfort} + \text{Increased salivation} + \text{Sweating} + \text{Nausea} + \text{Difficulty concentrating} + \text{Stomach awareness} + \text{Burping}$$

$$\text{Oculomotor} = \text{General discomfort} + \text{Fatigue} + \text{Headache} + \text{Eyestrain} + \text{Difficulty focusing} + \text{Difficulty concentrating} + \text{Blurred vision}$$

$$\text{Disorientation} = \text{Difficulty focusing} + \text{Nausea} + \text{Fullness of head} + \text{Blurred vision} + \text{Dizzy (eyes open)} + \text{Dizzy (eyes closed)} + \text{Vertigo}$$

Below are the total scores for the categories when multiplying by the scalar value, as well as the total overall sickness score. The scalar values are also provided by the SSQ.

$$\text{Nausea}_T = \text{Nausea} * 9.54$$

$$\text{Oculomotor}_T = \text{Oculomotor} * 7.58$$

$$\text{Disorientation}_T = \text{Disorientation} * 13.92$$

$$\text{Total Sickness} = (\text{Nausea} + \text{Oculomotor} + \text{Disorientation}) * 3.74$$

4.6 Interview

After the SSQ was filled, a semi-structured interview was conducted in order to further investigate how the participants felt about various aspects of the experiment. The interview started by asking about the participant's general feelings on the experiment, and whether they felt like something could be improved. The aim was to gather general feedback about the experimental process, as well as the virtual environment, in case similar experiments were to be conducted in the future.

The next questions were about whether any part of the experiment felt especially notable and whether there were significant differences in symptoms in different experimental sections. The aim of these questions was to gauge whether there were parts in the experiment that resulted in abnormal or difficult-to-describe symptoms.

Furthermore, examining whether different forms of VR stimuli result in different symptom types could help in understanding the deeper mechanics contributing to cybersickness.

The following two questions aimed to find which part of the experiment the participant felt was the worst and which they felt was the best. The questions were kept intentionally vague so that the participant would be able to interpret “best” and “worst” in their own way. The goal was to understand which aspects of the experience stood out the most in both a positive and a negative way, instead of constraining the participant’s answer to be about a specific topic, so that more insight could be gathered on what the participants felt the most strongly about.

The rest of the questions were about comparisons between the two mitigation methods, thus they were not asked of the control group. The first of these questions was about whether there were any differences in how the methods made the participant feel, with the goal being to investigate whether the participants noticed any physical or psychological changes as a result of the different mitigation styles. The second question was about whether the size of the mitigation methods was good, as some may have considered the tunnelling effects to be too limiting visually. The goal was to examine whether the size had any effect on their experience. The third question was about which method they preferred, which is important data for evaluating user comfort. The final question was about whether the participant feels like the inclusion of either method in a VR application would affect their experience either positively or negatively, and why. The purpose was to explore whether the potential increase in accessibility offered by these mitigation methods would increase willingness to engage with VR technology. This data could be useful for developers seeking to make VR more accessible for a wider audience, as well as generally providing understanding that may contribute to a wider adoption of the technology.

4.7 Demographics

A total of 15 participants took part in the experiment, 12 of whom were male and 3 female. Age distribution can be seen in Figure [32](#). The participants were divided into three groups, labelled A, B, and C. The groups were randomly assigned, and they determined which mitigation method was used first. Group A used vignette tunnelling first in each ES, while Group B started with camera passthrough. Group C was the

control group, which completed every ES twice without any mitigation methods. Groups A and B consisted of 6 participants each, whereas group C had 3 participants.

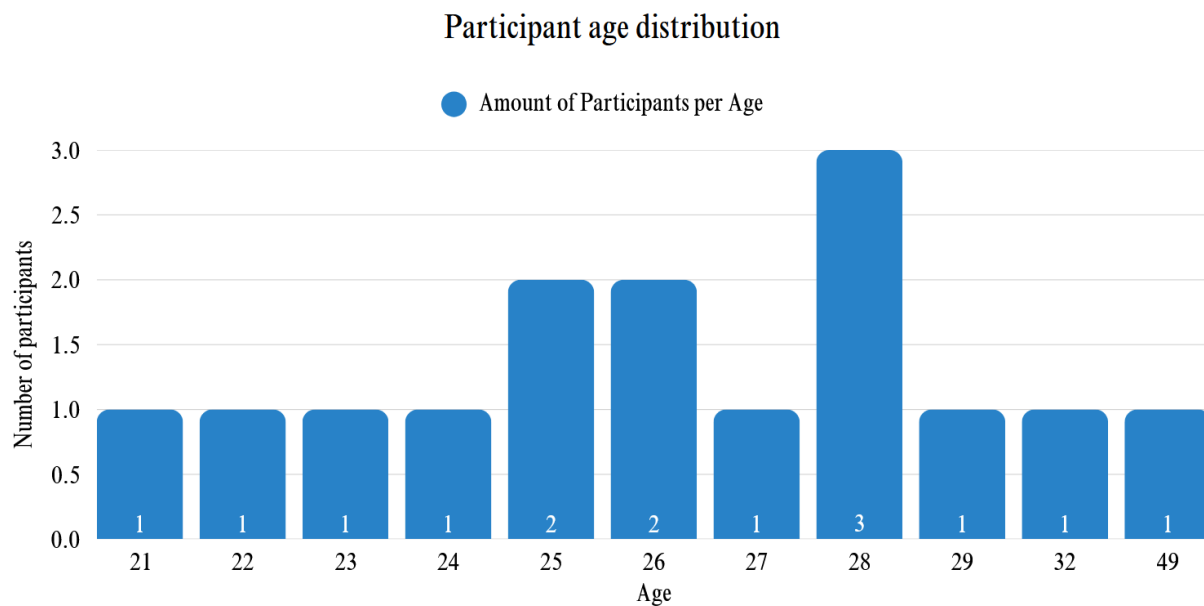


Figure 32: The age distribution in the experiment.

The discrepancy between the size of the control group and the sizes of the mitigation groups happened partly as a result of technological complications, leading to one group having a disproportionate amount of participants early on. As a result, the control group was left with fewer participants after reaching a balance with the mitigation group members. Having an equal balance in the mitigation groups was deemed more important, as the main goal of this experiment was to compare the mitigation methods. Furthermore, one of the participants who would have been in the control group was unable to take part in the experiment and had to drop out due to personal reasons. Their spot could not be filled, as the cancellation occurred towards the end of the experiment, and there were no participants left to take their spot. Regardless, the data collected from the mitigation groups still provided valuable results that could be compared to each other, although comparisons to the control group are limited due to its size.

Participants were asked to rate their prior experience with VR on a scale of *never used*, *rarely used*, *often use*, and *experienced user*. Figure [33](#) presents participant distribution in each experience category.

Participant experience with VR

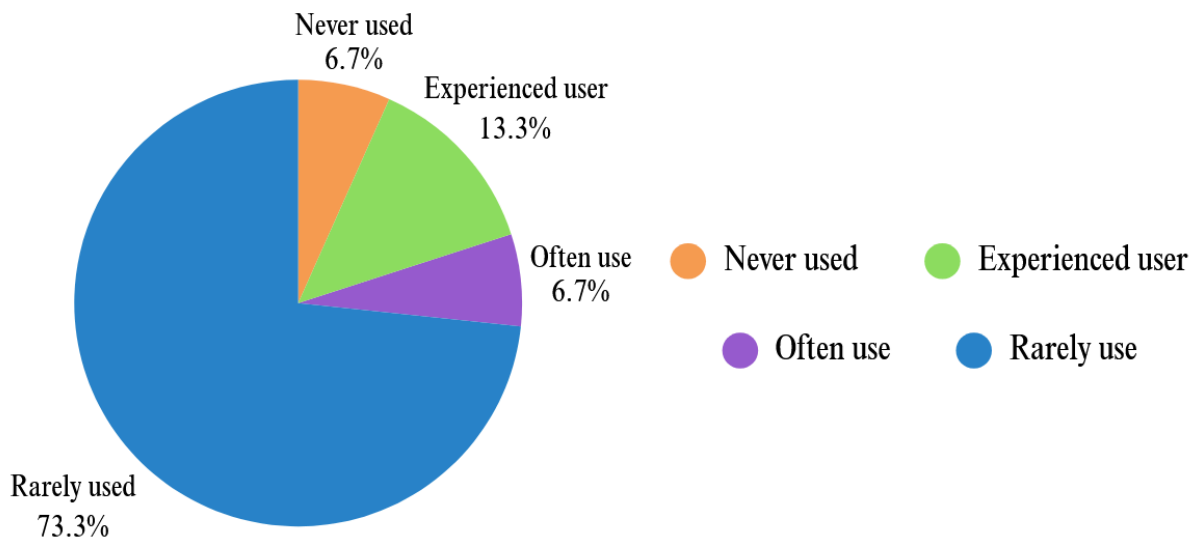


Figure 33: VR experience distribution among participants.

Using this to calculate the mean experience level in each experimental group results in data shown in Figure 34. Data is calculated by assigning a number to each experience category (e.g. never used = 1, experienced user = 4, etc.) and then calculating the mean in each group. The results indicate that the control group had the highest mean experience level, and group B had the lowest.

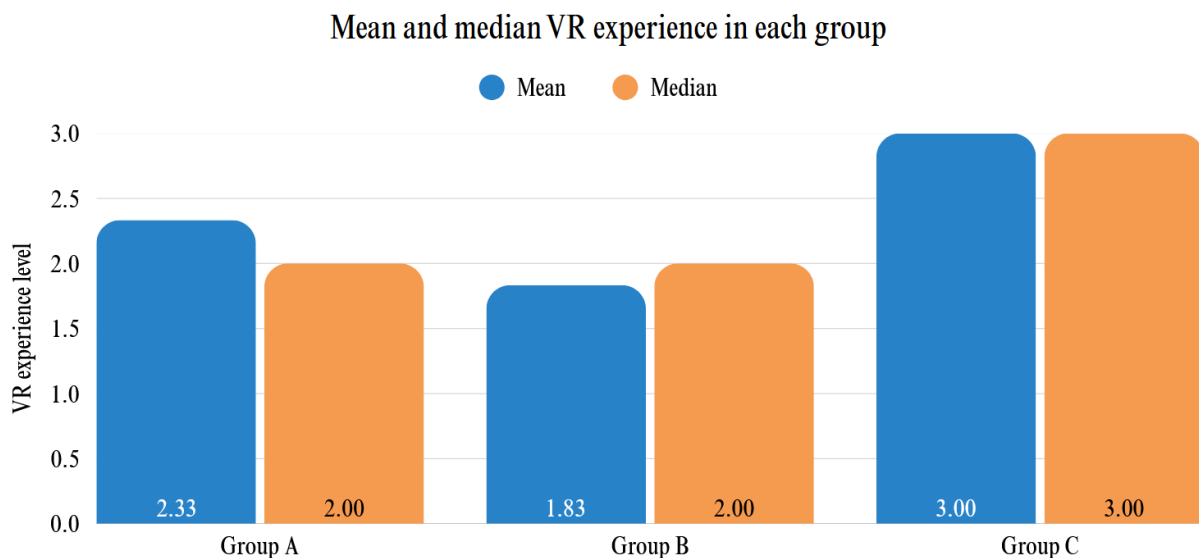


Figure 34: Mean and median experience level for each experimental group. Group A - vignette first, group B - passthrough first, group C - control group.

Participants were also asked to rate their susceptibility to motion sickness on a scale of 1 to 5, which can be seen in Figure 35. 9 participants rated their susceptibility

below the midpoint. Only 2 participants rated it above the midpoint, with 1 rating their susceptibility at maximum.

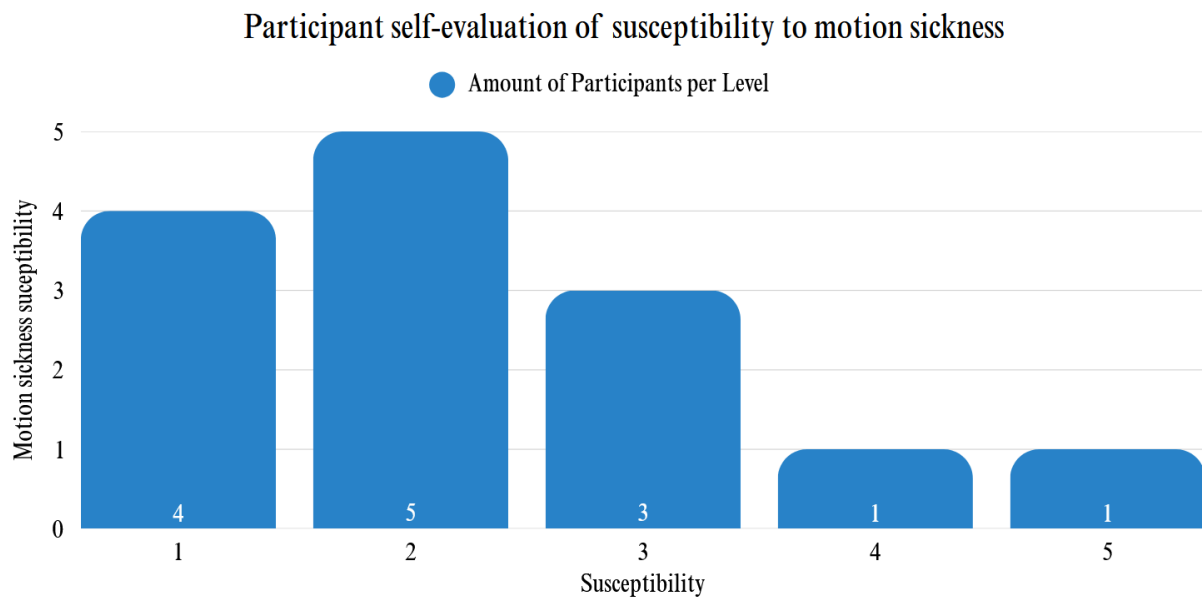


Figure 35: Participant self-evaluations of their susceptibility to motion sickness.

A table showing each participant separately by their ID, the experimental group they were assigned to, their experience level with VR, and their subjective self-evaluation of their motion sickness susceptibility can be seen in Table 4. The participants are sorted by their experimental group.

participant ID	Experimental group	VR experience	Motion Sickness Susceptibility
2	A	Rarely used	3
4	A	Experienced user	2
7	A	Rarely used	3
10	A	Rarely used	1
13	A	Rarely used	1
15	A	Rarely used	2
3	B	Rarely used	3
5	B	Never used	4
8	B	Rarely used	5
9	B	Rarely used	2
11	B	Rarely used	3
12	B	Rarely used	1
1	C	Experienced user	2
6	C	Often use	1
14	C	Rarely used	2

Table 4: Participant data from the pre-experimental questionnaire.

4.8 Ethical Considerations

This experiment was conducted in accordance with the ethical principles of research with human participants and complied with the requirements set by the Ethics Committee for Human Sciences at the University of Turku. Ethical review was requested by the committee, and permission to proceed with the experiment was granted. All the required forms for the application and the final statement from the Ethics Committee for Human Sciences are listed in the appendices.

All participants received written information prior to the experiment detailing the purpose, experimental procedures, the data collection methods and what data was being collected, the data management methods, the data processing methods, as well as their right to withdraw consent and terminate the experiment at any point with no negative consequences. This was done in order for the participants to be able to provide informed consent and voluntarily take part in the experiment. Additionally, data was stored and processed confidentially in accordance with the General Data Protection Regulation (GDPR). No personally identifiable information was collected and is not reported in this thesis.

5 Results and Analysis

This Chapter presents and analyses both the quantitative results from the FMS during the experiment and the post-experiment SSQ, as well as the qualitative results from the interviews and observations. Charts and graphs are used to display quantitative results, while the qualitative results are presented through text, with relevant paraphrased quotes from the participants. Wilcoxon signed-rank tests are used to evaluate the statistical significance of quantitative data whenever applicable.

5.1 Test Results

Figure 36 shows the mean and median sickness scores grouped by the participants' self-reported experience with VR. Of the 15 total participants, 11 rated their VR experience as "rarely use". Of the remaining 4 participants, 1 had never used VR before, 1 reported using VR often, and 2 rated themselves as experienced users. The results indicate a correlation between sickness score and VR experience, as participants with less experience tended to report higher sickness scores. However, due to the small sample size and uneven distribution between different experience categories, the observations do not serve as conclusive evidence and should be interpreted with caution.

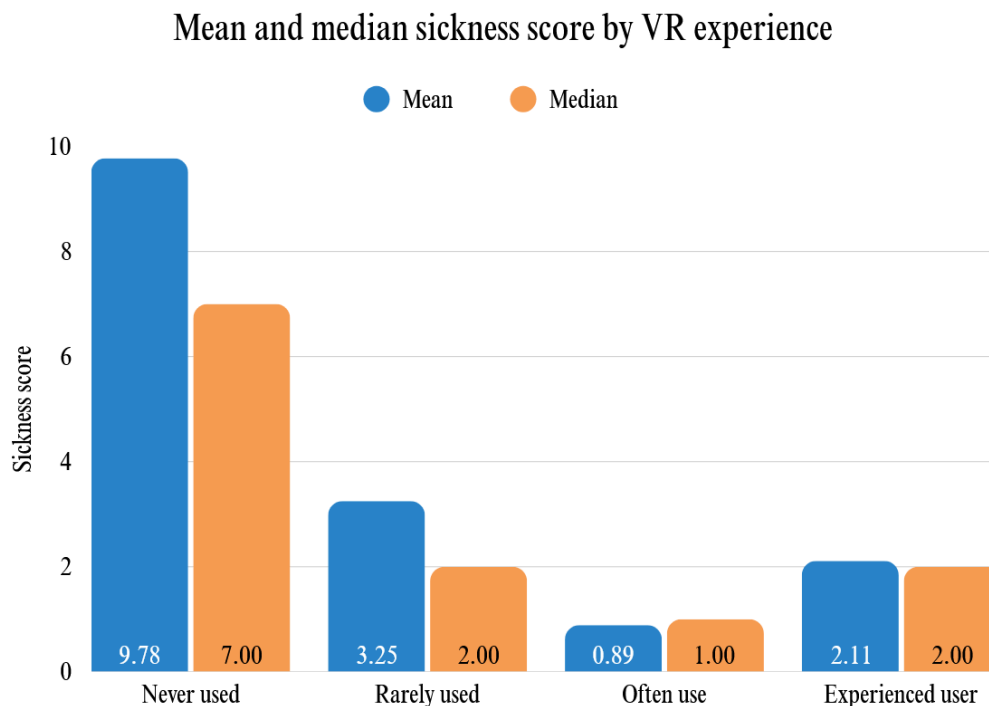


Figure 36: Mean and median sickness score by VR experience, the y-axis represents the sickness score.

The results from the FMS prompts at the end of each ES of the experiment present lower mean and median sickness scores when using passthrough as opposed to vignette tunnelling. FMS data can be seen in Figure 37, which indicates that passthrough is more effective at mitigating cybersickness than vignette tunnelling.

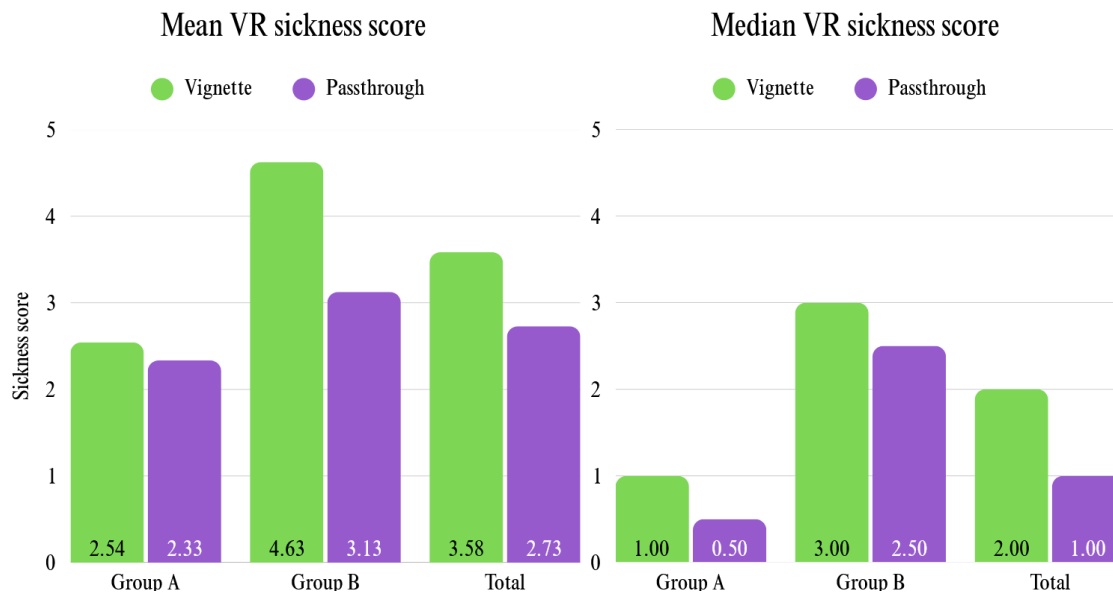


Figure 37: Mean (left) and median (right) cybersickness score by mitigation method

Figure 38 presents the mean FMS scores with both mitigation methods in each ES. Mean sickness scores for passthrough tended to be lower in all sections, except ES1, where vignette tunnelling produced a slightly lower score. Moreover, the median sickness score, visible in the box plot in Figure 39 and illustrated by the straight lines across the boxes, for the passthrough was lower in each ES, with the exception of ES2, where it produced a score equal to vignette tunnelling. Overall, these findings indicate lower sickness scores across most sections when passthrough was utilised.

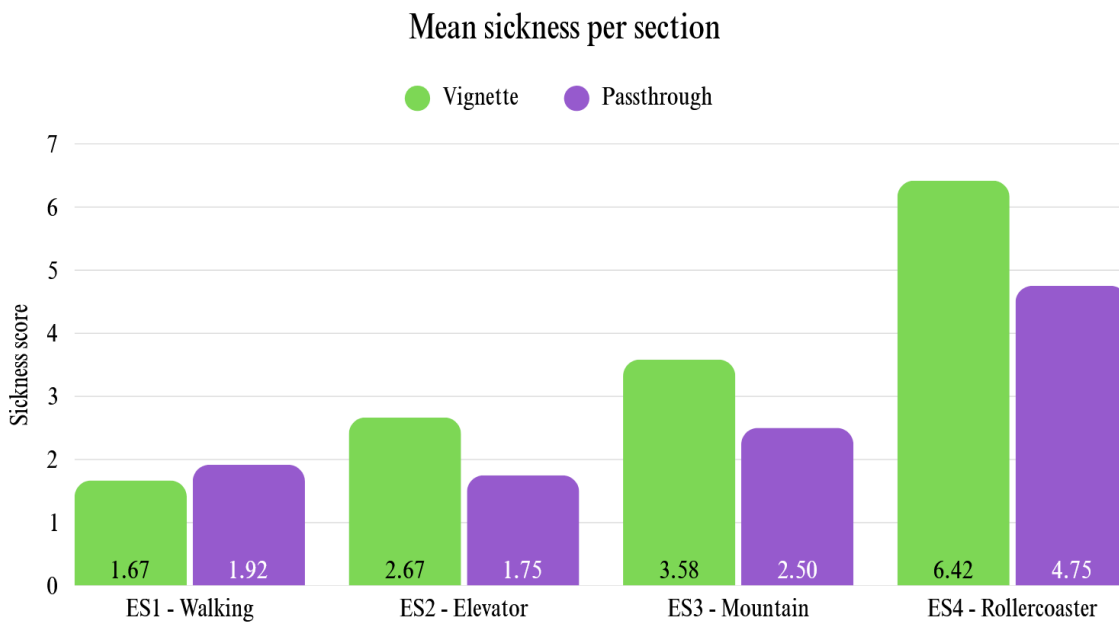


Figure 38: Mean cybersickness score per ES from the mitigation groups.

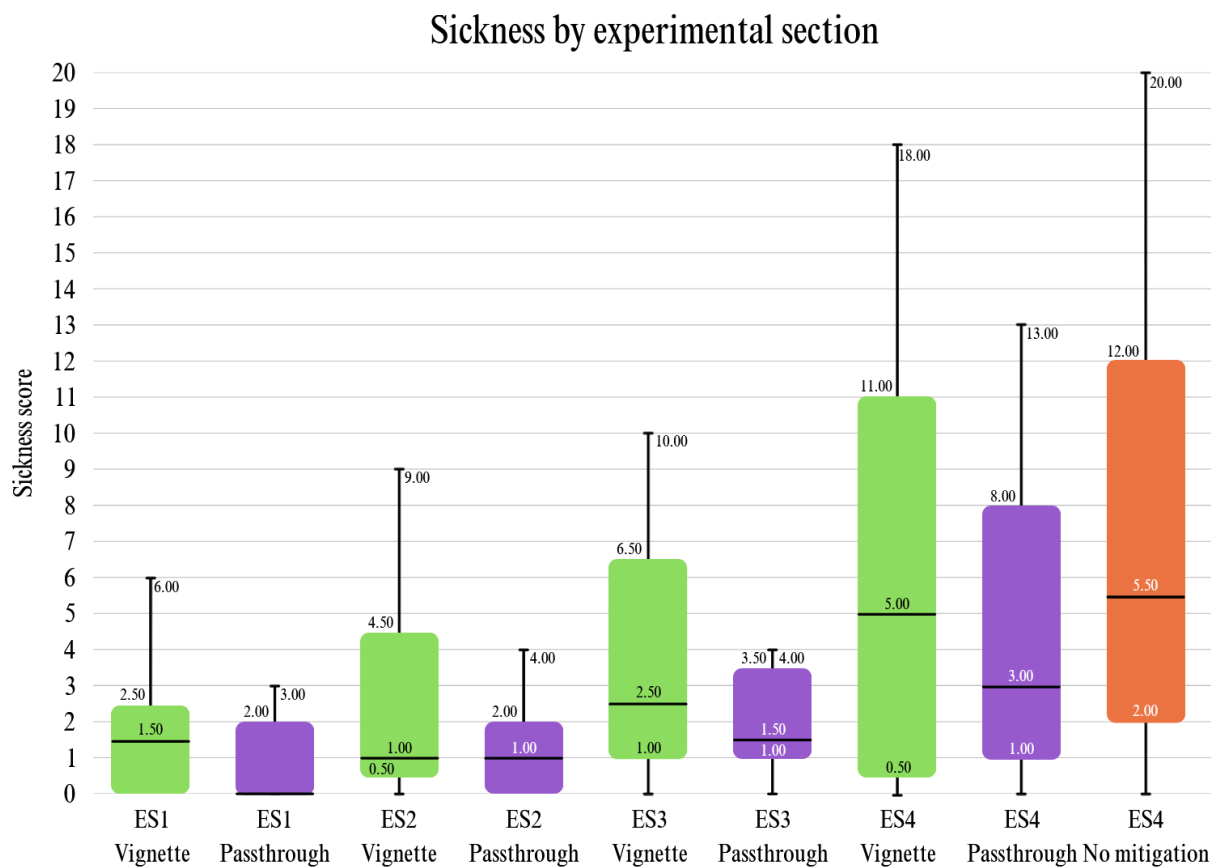


Figure 39: Box plot of sickness per ES, median sickness is represented by the straight lines across each bar.

To further determine whether the effectiveness of the mitigation methods differed significantly, a two-sided Wilcoxon signed-rank test was conducted on the FMS

scores. The results showed a significant difference between the mitigation methods ($p = 0.005043$, $W = 88.5$, with an effect size of 0.5207), with higher FMS scores for vignette tunnelling.

When designing the experimental sections, the EH1 stated that the ES2 (the elevator) would result in lower sickness scores than the ES1 (walking on the ground level), due to a potential familiarity with elevators. This was based on the assumption that using an elevator in a virtual environment closely resembles using one in the real world, thus reducing the sensory conflict at the root of cybersickness. However, comparing ES2 to ES1 shows a mean sickness score of 1.70 for ES1 and a mean of 2.03 for ES2, with a median of 1.00 for ES1 and 1.00 for ES2. The results show a non-significant small difference ($p = 0.511$, $W = 78.5$, $r = 0.1508$), indicating that EH1 was not supported in this experiment, although the difference was small.

The total sickness scores of the other sections show a mean of 2.80 and a median of 2.00 for ES3, and a mean of 5.17 and a median of 4.00 for ES4. The third round without mitigation was left out of the calculations for ES4, to provide a more equal representation of total sickness in comparison to the other sections, as the other 3 experimental sections did not include a third round without mitigation. Comparing the total sickness scores to ES1 results in a significant medium difference for ES3 ($p = 0.04161$, $W = 104.5$, $r = 0.3921$). For ES4, the results indicated a significant large difference ($p = 0.0008705$, $W = 38.5$, $r = 0.6659$). The total sickness scores used for these calculations are presented in Figure [40](#).

Using ES1 as the base level of comparison for sickness scores due to its low intensity, a gradually increasing difference across the experimental sections can be observed. This pattern supports both EH2 and EH3, stating that their higher intensity would result in greater sickness scores. However, it is unclear whether the higher sickness scores in ES3 are a result of the heightened fear and anxiety caused by high altitude, or if it is caused more by participants having been exposed to VR for longer by that time in the experiment. Feelings of heightened tension due to a fear of heights were reported by 2 participants, therefore it is likely that both factors contributed to the results.

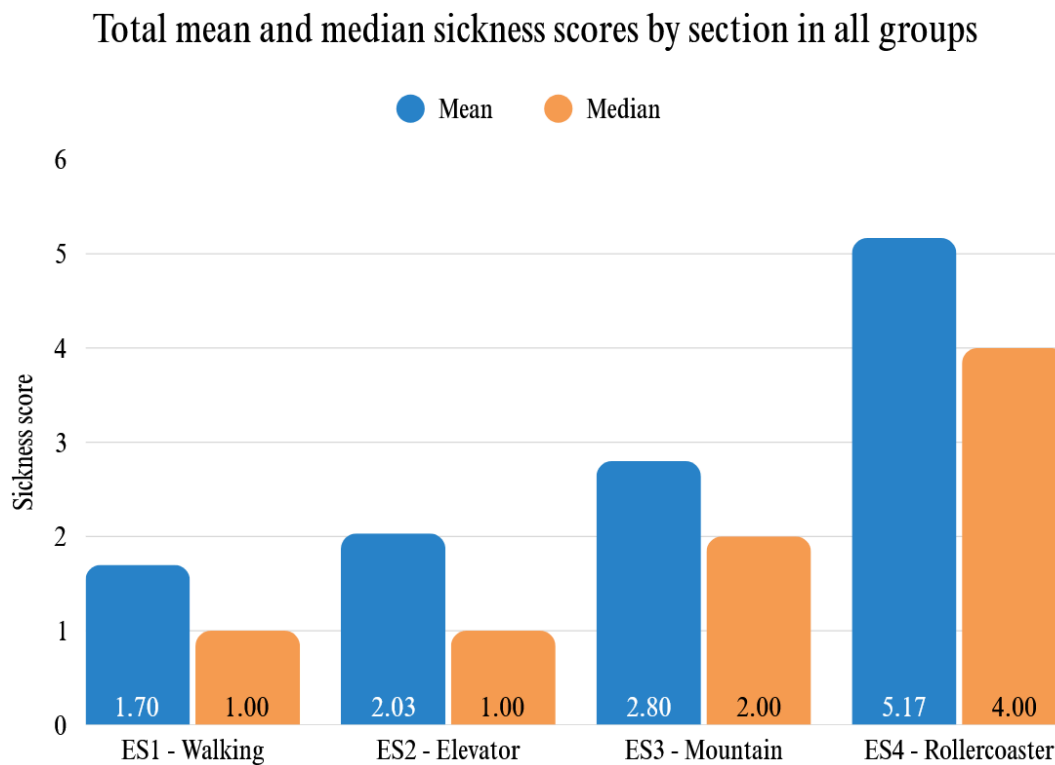


Figure 40: Total sickness scores from all groups (mitigation groups and control group).

To reduce a potential second-order effect, where the symptoms from the first mitigation method in an ES persist in the second part, the methods were used in a different order in both mitigation groups. Figure 41 presents the mean sickness scores for both groups. The bars in each ES represent the order in which the methods were used from left to right. The mean scores indicate a consistent trend of passthrough resulting in lower sickness scores regardless of the order in which the mitigation techniques were used. This further indicates that passthrough may be more effective, since the lower scores for passthrough would not be a result of habituation to the stimuli, as habituation would likely cause the second method to result in lower scores. Conversely, the increased exposure duration could also cause the second round to always result in higher sickness scores, which does not occur either. This, however, does not necessarily mean that a second-order effect does not exist, rather it suggests that passthrough may be able to negate symptoms despite a second-order effect taking effect.

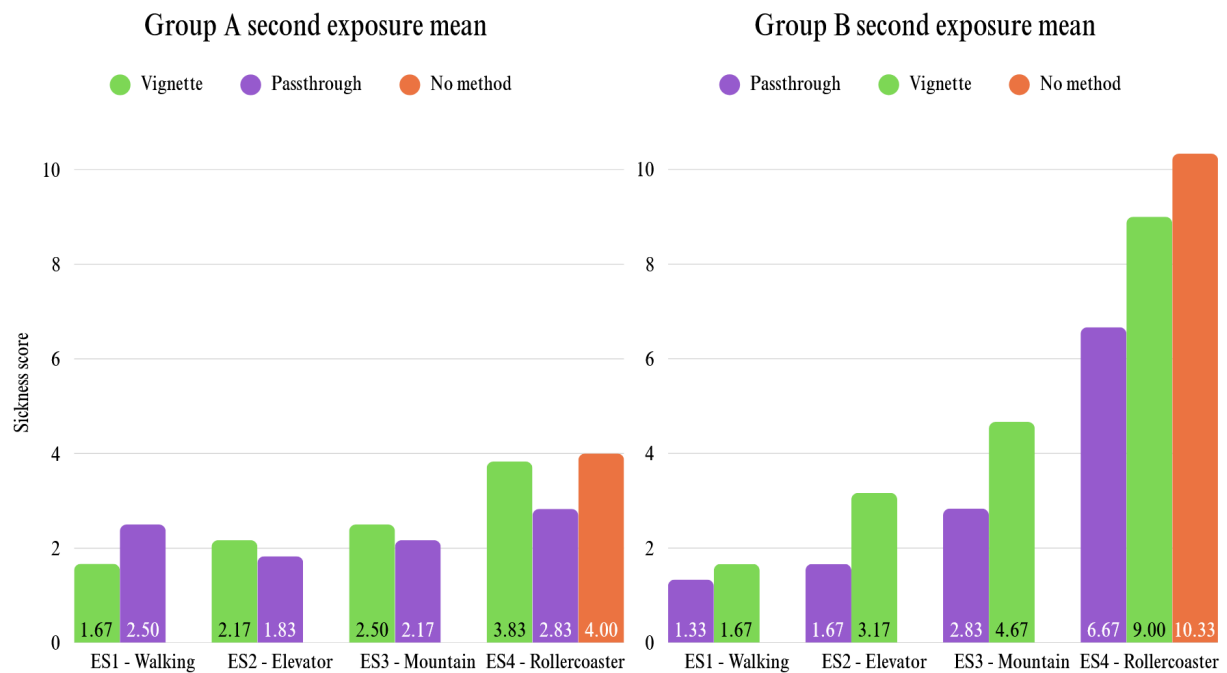


Figure 41: Mean cybersickness scores from both mitigation groups, with bars ordered from left to right in order of exposure to illustrate the order of exposure to the mitigation methods within each group.

Figure 42 shows the corresponding median sickness scores for both groups in order of exposure. The results again indicate lower sickness scores when passthrough was utilised, regardless of order. The consistency of these scores indicates that the order of exposure did not strongly affect the results.

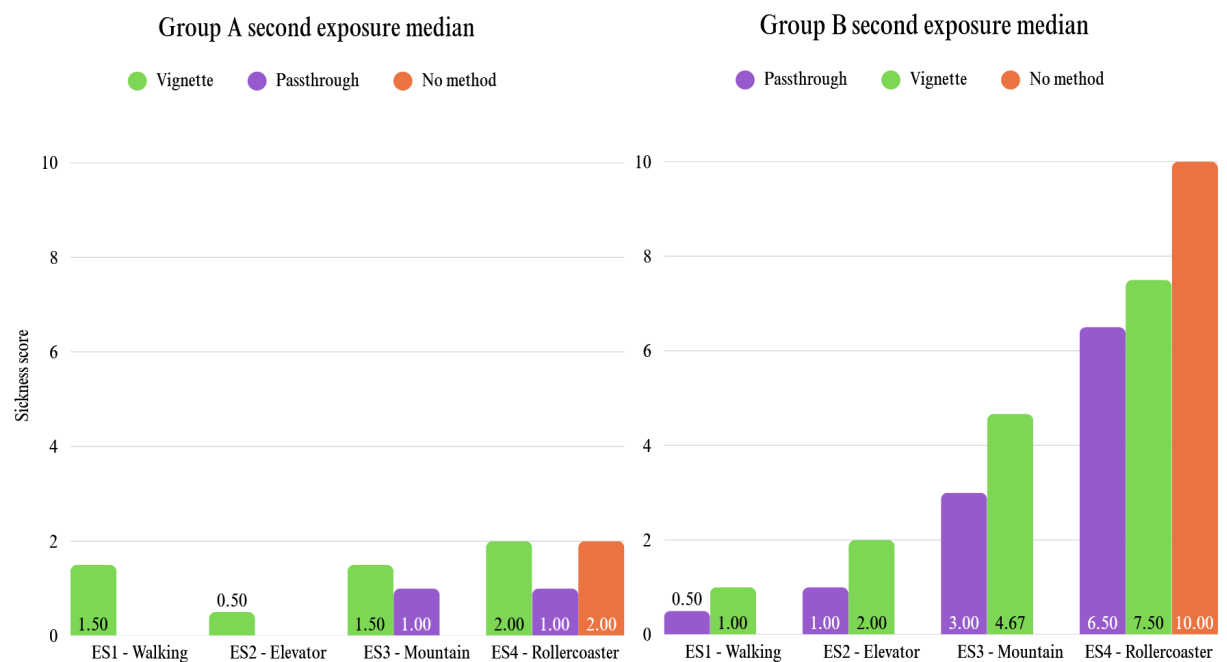


Figure 42: Median sickness scores in each group by order of exposure.

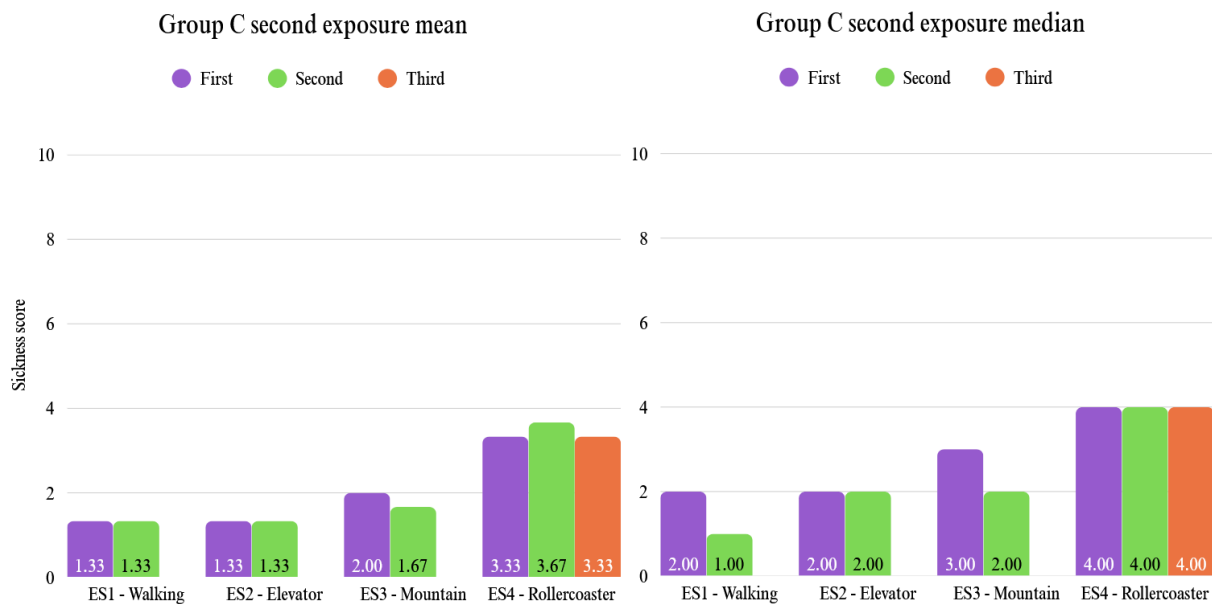
A Wilcoxon signed-rank test was conducted on both mitigation groups individually to examine the potential second-order effect. Group A (vignette before passthrough) resulted in a non-significant medium difference ($p = 0.2027$, $W = 27$, $r = -0.3533$). Although the results are not statistically significant, passthrough still received lower mean sickness scores in comparison to the vignette in group A.

Furthermore, the Wilcoxon test in group B (passthrough before vignette) resulted in a significant large difference ($p = 0.008387$, $W = 17$, $r = 0.659$). The results from both Wilcoxon tests indicate that the passthrough condition exhibited lower sickness scores in both groups, with group B showing significantly lower scores with the passthrough method.

These findings suggest a potential second-order effect. Specifically, group A, where vignette tunnelling was used first, exhibited a smaller contrast between the two conditions, which may have been a result of a more sickness-inducing first condition, thus potentially leading to higher sickness scores in the second condition. By comparison, group B, where passthrough was used first, would have experienced a more intense second condition after a less sickness-inducing first condition, potentially leading to a higher contrast between the first and the second.

However, the sickness scores were lower in group A in general, which could be a result of the higher mean VR experience level in said group, as well as the lower reported susceptibility to motion sickness. On a scale of 1 to 5, the motion sickness susceptibility evaluations prior to the experiment resulted in a mean and median score of 2 for group A and 3 for group B. Regardless, passthrough scores were lower in both groups, indicating that it may still be effective even when influenced by a second-order effect.

Figure [43](#) shows the mean and median sickness scores for the control group in each round of the experiment. The results show that the scores in each round of each ES tend to be closer to each other than the different rounds in both mitigation groups, suggesting that there is a difference between the two mitigation methods. This is because the sickness scores correlating to each mitigation method vary significantly more than any two subsequent control group ES scores.



Figures 43: Cybersickness scores in each round of each ES in the control group.

ES1 and ES3 involved continuous controller-based locomotion, in which the mean movement speed was recorded to examine its potential effect on sickness scores. Maximum movement speed when both sticks were pushed fully forward was 6, while only pushing one stick forward produced a movement speed of 3. A scatter plot is presented in Figure 44 to illustrate the potential correlation between sickness score, walking speed, and mitigation method. The sickness score is represented by the Y-axis, and the walking speed is represented by the X-axis. Each participant produced 4 dots for the scatter plot, as the vignette and passthrough rounds of both ES1 and ES3 are represented separately.

From the scatter plot, no clear correlation between movement speed and sickness score can be seen, as the highest sickness scores appear around movement speed 4, whereas the highest movement speeds still exhibit low sickness scores. By contrast, higher sickness scores were reported with the vignette, as 5 of the 8 dots displaying a sickness score of 6 (midway point with reported scores) or above occurred with vignette tunnelling, although the highest score (12) was with passthrough. By contrast, the control group recorded the greatest mean walking speeds, with the sickness scores in said group peaking with the highest walking speed, although they were significantly lower than those of the mitigation groups.

This discrepancy between scores in the control group and mitigation groups could be explained by the control group having a higher mean experience level, as 2 out of the

3 participants were experienced users. Similarly, higher mean walking speeds being recorded in the control group could also be a result of a higher experience level, as the participants would be more accustomed to moving in VR, therefore not requiring as much time to get used to the movement mechanics as the participants in the groups with less experience. Although, due to the small sample size in the control group, no clear conclusions can be drawn from the data.

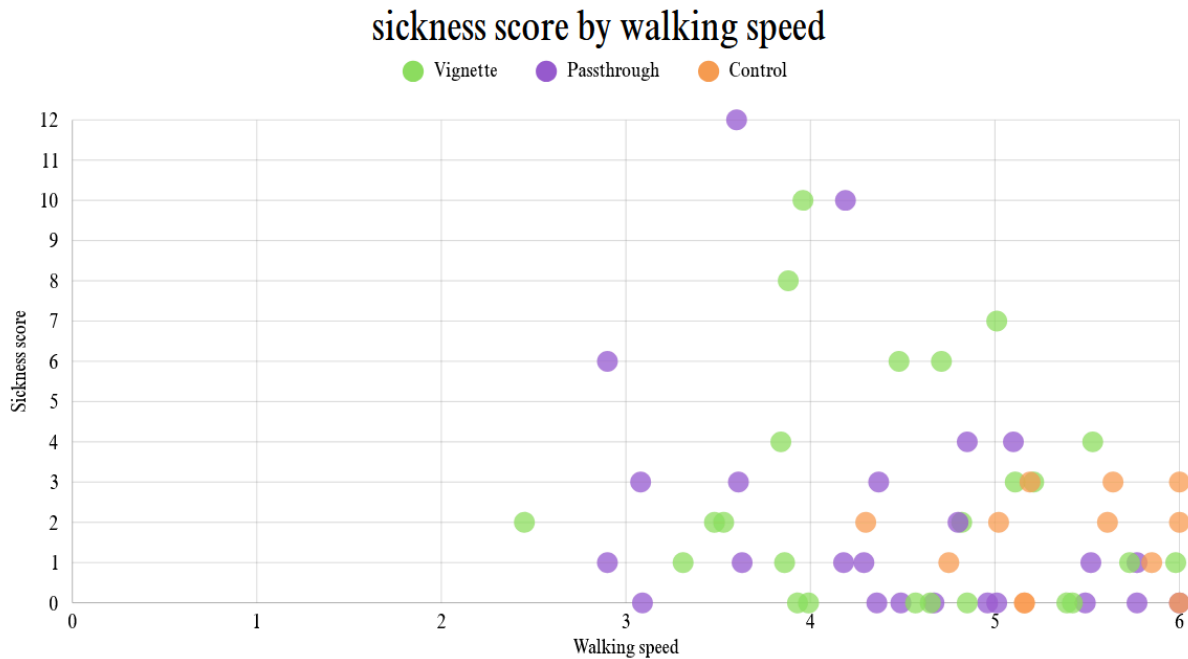


Figure 44: Scatter plot of the sickness scores by walking speed, coloured by the mitigation method.

To further compare the sickness score and walking speed in ES1 and ES3, Figure 45 presents a similar scatter plot, but with the dots coloured based on the ES. No clear correlation can be seen here either, although the fastest scores were recorded during ES3, with the sickness scores correlating to higher speeds being greater during ES3 than ES1. Similarly to the aforementioned scatter plot, 5 of the 8 scores above the midway point were reported during ES3, with the highest score exhibited during ES1, indicating that, on average, ES3 produced higher sickness scores in comparison to ES1. Taken together, however, the data does not suggest any clear correlation between sickness score and walking speed.

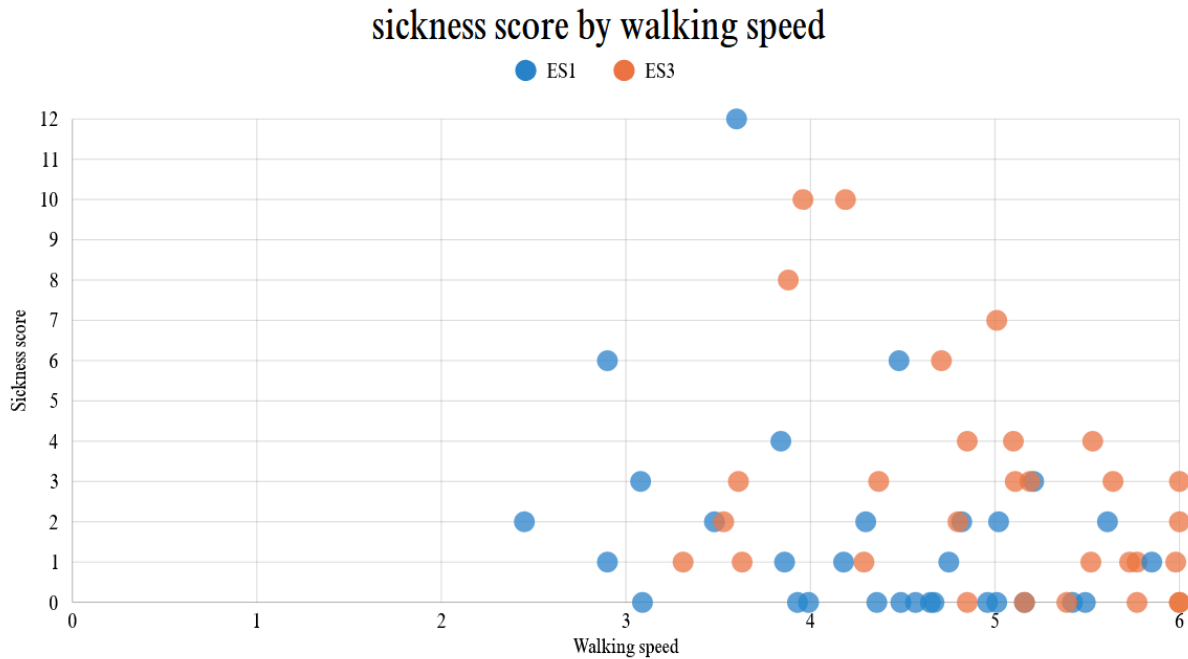


Figure 45: Scatter plot of the sickness scores by walking speed, coloured by the experimental section

In ES4, mitigation was manually controlled by the participants, and the mean strength of the mitigation was logged. Maximum mitigation strength when both joysticks were pressed fully forward was 100, while only holding one joystick down produced a mitigation strength of 50. The data indicates that both groups used more mitigation on the second part of ES4, although the sickness score was lower with passthrough regardless of whether it was used first or second. This indicates that a smaller amount of passthrough mitigation may be associated with a lower sickness score in comparison to a higher amount of vignette tunnelling.

The ES4 was conducted three times, with the last round not utilising any mitigation methods. This third part resulted in higher sickness scores in both groups. Reported sickness scores as well as the mean mitigation strength are presented in Figure 46 for group A and Figure 47 for group B. Passthrough and vignette tunnelling were used in a different order in both groups, which is reflected in the graph by the order of the bars from left to right.

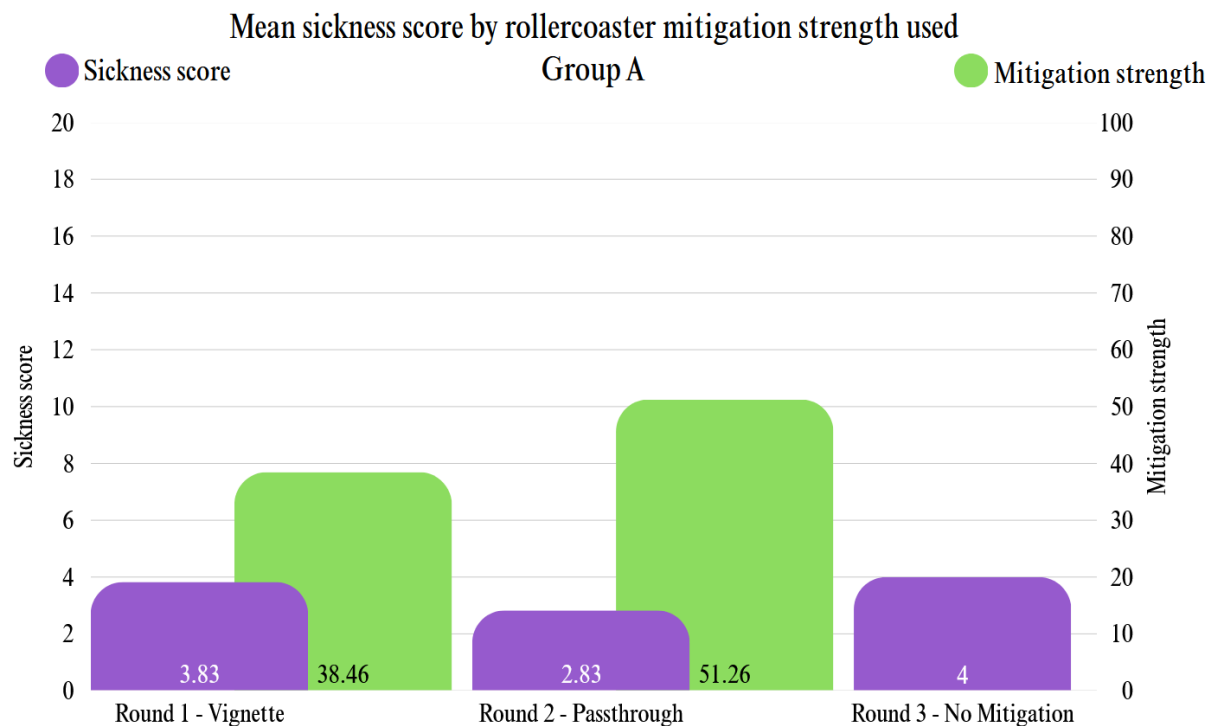


Figure 46: Mean sickness score by ES4 mitigation strength in the mitigation group A

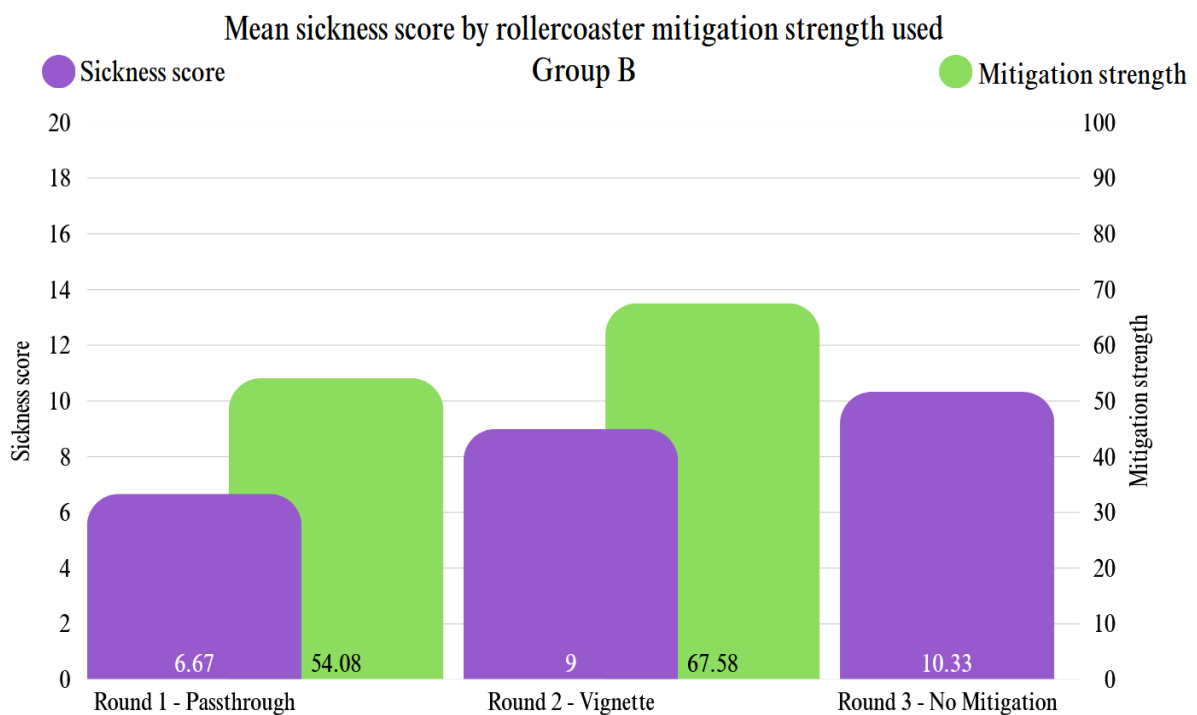


Figure 47: Mean sickness score by ES4 mitigation strength in the mitigation group B

Median sickness scores for the rollercoaster indicate a similar trend as the mean scores, with passthrough resulting in a lower mean regardless of order or mitigation strength in both groups. Moreover, the third round completed without mitigation

resulted in the largest median sickness score in group B, and an equal score to vignette tunnelling in group A. Median scores are shown in Figures 48 and 49.

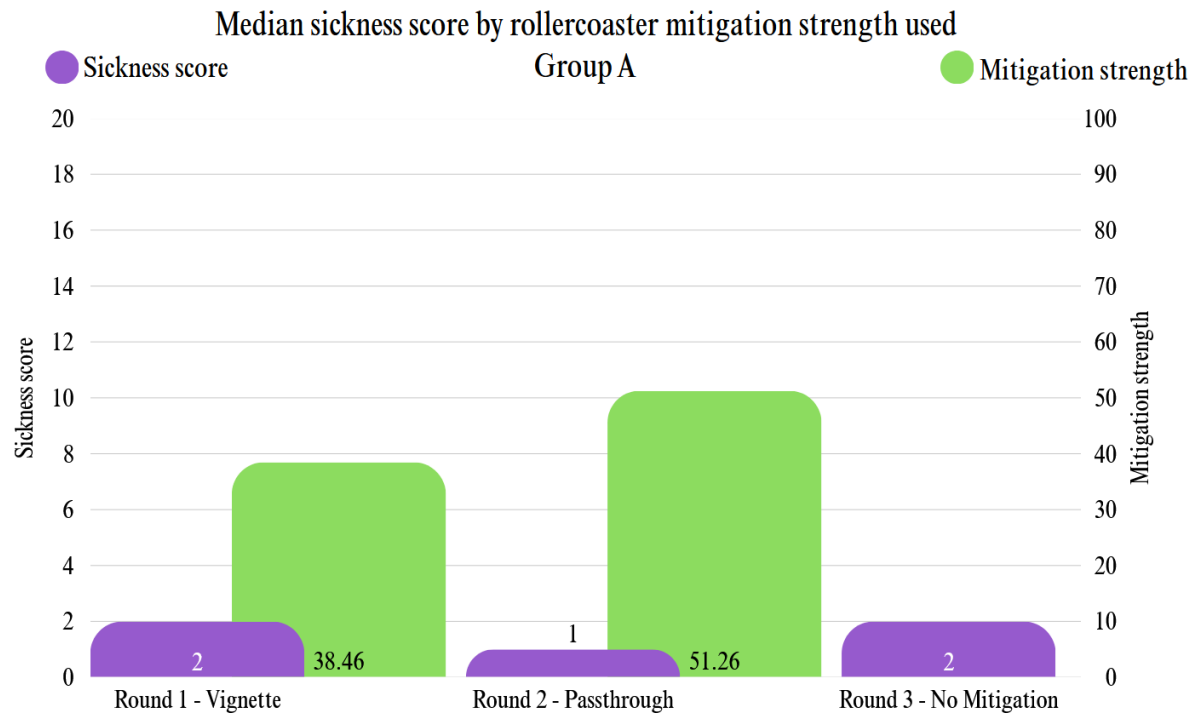


Figure 48: Median sickness score by ES4 mitigation strength in the mitigation group A

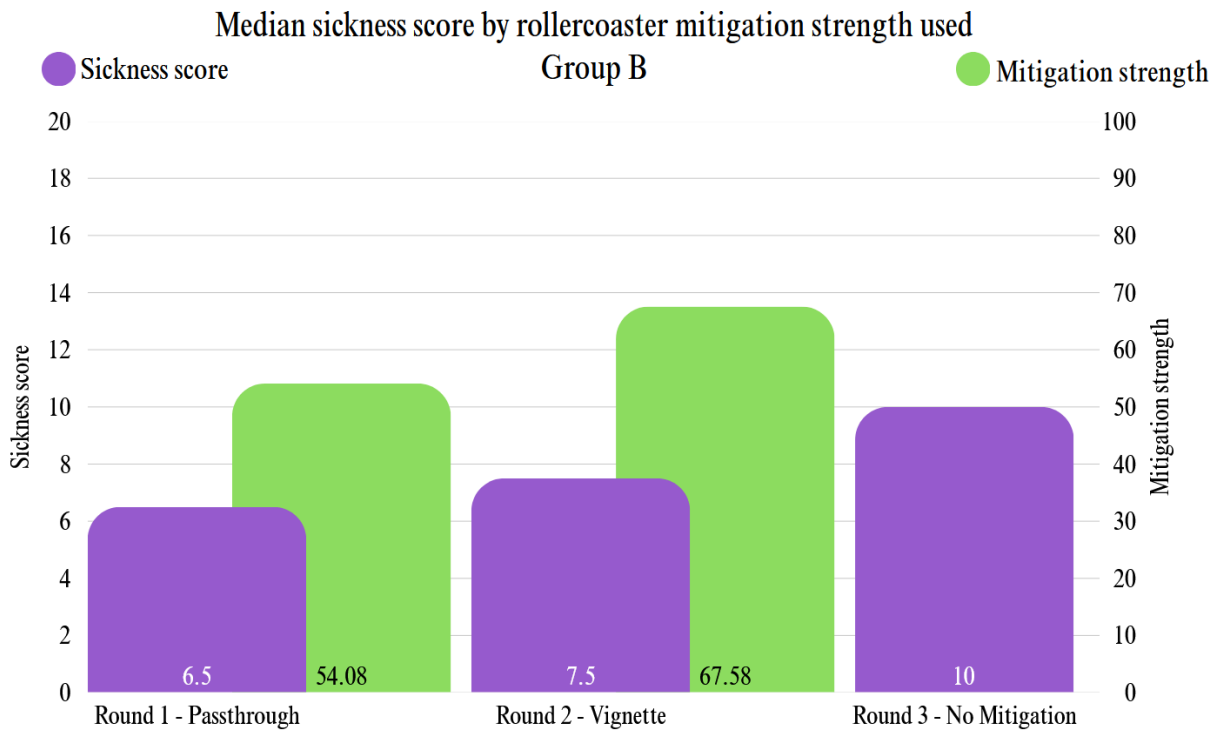


Figure 49: Median sickness score by ES4 mitigation strength in the mitigation group B

Mean and median sickness scores in the control group were fairly equal in each of the three rounds. The mean sickness scores were lower in each round, with the exception of the group A passthrough round. The median sickness scores were higher than those in group A in both the vignette and passthrough rounds, and equal in the round without mitigation, whereas they were lower than those in each round in group B. Mean and median scores in the control group are shown in Figure 50. As discussed before, the lower sickness scores in the control group may be a result of a higher mean VR experience level.

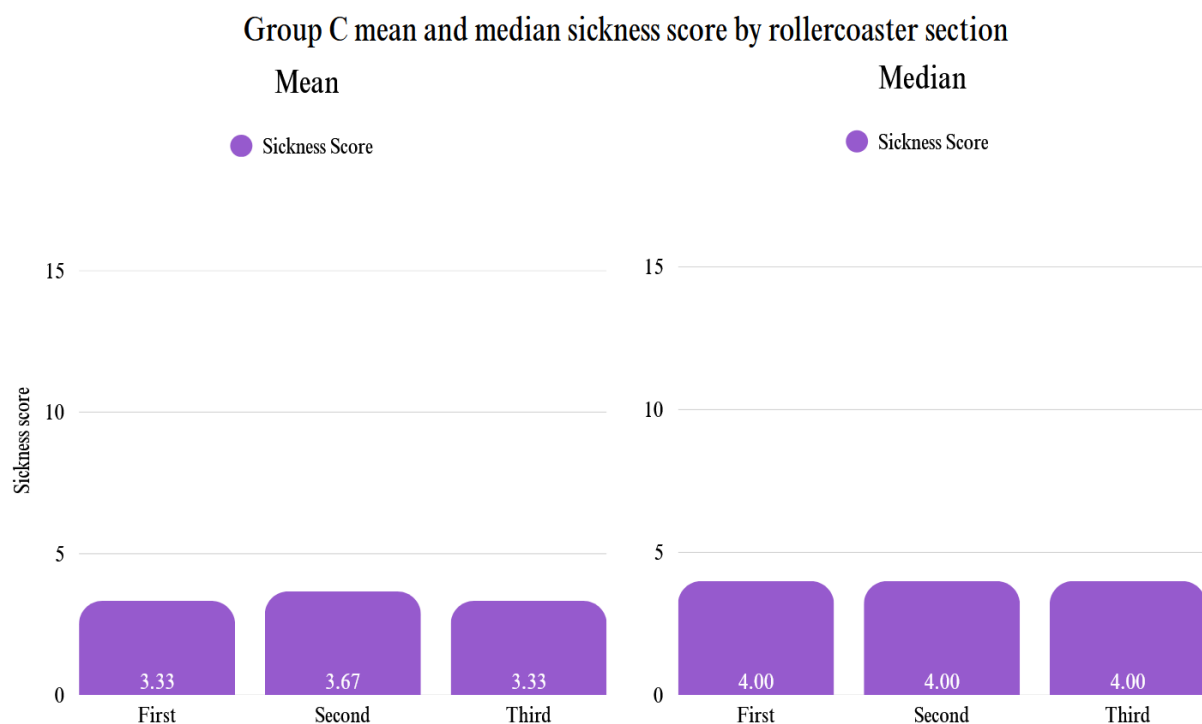


Figure 50: Mean and median sickness scores in the ES4 in the control group

5.2 SSQ scores

Based on the SSQ completed after the experiment, the most commonly reported symptoms were dizziness and vertigo. Both symptoms were experienced by 10 of the 15 participants to some degree. For dizziness, 9 reported slight symptoms, and 1 reported moderate symptoms. Vertigo was reported as slight by 8 participants and moderate by 2.

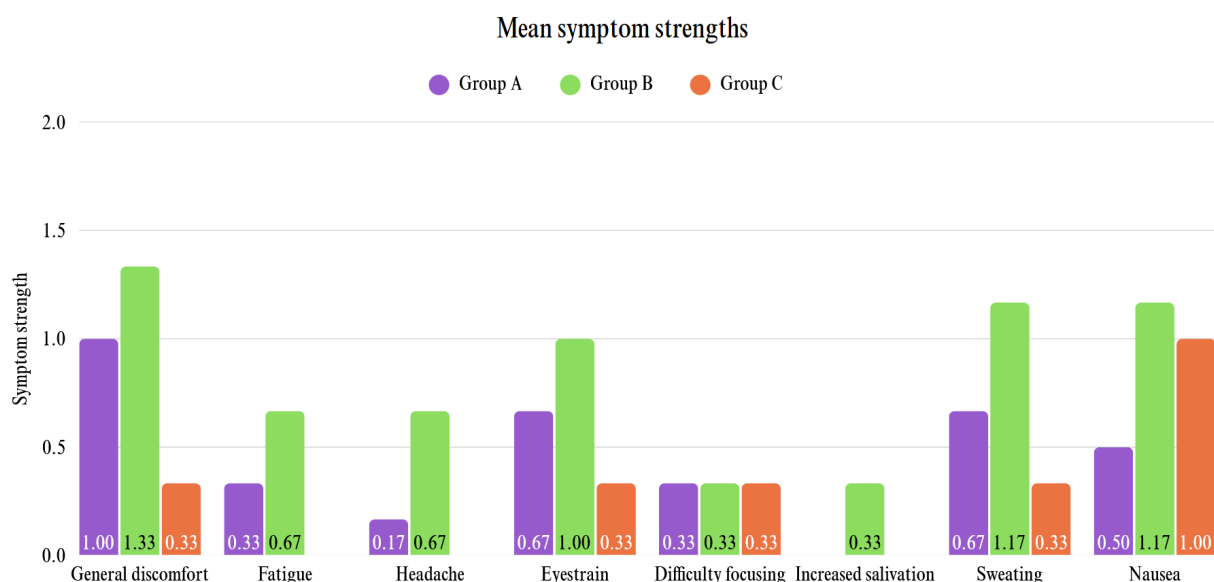
The second most common symptom was general discomfort, reported by 9 out of the 15 participants. Of those 9 participants, 4 rated it as slight, 4 as moderate, and 1 as

severe. Although general discomfort was observed fewer times than dizziness and vertigo, it exhibited a higher rate of moderate and severe ratings.

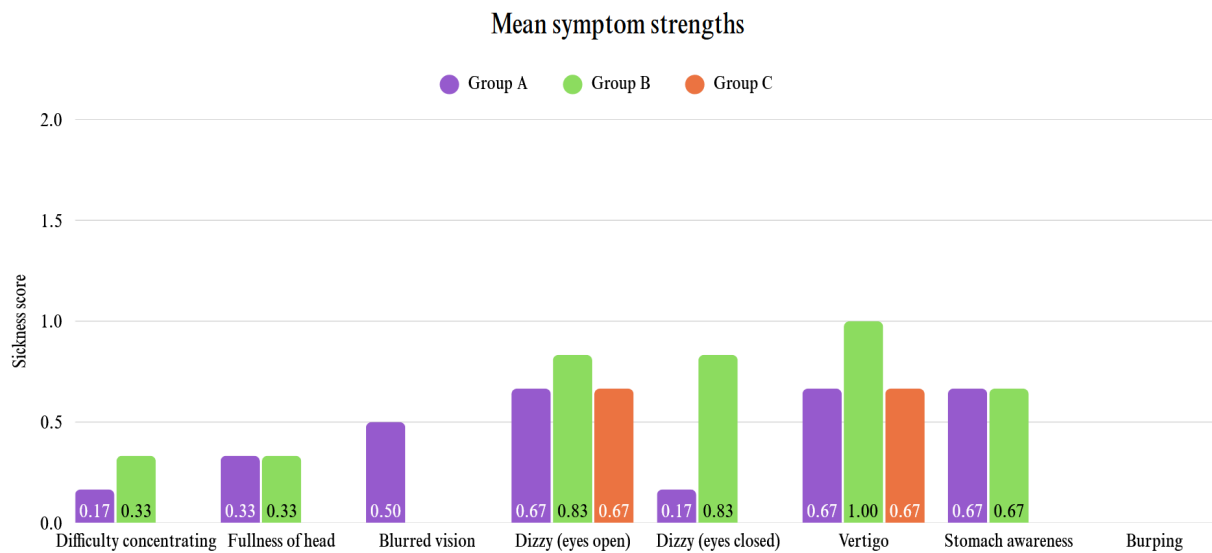
Nausea and eyestrain were the third most common symptoms, both reported by 8 participants. More participants reported higher levels of these symptoms in comparison to dizziness and vertigo, with 4 participants rating nausea at slight, 3 at moderate, and 1 at severe, whereas 6 rated eyestrain at slight, 1 at moderate, and 1 at severe.

Fatigue, sweating, and stomach awareness were each reported by 6 out of 15 participants. The rest of the symptoms were either not experienced at all (burping), or experienced by very few participants (blurred vision with 1 severe case, headache with 1 slight case and 2 moderate cases).

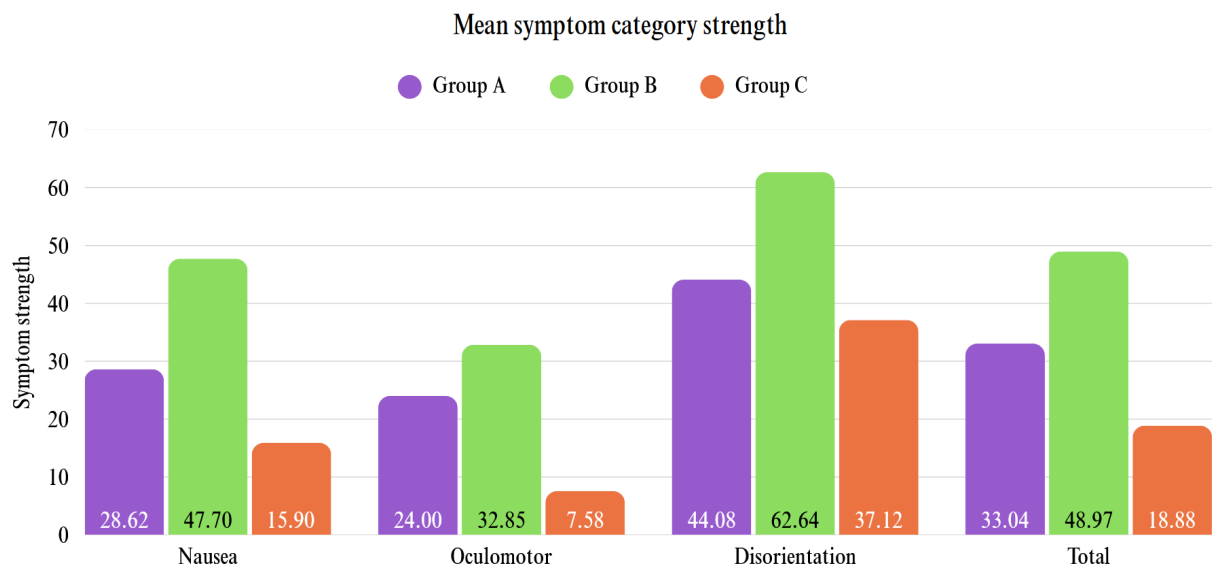
Figures 51 and 52 present the mean SSQ symptom strengths on a scale of 0 to 3, where the values 0, 1, 2, and 3 correspond to the SSQ answers *none*, *slight*, *moderate*, and *severe*. Figure 53 shows the mean strength of each category, as well as the total score, using the equations provided in Section 4.5. Table 5 presents the symptoms in descending order based on the frequency of total reports of any severity above *none*.



Figures 51: Mean scores from the first half of the SSQ symptom table



Figures 52: Mean scores from the second half of the SSQ symptom table



Figures 53: The calculated SSQ symptom categories

Symptom	None	Slight	Moderate	Severe	Total experienced
<i>Vertigo</i>	5	8	2	0	10
<i>Dizzy (eyes open)</i>	5	9	1	0	10
<i>General discomfort</i>	6	4	4	1	9
<i>Nausea</i>	7	4	3	1	8
<i>Eyestrain</i>	7	6	1	1	8
<i>Fatigue</i>	9	6	0	0	6
<i>Stomach awareness</i>	9	4	2	0	6
<i>Sweating</i>	9	2	2	2	6
<i>Difficulty focusing</i>	10	5	0	0	5
<i>Dizzy (eyes closed)</i>	11	2	2	0	4
<i>Headache</i>	12	1	2	0	3
<i>Fullness of head</i>	12	2	1	0	3
<i>Difficulty concentrating</i>	12	3	0	0	3
<i>Increased salivation</i>	13	2	0	0	2
<i>Blurred vision</i>	14	0	0	1	1
<i>Burping</i>	15	0	0	0	0

Table 5: The SSQ symptoms in descending order based on the total frequency of reported symptoms.

5.3 Observations and interview findings

Out of the 15 participants, 12 were unfamiliar with VR, thus requiring additional guidance during the preparation phase. However, several participants had experience with video games in the past and were consequently familiar with the

control scheme, although some had to be reminded that movement speed could be increased by using both joysticks simultaneously. Furthermore, during the ES4, where the mitigation methods were controlled manually, most participants had to be reminded of the controls again. Some also mentioned not initially activating the mitigation methods in order to experience the ES without mitigation.

Observable postural swaying was exhibited by 13 out of 15 during at least one part of the experiment. Notably, 6 participants reported that maintaining balance was easier with camera passthrough. During the experiment 1 participant also noted that it was easier to stay balanced while moving slowly in the virtual environment. A sharp, instinctive body sway was reported by 4 participants during abrupt changes in velocity caused by the elevator and the rollercoaster, suggesting a strong sense ofvection.

The participants were informed prior to the experiment that if their symptoms got too severe or if they started losing balance, they would be allowed to sit down on a chair. Out of the 15 participants, 3 chose to sit down. Out of these participants, 2 sat down during the ES4, and 1 sat down during the ES3. Additionally, upon sitting down, 1 participant paused briefly to close their eyes before continuing the experiment. In the post-experiment interview, the participant reported that closing their eyes helped with the symptoms. Another participant noted that, on top of sitting down, focusing their vision on the virtual hand models during the ES4 helped them feel less sick, indicating that maintaining a fixed reference point may help alleviate symptoms.

When comparing the different mitigation methods, the majority of participants either preferred passthrough in every scenario (6 participants) or preferred it in certain contexts (3 participants). With the participants expressing a contextual preference, they stated that the camera passthrough was immersion-breaking, and they felt that they would prefer the simpler vignette tunnelling effect when they wanted to be more immersed in the experience. Furthermore, 4 participants found the dynamic activation of passthrough during movement distracting or disorienting, stating that they'd prefer it if it were static at all times. These participants generally tended to prefer passthrough during the ES2 and ES4, where the mitigation size either remained constant (ES2) or was controlled by the user independently of movement

(ES4). Lastly, 1 participant who expressed a preference towards passthrough reported that the vignette increased the severity of their symptoms.

Out of the 15 participants, 3 reported an overall preference towards the vignette. Out of these participants, 2 felt like the passthrough was disorienting and unnatural, while 1 considered it too immersion-breaking. Moreover, 1 participant stated that the passthrough exacerbated their symptoms.

Smooth, continuous controller-based turning was used, and the participants were not instructed to turn in any specific way. They were able to either physically rotate their bodies or use the controllers to turn in the virtual environment. The aim was to examine whether there exists a correlation between sickness strength and the preferred turning method. Controller turning was initially used by 4 participants, who later transitioned to turning their physical bodies instead, stating that the continuous controller-based turning made them feel sick, while 3 participants either adapted to controller-based turning or never experienced discomfort using it. Out of the 15 participants, 6 primarily used physical turning, with none of them switching to the other method later on. 2 out of 15 participants used both methods simultaneously to speed up turning.

When asked which part of the experiment the participants considered the worst, 11 participants responded with the rollercoaster, with 5 further clarifying that sharp turns at fast velocity were especially discomforting. Although the question was left open-ended, as explained in Section [4.6](#), the participants predominantly associated cybersickness with being the main cause of discomfort. This aligns with prior research discussed in Sections [3.2.1](#) and [3.3.1](#), indicating sharp turns and fast velocity as primary causes for motion sickness in land-based vehicles. In addition, 1 participant felt that the ES1 and ES3 felt the worst due to controller-based turning, and 2 felt that the drop in the ES3 felt the worst. By contrast, 8 out of the 15 participants felt that the ES1 and ES3 felt the best, 2 stated that the ES2 felt the best, and the rest either did not feel strong enough symptoms to rank them, or they stated that the passthrough rounds in general were the most comfortable. Key interview findings are presented in Table [6](#)

Finding	Amount of participants
Familiarity with VR	12 rarely or never used
Familiarity with video games	13 experienced gamers
Postural swaying	13 during at least one part
The number of participants who chose to sit down	3 total, 1 during ES3, 2 during ES4
Method preference	6 passthrough 3 vignette 3 contextual
Dynamic-static mitigation preference	8 dynamic 4 static
Turning method	Controller turning by 7, with 4 transitioning to physical turning later Physical turning by 6, with none transitioning to controller turning later Both simultaneously by 2
Participant opinions on best/worst part	Best: ES1 as rated by 8 participants Worst: ES4 as rated by 11 participants

Table 6: Key interview findings

6 Discussion

In this chapter, the comparisons between the two mitigation methods are elaborated on, and possible reasons for the effectiveness of the methods are presented. Other factors outside of the mitigation methods that may have contributed to the sickness scores are also discussed here. Finally, this Chapter discusses potential answers to the research questions, as well as the possible limitations present in the conducted experiment.

6.1 Passthrough and vignette comparisons

The data indicate that camera passthrough could be a more effective way of mitigating cybersickness in comparison to a tunnelling vignette, as experimental sections utilising passthrough consistently resulted in lower sickness scores. Even in the experimental sections with slight variation between mean scores, median scores still favoured passthrough. Consequently, the majority of participants either had a strong or a contextual preference towards passthrough, suggesting a more comfortable user experience in certain scenarios, such as high-speed movement.

The order of exposure for both mitigation methods also supports this finding. The mean and median sickness scores for passthrough were consistently lower in comparison to vignette, regardless of order. This further suggests that passthrough is more effective at mitigating cybersickness, as the lower sickness scores are likely not due to either habituation to the virtual environment or the sensory conflict not being in effect yet. Furthermore, the sickness scores for the different rounds of the experimental sections in the control group were fairly equal, indicating that passthrough was more effective at mitigating cybersickness, as habituation did not seemingly have a strong effect on the sickness scores in the control group.

The control group was small in comparison to the mitigation groups, having only 3 participants in it, while the mitigation groups had 6 participants each. Therefore, the data may not be fully accurate with larger sample sizes. However, because the ES4 was completed three times, with the third round completed without any mitigation methods, the data could be extrapolated to indicate that the mitigation methods were both still effective at reducing symptoms. This is due to the third rollercoaster round having noticeably higher mean and median sickness scores in comparison to either

mitigation method, while all three rounds in the control group were fairly equal. Extrapolating from this, it is likely that the results could be similar in the other experimental sections as well, had they also been done a third time without mitigation methods. This, however, is speculative and does not serve as conclusive evidence.

In the ES4, where the mitigation methods had to be activated manually, the data showed that the participants used more mitigation in the second round, regardless of the mitigation method. This suggests that either the participants felt more motion sick after the first rollercoaster round and required more mitigation on the second, or that on the first round, it took the participants some time to figure out how the controls for the mitigation worked. Furthermore, one participant mentioned that they did not initially use mitigation because they wanted to see what it felt like to not use any. Regardless, the data also showed that passthrough resulted in lower sickness scores in both groups, suggesting that even smaller amounts of passthrough were more effective at mitigating cybersickness than using vignette tunnelling at a higher strength.

A possible reason for passthrough resulting in lower sickness scores could be the grounding effect mentioned in Section [4.1](#). This theory is supported by several findings, such as participants exhibiting noticeably less swaying while utilising passthrough, as well as interviews of participants stating that the passthrough helped anchor them in reality and stay balanced. Passthrough also provided the participants a fixed point to focus on during periods of intense movement, which several participants noted as helping with their symptoms. Several participants also mentioned that passthrough was less immersive than the vignette, which could be a result of passthrough grounding them in reality more effectively than the vignette. A possible explanation for these findings is that passthrough is able to negate the sensory conflict by reducing immersion in VR, thereby reducing motion sickness as well.

Preference towards passthrough correlated with susceptibility to cybersickness, as the participants with greater sickness scores tended to have a preference towards passthrough. This could be due to participants with low susceptibility to cybersickness not requiring strong mitigation methods to be able to use VR, which would lead to them having a preference for more immersive experiences instead.

Because passthrough had explicitly been noted as immersion-breaking by several participants, it is likely that having a low susceptibility to cybersickness could result in passthrough being less enjoyable to use. For these individuals, it may even be more enjoyable not to use any mitigation methods than to use passthrough.

Due to the control group reporting lower mean and median sickness scores, the data could also be interpreted to indicate that the mitigation methods actually exacerbate symptoms rather than mitigate them. However, this is unlikely based on several factors. Firstly, as mentioned before, the control group was both smaller and had a greater mean experience level, therefore potentially leading to skewed results. Alongside this, group B, which had the lowest mean experience level, consistently reported the highest sickness scores. As rehabilitation therapy has been shown by prior research to be effective at mitigating motion sickness [66], [75], [94], [95], [96], prior experience with VR would also likely greatly affect the sickness scores. Additionally, prior research has also shown peripheral visual manipulations to reduce symptoms [4], [106], with one of the previously discussed experiments utilising a mitigation method very similar to the vignette tunnelling used in this experiment.

Finally, the third round in ES4 without mitigation in both mitigation groups resulted in greatly increased sickness scores, whereas all ES4 rounds in the control group resulted in fairly equal sickness scores. This finding indicates that the sickness scores would not normally greatly increase over time during the different rounds within an individual ES, therefore the mitigation methods likely were able to mitigate symptoms. If the methods had been ineffective, the sickness scores within the rounds in each individual ES should have been similarly equal to each other as they were in the control group.

6.2 Other factors

The results indicate that less experience with VR correlates with a higher susceptibility to cybersickness, as the highest sickness scores tended to be reported by participants rating their experience as “rarely use”. This trend aligns with findings from prior research suggesting that rehabilitation therapy may be an effective way to treat motion sickness (see Section [3.3.2](#) on rehabilitation therapy). However, the sample size for this experiment was small, with only 4 out of 15 participants rating

their experience as something other than “rarely use”. Therefore, the results might not be accurate with larger sample sizes, although they do align with prior research.

2 out of the 3 control group users were experienced VR users, therefore their scores are not fully comparable to the mitigation groups, where the majority of participants had either rarely or never used VR before. Although the sample size for experienced users is very small, the data does suggest the methods do work in mitigating motion sickness, because the participants of comparable experience levels to the control group reported lower sickness scores. However, because the control group had only one participant in each of the experience levels represented in the group, this data is unreliable as it is essentially comparing one individual’s scores against the mitigation groups.

Several participants noted during the experiment, as well as during the interviews, that faster velocities with sharp turns were the biggest causes for cybersickness. This aligns with prior research discussed in Section [3.2.1](#), which stated that frequent changes in acceleration, as well as stops, starts, and sharp turns, are associated with motion sickness in land vehicles.

The amount of swaying seemed to have correlated with susceptibility to motion sickness, as the participants who experienced cybersickness more strongly tended to sway more during movement. Furthermore, as mentioned in Section [5.3](#), a few participants experienced a sharp involuntary sway as the elevator movement stopped. They mentioned that this was likely due to their bodies anticipating a change in velocity caused by the elevator stopping. A similar sensation would be standing on a moving bus as it is sharply slowing down. This may be due to the sensory conflict, as the bodies are expecting a quick change in velocity that did not end up happening in reality.

Out of the 3 participants who chose to sit down during the experiment, all of them noted that it helped reduce their symptoms. This is likely due to the chair providing more stability to the participants, resulting in less postural swaying. It is possible that the physical sensation of sitting down on a chair also grounded the participants more in reality, thus reducing the sensory conflict. Notably, of the participants who sat down, one also briefly paused to sit still and close their eyes. They noted that this pause helped alleviate their symptoms, which led to a lower sickness score in the

subsequent round of the experiment. It is possible that closing their eyes and sitting still broke the immersion enough to affect the sensory conflict, which consequently resulted in lower symptoms.

Another one of the participants who sat down during the experiment also noted that focusing their vision on the virtual hand models helped with their symptoms. This may have been due to the hand models offering a fixed point to focus on, creating a similar grounding effect as the camera passthrough. This aligns with several participants mentioning during interviews that, while the passthrough was active, if they started to feel too sick, they could focus on some fixed point visible from the cameras to ground themselves in reality.

From the symptom categories mentioned in Section [3.1.3](#), which were nausea, oculomotor, and disorientation, symptoms associated with disorientation were the most common, although nausea and oculomotor were also experienced. Symptom profiles in each group are distinctly D>N>O, which aligns with prior research on cybersickness discussed in Section [3.2](#). Symptom intensities were mostly slight, with some moderate cases and rare severe cases being reported as well. Furthermore, data does not indicate any correlation between age and sickness scores, although this may be due to a small sample size and the ages being skewed mostly in the range of 21-29.

6.3 Research Questions

RQ1 Can camera passthrough be used effectively to mitigate cybersickness?

RH1 Camera passthrough can be used effectively to help mitigate virtual reality sickness

The data gathered during the experiments suggest positive results for the hypotheses made for both research questions. The RQ1 asked whether camera passthrough could effectively be used to mitigate motion sickness, with RH1 stating that the technology could be an effective method to mitigate cybersickness. The assumption was that the passthrough would create a grounding effect, anchoring the participant in reality by displaying their physical surroundings in their peripheral view, thereby reducing symptoms. Because motion sickness is primarily caused by a sensory conflict between the visual and the vestibular systems, it is likely that

displaying the participant's physical surroundings in their peripheral vision reduces this conflict, as a part of their visual stimuli would match their vestibular input. Consequently, several participants noted in the interviews that the passthrough was less immersive and that it allowed them to stay balanced better in comparison to the vignette tunnelling. One participant also stated that the passthrough "tricked their brain into thinking they were looking at a regular computer monitor". This finding suggests a tradeoff between user comfort and immersion, where increasing comfort reduces immersion. Although it is unclear whether the reduction in cybersickness occurred as a result of a grounding effect, the findings do still support the hypothesis of the method being an effective technique to reduce cybersickness.

***RQ2** How does camera passthrough compare against vignette tunnelling in reducing symptoms of cybersickness?*

***RH2** Camera passthrough is more effective than vignette tunnelling in mitigating cybersickness*

The aim of RQ2 was to investigate how camera passthrough compares against vignette tunnelling in reducing symptoms, with RH2 stating that it should be more effective. The hypothesis was based on the assumption that the grounding effect would be a stronger form of mitigation than FoV reduction, which is based on minimising the amount of visual stimuli the user is able to see with the sides of their eyes. The experiment found that sickness scores were consistently lower when passthrough was utilised, thereby indicating that passthrough was more effective, thus supporting the hypothesis, although it is unclear whether the grounding effect is a reason for the increased effectiveness of camera passthrough. One potential explanation for why passthrough may be more effective is that, alongside the grounding effect, the passthrough also functions as an FoV reduction tool. Because both mitigation tools reduced the user's view with a circular shape of equal size, the actual view of the virtual environment was the same in both scenarios. Therefore, the passthrough method essentially included the functionalities of both methods, although it also contained the negative point of being less immersive.

6.4 Limitations

The greatest limitation of this experiment is the small sample size of only 15 participants, of which only 3 were in the control group. The participants in the control

group were also more experienced VR users, possibly leading to skewed results. If the experiment were to be done again, a larger control group with a more equal distribution of experience levels among the different groups would enable a more accurate comparison between the groups. The data had not started to saturate yet, thus a larger group in general could still be feasible as well. Notably, the age range skewed heavily between the ages of 21 and 29, with only 2 participants being over the age of 30. Out of these two, only one was above the age of 40. The mean age for the experiment was 27.5, and the median was 26.

Because the experiment used self-reporting as the main data collection method, it is possible that self-reporting biases could have had an effect on the results. Social desirability bias, for example, may have had an effect as the participants may have been subconsciously giving reports that they feel would be beneficial for the experiment. Recall bias is unlikely to have had an effect, because the FMS, SSQ, and the interview were all done either during the experiment or immediately afterwards.

However, for the FMS and the SSQ, the participants may also have perceived the symptoms and their strengths differently. Some might have underreported their severities, while others may have overreported them. The participants may also interpret the scales differently. As mentioned in Section [3.1.4](#), the FMS uses a scale of 0 to 20, where 0 represents no symptoms, and 20 represents vomiting. Different participants may have different perceptions of how close their symptoms are to vomiting, thus leading to inconsistencies in reporting.

Notably, due to the implementation of the SSQ in this experiment, it does not offer an accurate view of the symptoms with each specific mitigation method. This is due to the SSQ being completed after the experiment, instead of after every ES, which would have been time-consuming. Moreover, it would have likely been detrimental to the immersion factor if the participants had been required to remove the headset to do a questionnaire after each ES. Although the SSQ does not accurately tell how severely the symptoms were felt with each mitigation method, it does still offer a view of what symptoms were present with each participant and, together with the FMS, still provides valuable data, as it can be used to calculate total sickness, while the FMS can be used for sickness scores of specific experimental sections.

Some of the data, such as swaying, was also gathered by observing the participants during the experiment. Everything notable was written down and interpreted qualitatively, but as the experiment only had one person observing the participants, observations may have been influenced by both the observer's own biases and imperfect observations. Therefore, it is possible that some potentially notable observations were not noticed. If the experiment were to be replicated, it would be beneficial to have multiple observers writing down their own observations, which could then be compared for analysis. Despite these limitations, the consistency of reported results across the different mitigation methods and experimental sections suggests that the findings remain valuable, although appropriate caution should be taken when interpreting them.

7 Conclusion

The aim of this thesis was to investigate the root causes behind cybersickness and to determine whether utilising camera passthrough is an effective way of reducing it. To examine this, an experiment with the aim of comparing camera passthrough against vignette tunnelling was conducted, as vignette tunnelling is already an established mitigation technique [4], [5], [6]. The experiment involved the participants traversing across a virtual track purposefully designed to induce an onset of cybersickness. Due to the cybersickness persisting as a major factor limiting the wider adoption of VR, demand for research on mitigation techniques remains.

15 participants of varying levels of VR experience were recruited for this experiment. Data was collected using FMS, SSQ, observation, and interviews to determine how effective the used methods are at mitigating cybersickness in comparison to each other. The data indicates that utilising camera passthrough to display the user's physical surroundings in their peripheral view can be an effective way to mitigate the condition, as participants consistently reported lower sickness scores in various different scenarios when passthrough was used in comparison to the vignette tunnelling. Notably, the majority of participants either had a strong or a contextual preference towards passthrough. A possible explanation for the effectiveness of camera passthrough is a grounding effect caused by participants being able to see parts of their physical surroundings in their peripheral view. This grounding effect may have consequently anchored them into reality, thereby reducing the sensory conflict at the root of the condition. A reduction in the sensory conflict would also explain why the participants were able to stay balanced better while passthrough was being utilised, as their vestibular system would not be receiving mixed signals from their vision and their physical sensations.

The drawback to camera passthrough, as reported by several participants, is the way it breaks immersion. For users with low susceptibility to motion sickness, this could be seen as a negative, as they would likely be more interested in having immersive experiences in VR. In these cases, vignette tunnelling could be preferable to use. Participants with higher sickness scores, however, tended to still prefer passthrough over the vignette.

Other factors contributing to cybersickness, as indicated by the research data, include prior experience with VR, fast movement with a moving platform, turning in the VR environment, and standing up while using VR. Experienced VR users tended to experience fewer symptoms in this experiment, which aligns with prior research on rehabilitation therapy. Fast movement and sharp turns were also stated by several participants to feel the worst in terms of symptoms, while sitting down was mentioned as helping each of the participants who chose to sit down during the experiment. Furthermore, using the controllers to turn with the smooth continuous turning setting was stated by participants to also worsen symptoms in comparison to physically turning around.

The most common symptoms were found to be dizziness and vertigo, experienced by 10 out of 15 participants to some degree. Other common symptoms were nausea and eyestrain, both experienced by 8 out of the 15 participants, although these symptoms were reported with higher severity in comparison to dizziness and vertigo.

These findings may be useful for developers seeking to design more accessibility options in VR applications in order to help new users habituate to VR. Passthrough, in particular, may be useful for potential users who have been hesitant to try the technology because of their susceptibility to motion sickness. Additionally, several participants mentioned that it would be ideal if they were able to switch between different mitigation methods whenever required.

Because camera passthrough is a comparatively new technological advancement in VR devices, its potential to help new users habituate to virtual environments has not been studied extensively as of this thesis. Further research on this topic could include comparisons between static and dynamic mitigation methods. In this experiment, the methods activated during movement and their strength correlated with the user's velocity, with higher velocity leading to stronger mitigation. However, some participants felt that the constant changing of the strength of the mitigation methods felt distracting and disorienting. Therefore, it could be useful to investigate whether keeping the method static the entire time could be equally or more effective. Allowing users to manually control the size of the passthrough window could also provide useful data for what kinds of VR scenarios most induce motion sickness and require more mitigation. Alongside this, including eye tracking technology to examine

how frequently and for how long the participants direct their vision to the passthrough round of the screen during periods of intense motion could provide valuable data on how users tend to utilise the mitigation method. This would help determine whether the participants tend to focus on their physical surroundings for extended periods of time, or whether they tend to keep the passthrough camera image in their peripheral view.

Due to the tradeoff between user comfort and immersion introduced by camera passthrough, avenues for future research could involve finding a balance between these elements. This could be achieved by, for example, introducing smoothing on the passthrough circle, making the edges appear less sharp, implementing a semi-transparent passthrough displaying both the virtual and the physical environment simultaneously, or adding a coloured filter over the passthrough image corresponding to dominant colours in the virtual view.

Prior research on VIMS also indicated that pleasant music may potentially have an effect in reducing symptoms of motion sickness. As VR is frequently used for gaming, where soundtracks are commonly used to play ambient music during gameplay, further research on the effects of music on cybersickness could provide useful information on other potential mitigation techniques.

Furthermore, validating the data gathered in this experiment is also important, as the small sample size could have skewed the results. A larger sample size would also be beneficial in allowing for both mitigation methods to have their own groups, rather than both groups using both methods, which could cause a second-order effect, thereby influencing sickness scores.

Overall, the experiment provided positive results with regard to mitigating cybersickness, demonstrating that camera passthrough has the potential to be an effective technique to mitigate the condition. As the use of this technology for this purpose is still relatively unexplored, it is likely that there are more effective ways of designing passthrough-based mitigation tools than what was examined in this thesis, such as finding ways to combine it with other known techniques. The low cost and ease of implementation could contribute to wider adoption of VR technology by providing a more accessible way of experiencing VR for people hesitant to invest in the technology due to their susceptibility to cybersickness. By contrast,

hardware-based solutions requiring additional control interfaces tend to be more costly while potentially also requiring large amounts of empty space to be used, thereby introducing additional barriers for individuals interested in VR. Conversely, passthrough techniques can be implemented entirely in software on consumer headsets equipped with cameras.

As VR technology continues to expand into new fields beyond being a research curiosity, reducing cybersickness will become increasingly important to ensure accessibility for a wider consumer audience. By demonstrating the effectiveness of camera passthrough technology as a simple and cost-effective technique for reducing cybersickness, this thesis contributes to a growing body of research on making VR technology more comfortable for a wider user base and to support the development of more accessible immersive VR experiences.

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Appendices

Appendix 1. Initial Experiment plan

13.03.2025

Versio 5

Tutkimussuunnitelma virtuaalitodellisuuden aiheuttaman pahoinvoinnin minimoimisesta

Tutkimuksen tavoite ja tarkoitus

Virtuaalitodellisuus (VR) on kasvava teknologian ala, joka tarjoaa uusia mahdollisuuksia esimerkiksi viihteessä, koulutuksessa ja terveydenhuollossa. Kuitenkin VR-ympäristön käyttöön liittyy usein pahoinvointia, joka tunnetaan myös nimellä cybersickness. Pahoinvoinnin oireet, kuten huimaus, päänsärky ja pahoinvointi, voivat haitata teknologian käyttöä ja rajoittaa sen hyödyllisyyttä. Tämä tutkimus pyrkii kartoittamaan pahoinvointia aiheuttavia tekijöitä VR-ympäristöissä ja kehittämään keinoja sen minimoimiseksi.

Perustelut tutkimukselle

- **Virtuaalitodellisuuden laajeneva käyttö:** VR:n käyttö lisääntyy jatkuvasti eri toimialoilla, ja sen käyttökokemus on tärkeä osa teknologian hyväksyttävyyttä. Ymmärtämällä pahoinvoinnin syitä ja kehittämällä keinoja sen ehkäisemiseksi, voidaan parantaa VR:n saavutettavuutta.
- **Pahoinvoinnin vähentäminen parantaa käyttökokemusta:** VR-pahoinvointi on merkittävä este sen pitkäaikaiselle käytölle. Tämän tutkimuksen tulokset voivat johtaa VR-kokemuksen laadun parantamiseen.

Tutkimuskysymykset:

1. Mitkä ovat keskeiset tekijät, jotka aiheuttavat pahoinvointia VR-ympäristössä?
2. Kuinka eri teknologiset ratkaisut vaikuttavat pahoinvointiin?
3. Millaisia käytännön menetelmiä voidaan kehittää pahoinvoinnin minimoimiseksi VR-käytön aikana?

Tutkimusasetelma:

Tutkimus on kokeellinen tutkimus, jossa testihenkilöitä altistetaan pahoinvoinnille virtuaalitodellisuutta käyttäen ja heidän reaktionsa pahoinvointiin mitataan.

Tutkimusasetelma on kontrolloitu kokeilu, jossa verrataan useita eri pahoinvointia vähentäviä toimenpiteitä. Tutkimukseen sisällytetään myös kontrolliryhmä, jossa jokainen osallistuja käyttää järjestelmää ilman pahoinvointia vähentäviä metodeja. Kontrolliryhmään kuuluvat määritellään satunnaisvalinnalla.

Pahoinvointia aiheuttavana virtuaalitodellisuusympäristönä toimii rata, jonka läpi pelaajan tulee kulkea suuntamerkkejä seuraten. Rataan kuuluu ylä- ja alamäkiä, itsestään liikkuvia tasoja, riippusiltoja, sekä pudotuksia. Pahoinvointia pyritään minimoimaan näkökentän kaventamisella muutamalla eri tyylillä.

- Dynaamisella kaventamisella, jossa näkökenttä kapenee pelaajan nopeudesta riippuen joko mustalla, sumealla, tai värillisellä reunalla. Tarkoituksena selvittää vaikuttaako reunuksen väri pahoinvointiin
- Staattisella kaventamisella, jossa reunukset pysyvät koko ajan saman paksuisina ja ovat joko läpinäkyviä (camera passthrough) tai dynaamisia reunoja vastaavia. Tarkoituksena selvittää, vaikuttaako reunuksen dynaamisuus pahoinvointiin.

Testissä osallistujat pelaavat esteradan läpi kaikkia metodeja käyttäen niin, että käytettäviä metodeja testataan radan jokaisessa vaiheessa ennen seuraavaan siirtymistä. Esimerkiksi riippusilta ylitetään ensin dynaamisilla metodeilla ja sen jälkeen staattisilla metodeilla, jonka jälkeen siirrytään pudotukseen joka koetaan myös kaikilla metodeilla. Kontrolliryhmä vuorostaan pelaa esteradan läpi ilman mitään pahoinvointia vähentäviä metodeja. Kaikki radan vaiheet suoritetaan yhtä monta kertaa kuin koeryhmässä, jotta kontrolliryhmä olisi immersoitunut virtuaalitodellisuuteen koeryhmää vastaavan ajan verran.

Tiedonkeruumenetelmät:

Tutkimuksessa tietoa kerätään pääosin kyselylomakkeilla ja haastatteluilla, joissa testihenkilöt arvioivat omia kokemuksiaan pahoinvoinnista virtuaalitodellisuuden seurauksena. Käytettäviä mittareita voivat olla esimerkiksi

- Simulator Susceptibility Questionnaire (SSQ): Yksi yleisimmistä kyselyistä matkapahoinvointia tutkittaessa, joka täytetään tutkimuksen

jälkeen.

- Fast Motion Sickness Scale (FMS): Toinen yleinen matkapahoinvoinnin tutkimuksessa käytettävä mittari. Testihenkilöä pyydetään antamaan arvio pahoinvoinnin suuruudesta säännöllisin väliajoin tutkimuksen aikana.

Tietoa kerätään myös havainnoimalla esimerkiksi testihenkilön käyttäytymistä tai huojumista.

Tutkittavien rekrytointi

Tutkittavan henkilön tulee olla perusterve 18-50 vuotias ihminen. Poissulkeviin kriteereihin kuuluu esimerkiksi vakavat raskaus, psykologiset tai neurologiset ongelmat, sydänsairaudet, epilepsia yms. Aiempaa kokemusta virtuaalitodellisuudesta ei vaadita. Tutkittava henkilö ei saa olla päihtyneenä testiä tehdessä.

Tutkittavien henkilöiden arvioitu lukumäärä

Tutkimukseen osallistuu arvioidusti 10-20 ihmistä, joista osa toimii kontrolliryhmänä. Tutkimushenkilöiden rekrytoiminen lopetetaan, kun data alkaa saturoitumaan.

Tutkimuksen kulku ja arvioitu kesto

Ennen tutkimusta osallistujat täyttävät terveystarkastuksen ja ilmoittavat aikaisemmista VR-kokemuksistaan. Tämän jälkeen tehdään testauksen alkuvalmistelut, jossa lasit säädetään osallistujalle sopivaksi ja hänelle kerrataan testin kulku. Testauksen aikana henkilö altistetaan pahoinvointia aiheuttaville ärsykkeille ja häntä pyydetään arvioimaan pahoinvointinsa suuruus tasaisin väliajoin. Testin jälkeen tutkittava henkilö täyttää lomakkeen oireistaan.

Terveystarkastus ja alkuvalmistelu - noin 20 minuuttia

Testi - Enimmillään 30 minuuttia, voidaan pysäyttää milloin tahansa jos testihenkilö niin haluaa. Kirjallisuuskatsauksen mukaan pahimmat oireet ilmaantuvat yleensä noin 20 minuutin sisällä, mutta osalla saattaa tulla myöhemminkin.

Loppukysely - noin 20 minuuttia

Testattava henkilö osallistuu tutkimukseen arvioidusti siis noin tunnin ajan.

Eettiset näkökohdat:

- Tietoinen suostumus: Kaikilta osallistujilta kerätään kirjallinen suostumus, jossa selitetään tutkimuksen tarkoitus, kesto ja mahdolliset riskit. Osallistujia tiedotetaan oikeudestaan keskeyttää osallistuminen milloin tahansa ilman seuraamuksia.
- Anonymiteetti ja tietosuojat: Kaikki kerätty data anonymisoidaan, ja henkilötietoja käsitellään EU:n yleisen tietosuojalain mukaisesti. Tutkittavien henkilöiden tiedoista säilytetään ikä ja sukupuoli, koska tieto on olennaista tutkimuksessa. Kaikki muut tunnistettavat tiedot poistetaan, jonka jälkeen henkilölle määritellään numero. Henkilön tietoja käsitellään tästä eteenpäin tuona numerona. Anonymisoidut tiedot säilytetään salatussa tietokannassa enimmillään 10 vuotta, jonka jälkeen ne tuhoetaan.
- Mahdolliset riskit: Tutkimuksessa käytettävät VR-sessiot voivat aiheuttaa pahoinvointia. Osallistujille tehdään selväksi että he saavat keskeyttää session milloin tahansa ilman mitään seuraamuksia.

Tutkimuksen hyöty: Tulosten avulla voidaan kehittää VR-tekniikoita, jotka vähentävät pahoinvointia ja parantavat käyttökokemusta. Tämä voi edistää VR:n laajempaa hyödyntämistä eri aloilla.

Tutkimuksen vastuuhenkilöt:

- Tutkimuksen tekijä: Viljo Kankare
- Tutkimuksen ohjaajat: Olli Heimo ja Taneli Nyyssönen

Appendix 2. Experiment notice in Finnish

TIEDOTE TUTKIMUKSESTA

Mitigating Motion Sickness in Virtual Reality

Pyyntö osallistua tutkimukseen

Sinua pyydetään mukaan tutkimukseen, jossa tutkitaan mitkä tekijät vaikuttavat virtuaalitodellisuuden (VR) käyttäjillä esiintyvään pahoinvointiin ja miten tätä ilmiötä voitaisiin vähentää. Tämä tiedote kuvaa tutkimusta ja siihen osallistumista.

Sinua pyydetään osallistumaan tähän tutkimukseen, koska täytät tutkimuksen tutkittavalta vaadittavat kriteerit. Osallistumisen poissulkevat kriteerit ovat vakavat fyysiset, neurologiset tai psykologiset haitat, kuten sydänongelmat, epilepsia tai paniikkihäiriö.

Vapaaehtoisuus

Tutkimukseen osallistuminen on vapaaehtoista. Voit kieltäytyä osallistumasta tutkimukseen, keskeyttää tutkimuksen tai peruuttaa antamasi suostumuksen osallistua tutkimukseen milloin tahansa ilman, mitään negatiivisia vaikutuksia. Tutkimuksen keskeyttämiseen ja suostumuksen perumiseen riittää vain sanallinen ilmoitus tutkijoille missä tahansa vaiheessa.

Peruuttaessasi suostumuksesi henkilötietojesi käsittelyyn, sinusta siihen mennessä kerättyjä henkilötietoja ei voida käsitellä osana tutkimusta, vaan ne hävitetään, mikäli niiden poistaminen aineistosta on mahdollista.

Tutkimuksen toteuttaja ja rahoittaja

Tämän tutkimuksen toteuttavat Viljo Kankare

Tutkimuksessa ei ole rahoittajia tai mahdollisia eturistiriitoja.

Tutkimuksen kulku

Osallistujat käyttävät VR-laitteita ja suorittavat virtuaalitodellisuusympäristöön luodun radan. Koeryhmään kuuluvien osallistujien virtuaalitodellisuusympäristössä hyödynnetään eri metodeja pahoinvoinnin vähentämiseen. Koeryhmän lisäksi osa osallistujista jaetaan kontrolliryhmään, jossa esterata suoritetaan ilman mitään pahoinvointia vähentäviä metodeja. Ryhmiin jakaminen suoritetaan satunnaisella valinnalla.

Tutkimuksen aikana osallistujaa pyydetään tasaisin väliajoin kuvaamaan oireitaan. Tutkimuksen jälkeen osallistujat vastaavat kyselyyn, jossa kartoitetaan oireitaan, kuten huimausta, pahoinvointia ja epämukavuutta. Kokeen kesto on noin 1 tunti. Tutkimus toteutetaan Turun yliopiston Agora -rakennuksen Mixed Reality laboratoriossa.

Tutkimuksesta mahdollisesti aiheutuvat hyödyt ja haitat

Tutkimuksen tuloksia voidaan hyödyntää VR-teknologian kehittämisessä ja käyttökokemuksen parantamisessa.

VR-laitteiden käyttäminen saattaa aiheuttaa joillekin osallistujille lieviä pahoinvoinnin oireita, jotka kuitenkin yleensä häviävät nopeasti laitteen käytön lopettamisen jälkeen. Tutkimushenkilökunta on paikalla koko kokeen ajan ja tarjoaa tarvittaessa apua. Jos osallistuja haluaa keskeyttää tutkimuksen, paikalla oleva tutkija on valmiina heti pysäyttämään pelin ja poistamaan VR-lasit osallistujalta.

Tutkimuksesta maksettavat korvaukset

Tutkimukseen osallistumisesta ei makseta palkkiota.

Henkilötietojen käsittely

Tutkimuksessa saadut tiedot ovat luottamuksellisia. Aineiston keräämisen jälkeen kaikki tiedot anonymisoidaan ja heidän tietojaan käsitellään numerona. Tutkimuksessa kerättäviä henkilötietoja käsitellään tietosuojasetuksen mukaisesti (ks. tietosuojaseloste).

Tutkittavaa ei ole mahdollista tunnistaa tutkimuksessa käytettävistä tiedoista. Osallistujien henkilökohtaisista tiedoista säilytetään vain ikä ja sukupuoli. Tiedot säilytetään salasanalla suojatussa arkistossa, jonne on pääsyoikeus vain tutkimusryhmän jäsenillä.

Tutkimusaineiston säilyttäminen ja tutkimustulosten raportointi

Tutkimuksessa kerätyt aineistot säilytetään salasanalla suojatussa arkistossa, joihin pääsee käsiksi vain tutkimuksesta vastuussa olevat henkilöt. Tiedot säilytetään enimmillään 10 vuotta, jonka jälkeen ne tuhoetaan. Aineistot avataan uudestaan vain mikäli tutkija haluaa tehdä jatkotutkimusta kyseessä olevasta aiheesta.

Tutkimustulokset raportoidaan opinnäytetyössä.

Lisätietojen antajan yhteystiedot

Sinulla on mahdollisuus kysyä tutkimukseen liittyviä lisätietoja Viljo Kankareelta.

Viljo Kankare
Tekniikan kandidaatti
Tutkimuksen tekijä
Tietotekniikan laitos
vvkank@utu.fi
+358442807232

Tutkimuksen allekirjoittaa

Olli Heimo
Filosofian tohtori
Tutkimuksen ohjaaja
Tietotekniikan laitos
oli.heimo@utu.fi

Taneli Nyyssönen
Väitöskirjatutkija
Tutkimuksen ohjaaja
Tietotekniikan laitos
ttjnyy@utu.fi

Appendix 3. Consent Form in Finnish

Suostumus osallistua tieteelliseen tutkimukseen

Mitigating Motion Sickness in Virtual Reality

Turun yliopisto Agora -rakennus
huone 453, Mixed Reality lab

Turun Yliopiston teknillinen tiedekunta

Viljo Kankare

Minua on pyydetty osallistumaan yllä mainittuun tutkimukseen.

Olen lukenut ja ymmärtänyt saamani tutkimustiedotteen ja tietosuojaselosteen. Ymmärrän, että tutkimukseen osallistuminen on vapaaehtoista ja voin milloin tahansa syytä kertomatta keskeyttää osallistumiseni tutkimukseen tai peruuttaa antamani suostumuksen ilman kielteisiä seurauksia. Minusta suostumuksen peruuttamiseen saakka kerättyjä tietoja ei käytetä osana tutkimusaineistoa.

Olen saanut riittävät tiedot tutkimuksesta ja henkilötietojeni käsittelystä. Minulla on ollut mahdollisuus esittää tutkijoille tarkentavia kysymyksiä. Allekirjoituksellani osoitan suostumukseni tutkimukseen osallistumiseen.

Osallistumalla tutkimukseen suostun siihen, että tunnistettomia tietoja voidaan käyttää tutkimuksessa, joka tulee olemaan julkisesti saatavilla.

Osallistumalla tutkimukseen suostun siihen, että tunnistetun tutkimusaineisto voidaan arkistoida ja avata myöhempään käyttöön.

Vahvistus

Osallistuminen tutkimukseen tulkitaan vahvistuksena.

Yhteystiedot

Viljo Kankare vvkank@utu.fi

Appendix 4. Privacy Notice in Finnish

Mitigating Motion Sickness in Virtual Reality -tutkimuksen tietosuojaseloste

Olet ottamassa osaa Turun yliopistossa järjestettävään tieteelliseen tutkimukseen. Tässä tietosuojaselosteessa kerrotaan, miten henkilötietojasi käsitellään tutkimuksessa.

1. Rekisterinpitäjä

Tutkija: Viljo Kankare

Yhteyshenkilö tutkimusta koskevissa asioissa:

Nimi: Viljo Kankare

Puh.: +358 442807232

E-mail: vvkank@utu.fi

2. Kuvaus tutkimuksesta ja henkilötietojen käsittelystä

Tämä tutkimus pyrkii selvittämään, mitkä tekijät vaikuttavat virtuaalitodellisuuden (VR) käyttäjillä esiintyvään pahoinvointiin ja miten tätä ilmiötä voitaisiin vähentää. Tutkimuksen tuloksia voidaan hyödyntää VR-teknologian kehittämisessä ja käyttökokemuksen parantamisessa.

Tutkittavien henkilötiedoista käytetään virtuaalitodellisuuden aiheuttaman pahoinvoinnin oireita ja niiden vahvuutta. Sen lisäksi osallistujien tiedoista säilytetään ikä, sukupuoli ja aiempi kokemus virtuaalitodellisuudesta, koska niillä saattaa olla vaikutus tutkimustuloksiin. Kaikki tiedot kerätään ilman suoria tunnistetietoja ja tietoja käsitellään numerona. Tiedot säilytetään salasanalla suojatussa arkistossa, jonne on pääsyoikeus vain tutkimusryhmän jäsenillä.

3. Henkilöt, jotka osallistuvat henkilötietojen käsittelyyn

Viljo Kankare

4. Henkilötietojen käsittelyn kesto

Tietoja säilytetään enimmillään 10 vuotta, jonka jälkeen ne tuhotaan. Aineistot avataan uudestaan vain, mikäli tutkimuksen tekijä haluaa suorittaa jatkotutkimusta kyseisestä aiheesta. Tietoja käytetään julkisesti saatavilla olevassa opinnäytetyössä.

5. Henkilötietojen lainmukainen käsittelyperuste

Henkilötietojen käsittely perustuu tietosuoja-asetuksen 6(1) artiklan alakohtaan:

☒ yleistä etua koskeva tehtävä:

☒ tieteellinen tai historiallinen tutkimus tai tilastolliset tarkoitukset

☐ tieteellisten aineistojen tai kulttuuriperinnöllisten materiaalien arkistointi

☐ rekisteröidyn suostumus

☐ rekisterinpitäjän lakisääteisen velvoitteen noudattaminen

☐ rekisterinpitäjän tai kolmannen osapuolen oikeutettu etu

6. Tutkimusaineistoon sisältyvät henkilötiedot

Tutkimuksessa käsitellään seuraavia henkilötietoryhmiä: ikä, sukupuoli, aikasemmat kokemukset virtuaalitodellisuudesta.

7. Erityiset henkilötietoryhmät (arkaluontoiset henkilötiedot)

Tutkimuksessa käsitellään seuraavia erityisiä henkilötietoryhmiä: vakavat fyysiset, psyykkiset tai neurologiset oireet/diagnoosit (poislukevat tekijät), kärsiikö tutkittava matkapahoinvoinnista ja millaisin oirein.

8. Henkilötietojen keräämisen lähteet

Tutkimuksessa tietoa kerätään pääosin kyselylomakkeilla ja haastatteluilla, joissa testihenkilöt arvioivat omia kokemuksiaan pahoinvoinnista virtuaalitodellisuuden seurauksena. Käytettäviä mittareita voivat olla esimerkiksi

- Simulator Sickness Questionnaire (SSQ): Yksi yleisimmistä kyselyistä matkapahoinvointia tutkittaessa, joka täytetään tutkimuksen jälkeen.
- Fast Motion Sickness Scale (FMS): Toinen yleinen matkapahoinvoinnin tutkimuksessa käytettävä mittari. Testihenkilöä pyydetään antamaan arvio pahoinvoinnin suuruudesta säännöllisin väliajoin tutkimuksen aikana.

Tietoa voidaan myös kerätä havainnoimalla esimerkiksi testihenkilön käyttäytymistä tai huojumista.

9. Henkilötietojen suojatoimenpiteet

Tietojärjestelmissä käsiteltäviä tietoja suojataan seuraavilla tavoilla:

- ☒ käyttäjätunnus ja salasana
- ☐ käytön rekisteröinti/lokitus
- ☐ kulunvalvonta
- ☐ salaus/kryptaus
- ☐ kaksivaiheinen tunnistautuminen
- ☐ muu, mikä:

Suorien tunnistetietojen käsittely:

- ☐ Aineisto kerätään ilman suoria tunnistetietoja
- ☒ Suorat tunnistetiedot poistetaan analysointivaiheessa:
Kaikki tunnistettavat tiedot poistetaan ja jäljelle jätetään vain ikä ja sukupuoli.
- ☐ Aineisto analysoidaan suoran tunnistetiedon, koska:

10. Henkilötietojen siirtäminen ja jakaminen kolmansille osapuolille

Henkilötietoja ei siirretä rekisterinpitäjän ulkopuolelle.

11. Henkilötietojen siirtäminen EU:n tai ETA:n ulkopuolelle

Henkilötietoja ei siirretä Euroopan unionin tai Euroopan talousalueen ulkopuolelle.

12. Henkilötietojen käsittely tutkimuksen päättymisen jälkeen

- ☐ Tutkimusaineisto poistetaan
- ☐ Tutkimusaineisto säilytetään tämän tutkimuksen tulosten luotettavuuden arvioimista varten:
 - ☐ ilman suoria tunnistetietoja ☐ tunnistetiedoin

☒ Tutkimusaineisto säilytetään myöhempää, yhteensopivaa tieteellistä tutkimusta varten tietosuojasetuksen vaatimusten mukaisesti:

☒ ilman suoria tunnistetietoja ☐ tunnistetiedoin

Tutkimusaineisto säilytetään Seafilessä enimmillään 10 vuotta.

Tutkimusaineiston säilytys perustuu tietosuojasetuksen 5 artiklan 1 kohdan b ja e alakohtiin. Tutkimusaineiston uudesta tutkimuskäytöstä lähetetään tutkittaville uusi tietosuojaseloste, paitsi jos rekisterinpitäjä ei enää pysty tunnistamaan tutkittavia tutkimusaineistosta. Uudesta tutkimuksesta ei voida lähettää ilmoitusta rekisteröidylle myöskään silloin, jos tietojen toimittaminen olisi mahdotonta tai kohtuuttoman vaivalloista tai jos se estäisi tai vaikeuttaisi suuresti tutkimustarkoitusten saavuttamista (tietosuojasetuksen 14 artiklan 5 kohdan b alakohta).

13. Rekisteröidyn oikeudet sekä niihin tehtävät poikkeamat

Lisätietoa tietosuojasetuksen mukaisista oikeuksista antaa kohdassa 1 mainittu yhteyshenkilö.

Rekisteröidyn oikeudet

Tietosuojasetuksen mukaan rekisteröidyllä on oikeus:

- tarkistaa itseään koskevat tiedot (15 artikla)
- oikaista omia tietoja (16 artikla)
- poistaa tiedot ja tulla unohdetuksi (17 artikla)
- rajoittaa omien tietojen käsittelyä (18 artikla)
- siirtää tiedot rekisterinpitäjältä toiselle (20 artikla)
- vastustaa tietojen käsittelyä (21 artikla)
- olla joutumatta automaattisen päätöksenteon kohteeksi (22 artikla)

Rekisteröity ei kuitenkaan voi käyttää kaikkia oikeuksia kaikissa tilanteissa, riippuen esimerkiksi siitä, mikä on henkilötietojen käsittelyperuste.

Rekisteröidyn oikeuksiin tehtävät poikkeamat

Tietosuojalainsäädäntö mahdollistaa rekisteröidyn oikeuksista poikkeamisen silloin, kun henkilötietoja käsitellään tieteellisessä tutkimuksessa ja oikeuksien toteuttaminen estäisi tai vaikeuttaisi suuresti käsittelyn tarkoitusten saavuttamista. Tarve tehdä poikkeamia rekisteröityjen oikeuksiin arvioidaan aina tapauskohtaisesti.

Tämän tietosuojaselosteen tutkimuksessa on todennäköisesti tarpeen tehdä poikkeamia seuraaviin rekisteröityjen oikeuksiin:

- ☐ Oikeus tarkistaa itseään koskevat tiedot (15 artikla)
- ☐ Oikeus oikaista omia tietoja (16 artikla)
- ☐ Oikeus poistaa tiedot ja tulla unohdetuksi (17 artikla)
- ☐ Oikeus rajoittaa omien tietojen käsittelyä (18 artikla)
- ☐ Oikeus vastustaa tietojen käsittelyä (21 artikla)

Jos henkilötietojen käsittely tutkimuksessa ei edellytä rekisteröidyn tunnistamista eikä rekisterinpitäjä pysty tunnistamaan rekisteröityä, niin oikeutta tietojen tarkastamiseen, oikaisuun, poistoon, käsittelyn rajoittamiseen, ilmoitusvelvollisuuteen ja siirtämiseen ei

sovelleta, ellei rekisteröity pysty antamaan luotettavan tunnistamisen mahdollistavia lisätietoja (11 artikla).

Valitusoikeus

Sinulla on oikeus tehdä valitus tietosuojavaltuutetulle, jos koet, että henkilötietojasi on käsitelty soveltuvan tietosuojalainsäädännön vastaisesti.

Tietosuojavaltuutetun yhteystiedot:

Tietosuojavaltuutetun toimisto
Käyntiosoite: Lintulahdenkuja 4, 00530 Helsinki
Postiosoite: PL 800, 00531 Helsinki
Puhelinvaihe: 029 566 6700
Sähköposti (kirjaamo): tietosuoja(at)om.fi

Appendix 5. Experiment Notice in English

EXPERIMENT NOTICE

Mitigating Motion Sickness in Virtual Reality

Request to Participate in a Study

You are invited to participate in a study that investigates which factors influence the motion sickness experienced by users of virtual reality (VR) and how this phenomenon could be reduced. This notice describes the study and what participation involves.

You are being asked to take part in this study because you meet the criteria required of participants. Exclusion criteria include serious physical, neurological, or psychological conditions, such as heart problems, epilepsy, or panic disorder.

Voluntary Participation

Participation in the study is voluntary. You may refuse to participate, terminate the session, or withdraw your consent to participate at any time without any negative consequences. To terminate the session or to withdraw consent, a verbal notification to the researchers at any stage is sufficient.

If you withdraw your consent for the processing of your personal data, any personal data collected from you up to that point will no longer be processed as part of the study and will be deleted, provided that its removal from the data set is possible.

Study Organizer and Funding

This study is conducted by Viljo Kankare.

The study has no external funding or potential conflicts of interest.

Study Procedure

Participants will use VR equipment and complete a course created within a virtual reality environment. In the experimental group, different methods to reduce motion sickness will be utilized in the virtual environment. In addition to the experimental group, some participants will be assigned to a control group, in which the obstacle course is completed without any motion sickness mitigation methods. Group assignment will be carried out randomly.

During the study, participants will be asked at regular intervals to describe their symptoms. After the study, participants will complete a questionnaire assessing their symptoms, such as dizziness, nausea, and discomfort. The duration of the experiment is approximately one hour. The study will be conducted at the Mixed Reality Laboratory in the Agora building of the University of Turku.

Possible Benefits and Risks of the Study

The results of the study may be used in the development of VR technology and in improving the user experience.

The use of VR equipment may cause mild symptoms of nausea in some participants; however, these symptoms usually disappear quickly after stopping use of the device. Research staff will be present throughout the experiment and will provide assistance if needed. If a participant wishes to terminate the session, the researcher present will be ready to immediately stop the simulation and remove the VR headset from the participant.

Compensation for Participation

No compensation will be paid for participation in the study.

Processing of Personal Data

The data collected in the study will be treated as confidential. After data collection, all data will be anonymized and processed using numerical identifiers. Personal data collected in the study will be handled in accordance with data protection regulations (see the privacy notice).

Participants cannot be identified from the data used in the study. Only age and gender will be retained from participants' personal information. The data will be stored in a password-protected archive, accessible only to members of the research team.

Storage of Research Data and Reporting of Results

The data collected in the study will be stored in a password-protected archive, accessible only to those responsible for the research. The data will be retained for a maximum of 10 years, after which it will be destroyed. The data will only be reopened if the researcher wishes to conduct further research on the topic.

The results of the study will be reported in a thesis.

Contact Information for Further Details

You have the opportunity to ask for additional information about the study from Viljo Kankare.

Viljo Kankare
Bachelor of Science in Technology
Researcher
Department of Computing
vvkank@utu.fi
+358442807232

Study signatories

Olli Heimo
Doctor of Philosophy
Thesis supervisor
Department of Computing

oli.heimo@utu.fi

Taneli Nyyssönen
Doctoral Researcher
Thesis supervisor
Department of Computing

ttjnny@utu.fi

Appendix 6. Consent Form in English

Consent to Participate in Scientific Research

Mitigating Motion Sickness in Virtual Reality

University of Turku, Agora Building
Room 453, Mixed Reality Lab

Department of Computing, University of Turku

Viljo Kankare

I have been asked to participate in the above-mentioned study.

I have read and understood the research information sheet and the privacy notice provided to me. I understand that participation in the study is voluntary and that I may withdraw from the study or revoke my consent at any time without giving a reason and without any negative consequences. Any data collected from me up to the point of revocation of consent will not be used as part of the research data.

I have received sufficient information about the study and the processing of my personal data. I have had the opportunity to ask the researchers clarifying questions. By signing, I indicate my consent to participate in the study.

By participating in the study, I consent to the use of anonymized data in research that will be publicly available.

By participating in the study, I consent to the anonymized research data being archived and made available for later research.

Confirmation

Participation in the study is interpreted as confirmation.

Contact Information

Viljo Kankare vvkank@utu.fi

Appendix 7. Privacy Notice in English

Privacy Notice for the “Mitigating Motion Sickness in Virtual Reality” Study

You are about to participate in a scientific study conducted at the University of Turku. This privacy notice explains how your personal data will be processed in the study.

1. Data Controller

Researcher: Viljo Kankare

Contact person for matters related to the study:

Name: Viljo Kankare

Phone: +358 442807232

E-mail: vvkank@utu.fi

2. Description of the Study and Processing of Personal Data

This study aims to investigate which factors influence the motion sickness experienced by users of virtual reality (VR) and how this phenomenon can be reduced. The results of the study may be used to develop VR technology and improve the user experience.

The personal data collected from participants will include symptoms of VR-induced nausea and their severity. In addition, participants' age, gender, and previous VR experience will be recorded, as these may affect the study results. All data will be collected without direct identifiers and processed numerically. The data will be stored in a password-protected archive, accessible only to members of the research team.

3. Persons Involved in the Processing of Personal Data

Viljo Kankare

4. Duration of Personal Data Processing

The data will be stored for a maximum of 10 years, after which it will be destroyed. The data will only be accessed again if the researcher wishes to conduct follow-up research on the topic. The data will be used in a publicly available thesis.

5. Legal Basis for Processing Personal Data

The processing of personal data is based on Article 6(1) of the GDPR:

- ☒ Task carried out in the public interest:
 - ☒ Scientific or historical research or statistical purposes
 - ☐ Archiving of scientific or cultural heritage materials
- ☐ Consent of the data subject
- ☐ Compliance with a legal obligation of the data controller
- ☐ Legitimate interests of the data controller or a third party

6. Personal Data Included in the Research Dataset

The study will process the following categories of personal data: age, gender, and previous experience with virtual reality.

7. Special Categories of Personal Data (Sensitive Personal Data)

The study will process the following special categories of personal data: severe physical, psychological, or neurological symptoms/diagnoses (exclusion criteria), whether the participant suffers from motion sickness, and the nature of their symptoms.

8. Sources of Personal Data Collection

In this study, data will primarily be collected through questionnaires and interviews, in which participants assess their own experiences of nausea resulting from virtual reality. The measures used may include, for example:

- 1 Simulator Sickness Questionnaire (SSQ): One of the most common questionnaires used to study motion sickness, completed after the experiment.
- 2 Fast Motion Sickness Scale (FMS): Another common measure in motion sickness research. Participants are asked to rate the severity of their nausea at regular intervals during the study.

Data may also be collected through observation, such as monitoring participants' behavior or signs of swaying.

9. Measures to Protect Personal Data

Data processed in information systems is protected using the following methods:

- ☒ Username and password
- ☐ Usage logging
- ☐ Access control
- ☐ Encryption
- ☐ Two-factor authentication
- ☐ Other, specify:

Processing of Direct Identifiers:

- ☐ Data is collected without direct identifiers
- ☒ Direct identifiers are removed during the analysis phase:
 - All identifiable information is removed, leaving only age and gender.
- ☐ Data is analyzed with direct identifiers because:

10. Transfer and Sharing of Personal Data with Third Parties

Personal data will not be transferred outside of the data controller.

11. Transfer of Personal Data Outside the EU or EEA

Personal data will not be transferred outside the European Union or the European Economic Area.

12. Processing of Personal Data After the Completion of the Study

- ☐ The research data will be deleted.
- ☐ The research data will be retained to assess the reliability of this study's results:
 - ☐ without direct identifiers ☐ with direct identifiers
- ☒ The research data will be retained for future, compatible scientific research in accordance with the GDPR:
 - ☒ without direct identifiers ☐ with direct identifiers

The research data will be stored in Seafire for a maximum of 10 years.

The retention of research data is based on Articles 5(1)(b) and 5(1)(e) of the GDPR. A new privacy notice will be sent to participants if the data are used for new research, except when the data controller can no longer identify the participants from the research data. Notification will also not be sent if providing the information is impossible, unreasonably difficult, or would significantly hinder or obstruct the achievement of the research purposes (Article 14(5)(b) of the GDPR).

13. Rights of the Data Subject and Exceptions to Those Rights

Further information about your rights under the GDPR can be obtained from the contact person mentioned in Section 1.

Rights of the Data Subject

Under the GDPR, data subjects have the right to:

- Access their personal data (Article 15)
- Rectify their personal data (Article 16)
- Erase their personal data and be forgotten (Article 17)
- Restrict the processing of their personal data (Article 18)
- Data portability – transfer data from one controller to another (Article 20)
- Object to the processing of their data (Article 21)
- Not be subject to automated decision-making (Article 22)

However, data subjects may not be able to exercise all rights in every situation, depending, for example, on the legal basis for processing the personal data.

Exceptions to the Data Subject's Rights

Data protection legislation allows for exceptions to data subject rights when personal data is processed for scientific research, and exercising those rights would significantly prevent or hinder the achievement of the processing purposes. The need for exceptions is assessed on a case-by-case basis.

In this study, it may be necessary to make exceptions to the following data subject rights:

- ☐ Right to access personal data (Article 15)
- ☐ Right to rectify personal data (Article 16)
- ☐ Right to erase personal data and be forgotten (Article 17)
- ☐ Right to restrict the processing of personal data (Article 18)
- ☐ Right to object to data processing (Article 21)

If the processing of personal data in the study does not require identifying the data subject and the data controller cannot identify the data subject, the rights to access, rectify, erase, restrict processing, notification obligations, and data portability do not apply, unless the data subject provides additional information that enables reliable identification (Article 11).

Right to Lodge a Complaint

You have the right to lodge a complaint with the Data Protection Authority if you believe that your personal data has been processed in violation of applicable data protection legislation.

Tietosuojavaltuutetun yhteystiedot:

Contact Information for the Data Protection Authority:

Data Protection Ombudsman Office

Visiting Address: Lintulahdenkuja 4, 00530 Helsinki

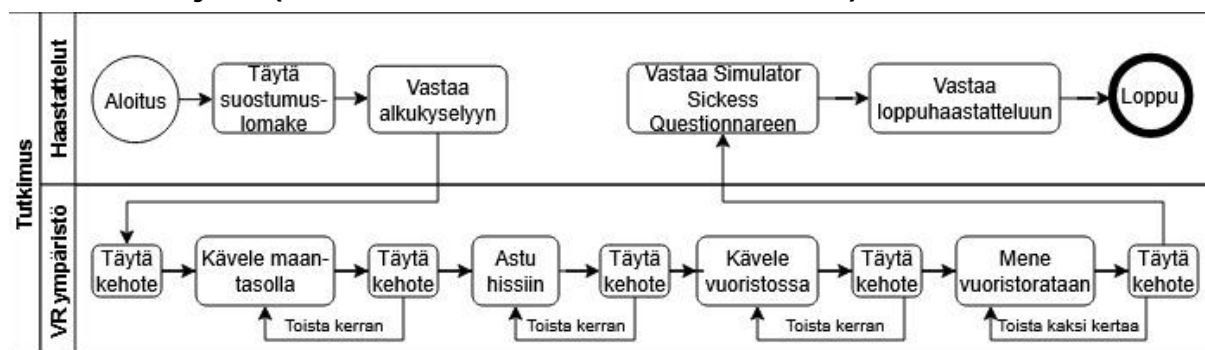
Postal Address: P.O. Box 800, 00531 Helsinki

Phone: +358 29 566 6700

Email (Registry): tietosuoja(at)om.fi

Appendix 8. Experiment Instructions in Finnish

Kokeen ohjeet (kokonaiskesto ~45-75 minuuttia)



Ennen koetta osallistuja lukee läpi ohjeistukset ja allekirjoittaa suostumuslomakkeen. Tämän jälkeen suoritetaan lyhyt alkukysely.

Liikepahoinvointi virtuaalitodellisuudessa on suuri teknologian yleistymistä ja käyttömukavuutta rajoittava tekijä, ja tutkimuksen pääasiallinen tavoite on löytää tapoja vähentää pahoinvointia. Kokeessa kartoitetaan liikepahoinvoinnin esiintymistä virtuaalitodellisuudessa, sekä vertaillaan kahta eri menetelmää pahoinvoinnin vähentämiseksi. Ensimmäinen käyttää VR -lasien kameroita fyysisen ympäristön näyttämiseen näkökentän reunoilla liikkeen aikana (läpivienti). Toinen käyttää mustaa vinjettiä näkökentän kaventamiseen liikkeen aikana. Tutkimuksesta kerätyllä datalla on mahdollista tehdä VR-teknologiasta saavutettavampaa laajemmalle yleisölle.

Kokeen aikana VR-sovellus pyytää ilmoittamaan liikepahoinvoinnin oireiden voimakkuuden asteikolla 0-20, jossa 0 tarkoittaa oireiden puutetta ja 20 tarkoittaa oksentamista. **Mikäli koet oireiden muuttuvan liian voimakkaiksi, voit keskeyttää kokeen milloin tahansa ilman seurauksia.** Lisäturvallisuuden vuoksi ohjaaja on lähellä tarkkailemassa tilannetta mahdollisen kaatumisen varalta. Älä epäröi ilmoittaa ohjaajalle/valvojalle, mikäli tunnet alkavasi menettää tasapainoasi, tai haluat keskeyttää kokeen mistä tahansa muusta syystä.

Ohjaimet

- Liikkuminen tapahtuu kumman tahansa ohjaimen sauvan avulla
 - Useamman sauvan käyttäminen saa sinut liikkumaan nopeammin
 - Vuoristoradassa läpiviennin/vinjetin kokoa säädetään samalla tavalla
- Kehotteen liikusäätimen ja "vahvista" napin painaminen tapahtuu kumman tahansa ohjaimen liipaisin -napin avulla
- Mikäli jäät jumiin, voit käyttää ohjainten B tai Y -nappia teleportataksesi edelliselle välietapille
- Radan alussa on lyhyt harjoitus ohjaimille
 - Takanasi on kehote, käänny ympäri ohjainta käyttäen, syötä jokin numero ja paina "vahvista"
 - Numerolla ei ole tässä harjoituksessa vielä väliä
 - Koe alkaa numeron syötön jälkeen, et pysty liikuttamaan itseäsi VR -ympäristössä ennen harjoituksen suoritusta

VR-rata

- Neljä vaihetta
 - Kävely maan tasolla, hissi, kävely vuoristossa, vuoristorata
- Kaikki vaiheet kahdesti, kerran kummallakin pahoinvointia vähentävällä menetelmällä
 - Kontrolliryhmä suorittaa kaikki vaiheet kahdesti ilman mitään lievennysmenetelmiä
- Ensimmäisessä kolmessa osiossa menetelmät aktivoituvat automaattisesti liikkeen aikana
- Vuoristoradassa menetelmät aktivoidaan manuaalisesti ohjainten sauvojen avulla

- Vuoristorata suoritetaan myös kolmannen kerran ilman lieventäviä menetelmiä
- Kokeen aikana nouseaan kahdesti hissiin, jotka aktivoituvat käveltäessä niiden keskellä olevalle harmaalle alustalle
- Kun näet kyltin “odota hissiä”, ylitä maahan merkitty viiva, jolloin hissi laskeutuu pian eteesi merkittyyn kohtaan
- Vuoristorataosuudessa vaunuun siirtyminen tapahtuu automaattisesti lähestyessä sitä merkitystä suunnasta
 - Mikäli katseesi ei ole automaattisesti ajosuuntaa kohti, suuntaa se sinne

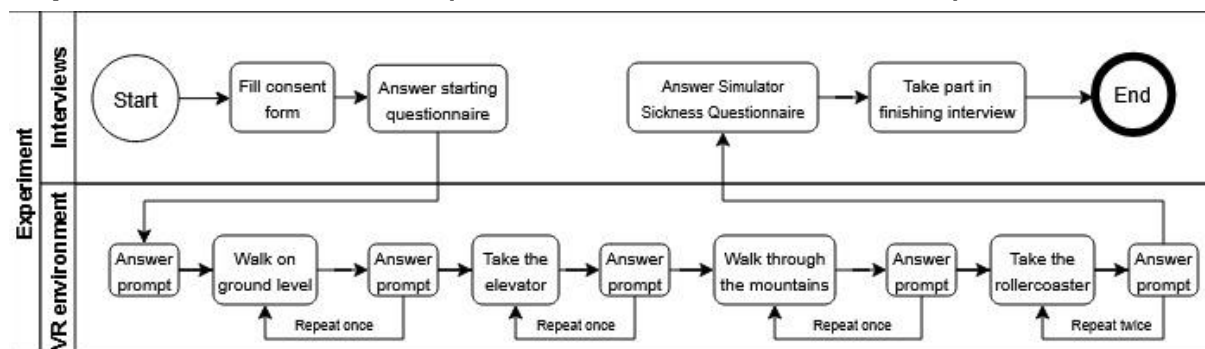
Kokeen jälkeen

- Täytetään *Simulator Sickness Questionnaire* (SSQ)
 - Kartoittaa liikepahoinvoinnin eri oireita ja niiden vahvuuksia
- Semistrukturoitu haastattelu tutkimuksesta
- Kokeesta tallentuu lokitietoja myöhempää analysointia varten.
 - Tietoihin kuuluu kokeen kesto, keskimääräiset liikkumisnopeudet eri vaiheissa, keskimääräinen vahvuus vuoristoradan läpiviennistä/vinjetistä.
- Kokeen jälkeen suoritettavasta haastattelusta tehdään luvan kanssa nauhoite
 - Haastattelusta voi halutessaan kieltäytyä ilman seuraamuksia, jolloin siitä otetaan vain kirjalliset muistiinpanot
- Tutkimuksen osallistujat voivat myös pyytää nähdä tiedonhallintasuunnitelman.

Kokeen voi keskeyttää koska tahansa mistä tahansa syystä ilman mitään seuraamuksia. Halutessaan osallistujat voivat myös pyytää datan tuhoamista, mutta myös kesken jääneiden kokeiden tiedoista on hyötyä tutkimuksen kannalta.

Appendix 9. Experiment Instructions in English

Experiment instructions (full duration ~45-75 minutes)



Before the experiment the participant will read through the instructions and sign the consent form. After this there will be a short starting questionnaire.

The experiment investigates the occurrence of motion sickness in virtual reality and compares two different methods of reducing its symptoms. The first uses camera passthrough to display the user's physical environment at the edges of their field of view during movement. The second method uses a black vignette to reduce the user's field of view during movement. Motion sickness in virtual reality is a major factor in limiting the accessibility and usability of the technology, and the main goal of this research project is to find ways to reduce its symptoms. The data collected from this study could help make VR technology more accessible to a wider audience.

Throughout the experiment the VR application will prompt you to input the severity of your motion sickness symptoms on a scale of 0-20, with 0 meaning no symptoms and 20 meaning vomiting. **If you feel that the symptoms are becoming too severe, you may terminate the experiment at any time without consequences.** For additional safety the supervisor will be nearby monitoring the situation in case of an imminent fall. Please do not hesitate to alert the supervisor if you feel like you are starting to lose your balance or wish to terminate the experiment for any other reason.

Controls

- Moving happens by using either controller's joystick
 - Using multiple joysticks makes you move faster
 - During the rollercoaster ride, the passthrough/vignette size is controlled in the same way
- The trigger button on either controller is used to interact with the prompt's slider and the "confirm" button
- If you get stuck, you can use the B or Y button on the controllers to teleport to the most recent waypoint
- The track begins with a short tutorial for the controls
 - Behind you is a prompt, turn around using the controller, input a number, and press "confirm"
 - The number inputted in the tutorial does not matter
 - The test begins after inputting a number, you will not be able to move yourself in the VR environment before completing the tutorial

VR-track

- Four sections
 - Walking on the ground, elevator, walking in the mountains, rollercoaster
- Each section is done twice, once with both mitigation methods
 - The control group completes each section twice without any mitigation methods
- During the first three sections, the mitigation methods activate automatically during movement
- During the rollercoaster, the mitigation methods are activated manually with the controller's joystick

- The rollercoaster is also done a third time without any mitigation methods
- During the experiment you will take an elevator twice, activating them by stepping on the grey spot in the middle
- When you see the sign “wait for the elevator”, cross the marked line and an elevator will descend in a marked spot shortly
- Entering the rollercoaster cart happens automatically when approaching it from the marked path
 - If your eyes are automatically not directed at the front, orient yourself towards it

After the experiment

- Fill the *Simulator Sickness Questionnaire* (SSQ)
 - Assesses different symptoms of motion sickness and their strength
- Semi-structured interview
- The experiment will log data for further analysis
 - Logged data includes the duration of the experiment, the average movement speeds in different sections, and the average strength of passthrough/vignette during the rollercoaster
- With permission, the post-experiment interview may be recorded
 - You are allowed to decline the recording without any consequences, in which case only written notes will be taken
- You may also request to view the data management plan

The experiment may be terminated at any point for any reason with no consequences. You may request all collected data to be deleted, although data from incomplete experiments will still be useful for the purposes of the research.

Appendix 10. Data Management Plan

Plan Overview

A Data Management Plan created using DMPTuuli

Title: Mitigating Motion Sickness in Virtual Reality

Creator: Viljo Kankare

Affiliation: University of Turku

Template: Research data management plan for students

Project abstract:

The project's goal is finding ways to reduce the motion sickness induced by virtual reality. This is done through an experiment where volunteer participants play through a motion sickness inducing virtual reality game while utilizing one or more techniques for reducing said sickness. The data is gathered via a questionnaire filled after the experiment where the participant goes through the motion sickness symptoms experienced throughout the experiment.

ID: 27049

Start date: 01-10-2024

End date: 31-07-2026

Last modified: 08-04-2026

Mitigating Motion Sickness in Virtual Reality

Research data

List of research data:

Research data type	Contains personal details/information*	I will gather/produce the data myself	Someone else has gathered/produced the data	Other notes
Questionnaire		x		Data will be anonymised
Observation		x		
Interview		x		Data will be anonymised

Questionnaire contains data about the symptoms of motion sickness, as well as the participant's sex and age. Observation contains data about the participant's behaviour as affected by the experiment. Interview is a general open interview where the participant can give feedback about the experiment as well as any extra details about their symptoms.

Processing personal data in research

Does your data contain personal data?

- My data does not contain personal data

Who is the data controller?

- My data does not contain any personal data

Permissions and rights related to the use of data

Who has collected the data you use in your research?

- I have collected the data

If you use data that you have collected by yourself you may need separate permissions to use the data you collect or produce, both in research and in publishing the results. If you are archiving your data, remember to ask the research participants for the necessary permissions for archiving and further use of the data. Also, find out if the repository/archive you have selected requires written permissions from the participants.

Every participant is given information about the experiment beforehand as well as the option to ask any extra questions about it. After that they sign an informed consent document that allows the usage of their data. The data will be handled in a way that complies with the GDPR.

If you use data that someone else has collected: do you have the necessary permissions to use the data in your research and to publish the results? Are

there copyright or licencing issues involved in the use of the data? Note, for example, that you may need permission to use the images or graphs you have found in publications.

Data collected by outside parties will not be used.

Storing the data during the research process

Where will you store your data during the research process?

- In the university-provided Seafire Cloud Service

If you don't use University's data storage services tell, where are you going to store your data and specify how you will ensure data security and file backups?

Data will be stored in the University's Seafire cloud service.

Documenting the data and metadata

Can you describe what has happened to your research data during the research process? Data documentation is essential when you try to track any changes made to the data.

- To document the data, I will use A separate document where I will record the main points of the data, such as changes made, phases of analysis, and significance of variables

I will keep a separate document that contains the collected data of the symptoms, how severe the symptoms are and how long it took the participant to reach the symptoms. I will also write down any observations on the participants' behaviour throughout the experiment as well as the interview questions and answers.

If you don't use any of the above mentioned, describe, how you document your research process?

See above

How will you keep your data in order and intact, as well as prevent any accidental changes to it?

- I will keep the original data files separate from the data I am using in the research process, so that I can always revert back to the original, if need be

The data will not be modified.

Metadata is a description of your research data. Based on metadata someone unfamiliar with your data will understand what it consists of. Metadata should include, among others, the file name, location, file size, and information about the producer of the data. Will you require metadata?

- I will not store my data into a public archive/repository, and therefore I will not need to create any metadata.

Data after completing the research

What happens to your research data, when the research is completed?

Data will be stored at most for 10 years, after which it will be destroyed.

If you will store the data, please identify where and for how long?

All data will be kept in the University's Seafire cloud service until it is destroyed.

Appendix 11. Explanation of the Participant Recruiting and Consent Acquisition Processes

Selvitys tutkittavien valinnasta

Tutkittavia etsitään pääosin mainostamalla erilaisia tietokanavia pitkin, (Discord, Sosiaalinen media) ja hyödyntämällä henkilökohtaisia suhteita. Tutkimukseen osallistuminen on vapaaehtoista ja tutkimusmainoksessa annetaan yhteystiedot vastuuhenkilölle, jotta he voivat ottaa itse yhteyttä tutkijaan ilman mitään painostusta. Yhteydenoton jälkeen tutkittavan kanssa sovitaan tapaamisaika yliopiston Mixed Reality -laboratoriossa, joka tulee olemaan ainoa tapaaminen tutkittavan kanssa tutkimuksen tiimoilta

Kuvaus suostumuksen saamiseksi noudatettavasta menettelystä

Tutkittavalle annetaan lomakkeet, jossa selitetään tutkimuksen tarkoitus, kulku ja mahdolliset riskit. Lisäksi tutkittavalle annetaan mahdollisuus kysyä lisätietoa niin paljon kuin hän kokee tarvitsevänsä. Tutkittavaa ei missään välissä painosteta antamaan suostumusta ja hänelle tehdään selväksi, että hän voi missä välissä tahansa vetää suostumuksensa pois ja lähteä tutkimuksesta ilman mitään negatiivisia seurauksia.

Appendix 12. Estimate of the Ethicality of the Experiment

Arvio tutkimuksen eettisyydestä

Tutkimuksen aihe: Virtuaalitodellisuuden aiheuttama pahoinvointi

Tutkittavien informointi ja rekrytointi: Tutkimukseen osallistuville annetaan kattava ja selkeä informaatio tutkimuksen tavoitteista, menetelmistä, mahdollisista riskeistä ja osallistumisen vapaaehtoisuudesta. Osallistujille tarjotaan mahdollisuus kysyä lisäkysymyksiä ennen suostumuksen antamista, ja kirjallinen suostumus kerätään ennen tutkimuksen aloittamista. Rekrytointi tapahtuu avoimesti ja syrjimättä, ja osallistujia informoidaan siitä, että he voivat keskeyttää osallistumisensa milloin tahansa ilman negatiivisia seuraamuksia.

Käytetyt menetelmät ja aineiston keräämisen käytännöt: Tutkimusmenetelmät on suunniteltu minimoimaan osallistujille aiheutuvaa pahoinvointia.

Tutkimushenkilökunta on jatkuvasti läsnä tarjoamassa apua ja tarvittaessa keskeyttämässä kokeen, mikäli osallistuja kokee mahdolliset pahoinvoinnin oireet liian vahvoiksi. Aineiston kerääminen tapahtuu kyselylomakkeen avulla, jossa kysytään vain tutkimuksen kannalta olennaisia asioita. Kaikki data anonymisoidaan henkilötietojen suojaamiseksi.

Aineiston analyysi ja tulkinta: Aineiston analyysi suoritetaan tieteellisesti ja objektiivisesti varmistaen, että tulokset ovat luotettavia ja oikeudenmukaisia. Mahdolliset harhat ja virheet pyritään minimoimaan huolellisella suunnittelulla ja toteutuksella. Kaikki tulokset raportoidaan rehellisesti, eikä negatiivisia tai odottamattomia tuloksia piiloteta.

Aineiston säilytys ja arkistointi: Tutkimuksessa kerätty aineisto säilytetään turvallisesti ja luottamuksellisesti. Vain tutkimusryhmän jäsenillä on pääsy aineistoon, ja kaikki henkilötiedot anonymisoidaan ennen analyysiä. Aineisto arkistoidaan siten, että se on myöhemmin hyödynnettävissä jatkotutkimuksia varten, mikäli sille on tarvetta. Aineisto säilytetään enimmillään 10 vuotta, jonka jälkeen se tuhotaan.

Tulosten julkaisu: Tutkimuksen tulokset julkaistaan avoimesti ja rehellisesti julkisesti saatavilla olevassa opinnäytetyössä, huomioiden osallistujien anonymiteetti.

Tutkimuksessa saavutetut tulokset esitetään objektiivisesti, ja mahdolliset rajoitukset tuodaan esiin selkeästi.

Aineiston omistajuus ja hallinnointi: Tutkimusryhmässä on sovittu aineiston omistajuudesta ja hallinnoinnista ennen tutkimuksen aloittamista. Kaikki osapuolet ovat tietoisia aineiston käyttöoikeuksista ja -rajoituksista. Julkaisujen tekijyyttä ja tekijänoikeuksia koskevat sopimukset on tehty kirjallisesti, jotta mahdolliset riitatilanteet voidaan välttää.

Riskien arviointi:

- **Fyysiset riskit:** Lievät pahoinvoinnin oireet, kuten huimaus ja oksettava olo, ovat mahdollisia VR-laitteiden käytön yhteydessä. Riskien hallitsemiseksi osallistujia seurataan jatkuvasti, ja heille tarjotaan mahdollisuus keskeyttää koe milloin tahansa.
- **Psykologiset riskit:** Psykologiset riskit ovat vähäisiä, mutta osallistujia kannustetaan raportoimaan mahdollisista epämukavuuden tunteista.
- **Sosiaaliset ja taloudelliset riskit:** Tutkimus ei sisällä merkittäviä sosiaalisia tai taloudellisia riskejä osallistujille. Osallistuminen ei aiheuta heille kustannuksia, eikä osallistujien anonymiteetti vaarannu.
- **Ympäristöriskit:** Tutkimuksessa ei ole ympäristöriskejä.

Riskienhallinta: Riskien toteutumisen todennäköisyys on alhainen, ja käytössä on riittävät keinot riskien hallitsemiseksi. Mikäli riski toteutuu, tutkimushenkilökunta on valmis tarjoamaan tarvittavaa apua ja tukea.

Suostumuksesta poikkeaminen: Tutkimuksessa ei poiketa tietoon perustuvan suostumuksen periaatteesta. Kaikki osallistujat antavat suostumuksensa vapaaehtoisesti ja tietoisesti.

Allekirjoitukset:

Opinnäytetyön ohjaajat:

Taneli Nyyssönen

Taneli Nyyssönen



Olli Heimo

Opinnäytetyön tekijä:

VKankare

Viljo Kankare

Appendix 13. Data Processing Impact Assessment

Henkilötietojen suoja koskeva vaikutustenarviointi (DPIA) tieteellisessä tutkimuksessa

Vaikutustenarvioinnin (DPIA = Data Processing Impact Assessment) tarkoituksena on auttaa tunnistamaan, arvioimaan ja hallitsemaan henkilötietojen käsittelyyn sisältyviä riskejä. Vaikutustenarviointi on osa tietosuojalainsäädännön vaatimusten noudattamista ja dokumentointia.

Tietoa vaikutustenarvioinnista:

<https://tietosuoja.fi/vaikutustenarviointi>

Vaikutustenarviointi on tehtävä silloin, kun suunniteltu käsittely todennäköisesti aiheuttaa korkean riskin ihmisten oikeuksille ja vapauksille. Vaikutustenarviointi on tehtävä tieteellisessä tutkimuksessa erityisesti silloin, kun

- 3 Henkilötietojen käsittelyssä käytetään uutta teknologiaa
- 4 Käsitellään rikostuomioita, rikkomuksia tai erityisiä henkilötietoryhmiä, kuten terveystietoja, etnistä alkuperää, poliittisia mielipiteitä, uskonnollista vakaumusta tai seksuaalista suuntautumista
- 5 Tehdään profilointia tai automaattisia päätöksiä
- 6 Käsitellään geneettisiä tietoja
- 7 Rekisterinpitäjä poikkeaa rekisteröidyn informoinnista. Vaikutustenarviointi on tehtävä silloin, kun rekisterinpitäjä kerää henkilötiedot muualta, kuin rekisteröidyltä ja poikkeaa tietosuoja-asetuksen mukaisesta informoinnista, koska

- o tietojen toimittaminen osoittautuu mahdottomaksi (erityisesti, kun tietoja käsitellään yleisen edun mukaisia arkistointitarkoituksia taikka tieteellisiä tai historiallisia tutkimustarkoituksia tai tilastollisia tarkoituksia varten)
 - o tietojen toimittaminen vaatisi kohtuutonta vaivaa (erityisesti, kun tietoja käsitellään yleisen edun mukaisia arkistointitarkoituksia taikka tieteellisiä tai historiallisia tutkimustarkoituksia tai tilastollisia tarkoituksia varten)
 - o informointiin vaadittujen tietojen toimittaminen todennäköisesti estää tarkoitusten saavuttamisen tai vaikeuttaa sitä suuresti.
- Kun aiotaan poiketa määrätystä rekisteröityjen oikeuksista ja käsitellään erityisiä henkilötietoja. Tällöin vaikutustenarviointi täytyy lisäksi toimittaa tietosuojavaltuutetulle ennen tutkimuksen aloittamista.

Tarkempi luettelo tilanteista, joissa vaikutustenarviointi on tehtävä:

<https://tietosuoja.fi/luettelo-vaikutustenarviointia-edellyttavista-kasittelytoimista>

1. Henkilötietojen käsittelyn kuvaus

- **Käsittelyn luonne**

Tutkimuksessa pyritään selvittämään tapoja minimoida virtuaalitodellisuuden aiheuttamaa pahoinvointia. Osallistujilta kerätään tietoja tutkimuksen aikana aiheutuvasta pahoinvoinnista ja tuloksia käytetään selvittämään mitkä keinot johtavat pienimpään määrään pahoinvointia.

- **Käsittelyn laajuus**

Käsiteltävään tietoon kuuluu osallistujan pahoinvointi testin eri vaiheissa, osallistujan ikä ja osallistujan sukupuoli. Pahoinvoinnin tiedot kerätään tutkimuksen aikana tasaisin väliajoin pyytämällä osallistujaa arvioimaan pahoinvoinnin suuruutta jollain asteikolla, sekä tutkimuksen jälkeen tarkemmalla kyselylomakkeella eri pahoinvoinnin oireista. Tutkimukseen oletetaan osallistuvan noin 10-30 ihmistä ja kerättyjä tietoja säilytetään salatussa arkistossa enimmillään 10 vuotta.

- **Käsittelyn toiminnallinen kuvaus** (millaista käsittelyä tietoon kohdistuu)

Tiedot kerätään kyselylomakkeella ja tutkimuksen aikana tapahtuvalla havainnoinnilla. Aineistosta poistetaan kaikki mahdolliset tunnistettavat tiedot. Tietoja analysoidaan vertaamalla eri pahoinvoinnin minimointimetodien aikana aiheutuneita oireita toisiinsa, jotta voidaan määritellä mikä metodi toimisi parhaiten oireiden minimoimiseen.

- **Käsittelyn resurssien yksilöinti**

Tietoon pääsee käsiksi vain tutkimusryhmän jäsenet. Tietoja säilytetään salasanalla suojatussa arkistossa (Seafile). Tiedonsiirron kanavana toimii arkistona käytävä pilvipalvelu.

2. Käsittelyn oikeasuhteisuutta ja tarpeellisuutta edistävät toimenpiteet

- **Nimeä yksi tai useampi käsittelyn tietty, nimenomainen ja laillinen tarkoitus**

Käyttötarkoituksena on tieteellinen tutkimus opinnäytetyönä.

- **Nimeä käsittelyn lainmukaisuuden peruste**

Tutkimus on tieteellisenä tutkimuksena yleistä etua koskeva, sekä tutkittava antaa tietoisien suostumuksensa.

- **Kuinka on huolehdittu siitä, että tiedot ovat olennaisia, asianmukaisia ja rajoitettuja siihen, mikä on tarpeellista tietojenkäsittelyn tarkoitusten toteuttamista varten**

Tiedot kerätään enimmäkseen kyselylomakkeilla, joihin on rajattu aiheiksi vain tutkimukselle olennaiset tiedot. Tutkimussuunnitelmassa on tarkempi kuvaus tutkimuksessa kerättävästä tiedosta, sekä tutkimuksen tarkoituksesta ja tavoitteista.

- **Kuinka käsiteltävien henkilötietojen elinkaaren aikana on huolehdittu siitä, että tiedot säilytetään muodossa, josta tutkittava on tunnistettavissa ainoastaan niin kauan kuin on tarpeen tietojenkäsittelyn tarkoitusten toteuttamista varten**

Kyselylomakkeissa kysytään vain ja ainoastaan tutkimuksessa käytettäviä tietoja, jolloin mitään tunnistettavia tietoja ei tule niistä esille.

3. Tutkittavien oikeuksia edistävät toimenpiteet tutkimuksessa

- **Tutkittavalle annetut tiedot**

Tutkittaville jaetaan tiedotteet tutkimuksesta sekä siitä, miten heidän tietojaan aiotaan käyttää. Tutkittaville annetaan myös mahdollisuus kysyä lisäkysymyksiä niin paljon kuin he kokevat tarpeelliseksi.

- **Kuinka tutkittavan oikeus tarkastaa tiedot toteutetaan?**

Tutkittaville annetaan tutkimuksen vastuuhenkilön yhteystiedot, jolta he voivat kysyä tiedoistaan, mikäli ne on vielä mahdollista yhdistää tutkittavaan henkilöön hänen pyynnöstään tietojen anonymisoinnin jälkeen.

- **Jos tutkittavalla on oikeus siirtää tiedot järjestelmästä toiseen, kuinka tämä toteutetaan?**

Tutkittava voi käyttää oikeuttaan ottamalla yhteyttä tutkimuksen vastuuhenkilöön

- **Kuinka tutkittavan oikeus oikaista/poistaa tiedot toteutetaan?**

Tutkittava voi käyttää oikeuttaan ottamalla yhteyttä tutkimuksen vastuuhenkilöön.

- **Kuinka tutkittavan oikeus vastustaa tai rajoittaa käsittelyä toteutetaan?**

Tutkittava voi käyttää oikeuttaan ottamalla yhteyttä tutkimuksen vastuuhenkilöön.

- **Käytetäänkö tutkimuksessa henkilötietojen käsittelijöitä ja miten toiminta on ohjeistettu?**

Tutkittavien tietoja voivat käsitellä ainoastaan tutkimusryhmän jäsenet.

- **Yksilöi tutkimuksessa tapahtuvat kansainväliset tietojen siirrot ja niihin liittyvät suojatoimet**

Kansainvälisiä tiedonsiirtoja ei tule tapahtumaan.

4. Riskien arviointi ja tarvittavat suojakeinot

Tutkittavalle voi aiheutua erilaisia riskejä mm. a) henkilötietojen luvattoman julkaisemisen tai asiattoman tai käyttämisen perusteella b) henkilötietojen häviämisen vuoksi sekä c) henkilötietojen muuttumisen vuoksi. Henkilötietojen käyttämisestä voi aiheutua myös muun laisia riskejä tutkittaville.

- **Riskitekijät**

Ainoat riskitekijät ovat huolimaton tutkimusryhmän jäsen sekä tietojen väärinymmärrys.

- **Arvio riskin ja uhan toteutumisen vaikutus rekisteröidylle**

Vähäinen vaikutus. Arvioidusti tutkittava kokee korkeintaan lievää mielipahaa, mikäli hän kokee tutkimuksessa käytettävien tietojen antavan virheellisen kuvan pahoinvoinnin oireista. Tutkittavaa ei kuitenkaan pysty tunnistamaan käytettävistä tiedoista, tarkoittaen että todennäköisyys tämän tapahtumiselle on erittäin pieni.

- **Mitä suojatoimia kyseisten riskien vähentämiseksi tai torjumiseksi on tehty.**

Riskeiltä suojaudutaan olemalla erityisen huolellisia tietoja käytettäessä sekä analysoimalla tietoja tarkasti kaikkien mahdollisten väärinymmärrysten minimoimiseksi.

Appendix 15. Summary of Experiment plan

Tutkimussuunnitelman tiivistelmä

Tutkimuksen tavoite ja tarkoitus sekä perustelu tutkimuksen suorittamiselle
Tavoite selvittää tapoja virtuaalitodellisuuden tuottaman pahoinvoinnin helpottamiselle. Pahoinvointi on yleinen ongelma virtuaalitodellisuuden käyttäjien keskuudessa ja sen vähentäminen on tärkeää, jotta useammat ihmiset pystyisivät käyttämään laitteita ilman huonoa oloa.

Tutkimusasetelma ja tiedonkeruumenetelmät

Tutkimuksessa käytetään virtuaalitodellisuuslaseja tuottamaan pahoinvointia testihenkilöille. Tavoitteena on parantaa ymmärrystä virtuaalitodellisuuden aiheuttamasta pahoinvoinnista, jotta sitä voidaan ehkäistä tulevaisuudessa. Tieto kerätään tutkimuksen jälkeen tehtävällä kyselyllä.

Tutkittavien rekrytointi sekä tärkeimmät tutkittavien poissulku- ja sisäännottokriteerit

Tutkittavien tulee olla perusterveitä ja täysi-ikäisiä. Tutkittavat eivät myöskään saa olla päihtyneenä tutkimuksen aikana.

Tutkittavien henkilöiden arvioitu lukumäärä ja perustelut sille, onko aineisto riittävän suuri tutkimuksen kysymyksenasettelun kannalta

10-30 tai kunnes data alkaa saturoitumaan.

Tutkimusmenetelmä, tutkimuksen kulku ja toimenpiteiden kuvaus

Tutkittaville kerrotaan ohjeet siitä, mitä heidän tulee tehdä virtuaalitodellisuudessa. Heitä muistutetaan varotoimista, jos heille tulee liian huono olo. Tutkimuksen aikana tutkittava pitää päässään VR laseja ja pelaa peliä itsenäisesti. Pelissä esiintyy paljon liikettä ja mahdollisia muita pahoinvointia aiheuttavia ärsykeitä. Tutkimuksen jälkeen tutkittava täyttää kyselyn pahoinvoinnin oireista.

Mitä tutkimukseen osallistuminen tarkoittaa konkreettisesti tutkittavalle (esim. tutkimus- ja haastattelukertojen lukumäärä, tutkimukseen osallistumisen kesto)

Tutkittava osallistuu tutkimukseen yhden kerran. Peliä pelataan enimmillään 20 minuuttia, mutta tutkittava voi keskeyttää pelin milloin tahansa ilman mitään seurauksia, jos hänen olonsa huononee liikaa. Tutkimuksen jälkeen tutkittavaa haastatellaan ja hän täyttää kyselylomakkeen, joka kestää arvioidusti noin 20 minuuttia. Alkuvalmistelut mukaan lukien tutkittava osallistuu tutkimukseen kokonaisuudessaan siis noin tunnin ajan.

tutkimusaineiston käsittely, säilytys, arkistointi ja avaaminen

Aineistoa käytetään kartoittamaan miten hyvin tutkimuksessa kehitetyt metodit onnistuvat vähentämään virtuaalitodellisuuden aiheuttamaa pahoinvointia. Aineisto kerätään digitaalisen kyselylomakkeen ja tutkimuksen aikana suoritettavan tarkkailun avulla. Aineisto anonymisoidaan ja säilytetään alustavasti Seafilessä tai muussa vastaavassa yksityisessä salasanalla suojatussa arkistossa, johon pääsee käsiksi ainoastaa tutkimusryhmän jäsenet. Aineisto säilytetään enimmillään 10 vuotta, jonka jälkeen se tuhotaan. Anonymisoituja tietoja käytetään julkisesti saatavilla olevassa tutkimuksessa.

henkilötietojen käsittely tutkimuksessa ja tietosuojajärjestelyt

Tutkittavien henkilöllisyyksiä ei paljasteta, mutta ikä ja sukupuoli mainitaan tutkimuksessa. Kaikki tunnistettavat tiedot poistetaan välittömästi, jonka jälkeen tutkittavalle määritellään numero. Tästä eteenpäin tutkittavan tietoja käsitellään vain numerona.

Appendix 16. Initial Interview Plan

Haastattelukysymykset

Haastattelumallina toimii avoin haastattelu, eli tarkkoja kysymyksiä ei ole.

Haastattelun tavoitteena on yleisesti vain kysyä osallistujalta mielipiteitä tutkimuksesta, pitivätkö he siitä ja onko siinä jotain parannettavaa. Osallistujalle annetaan myös mahdollisuus kuvata tarkemmin pahoinvoinnin oireita, jos he niin haluavat. Haastattelun vastaukset kirjoitetaan paperille, jonka jälkeen ne digitoidaan, mahdolliset tunnistettavat tiedot poistetaan ja alkuperäiset paperit tuhotaan.

Appendix 17. Initial Observation Plan

Havainnointisuunnitelma

Osallistujan havainnointi alkaa hänen saapuessa testipaikalle. Havainnoinnissa kiinnitetään erityisesti huomiota osallistujan tasapainoon ja muihin liikkeisiin. Havainnointia jatketaan osallistujan aloittaessa testin. Testin aikana kaikki mahdolliset virtuaalitodellisuuden aiheuttamat muutokset tasapainoon ja muihin liikkeisiin kirjataan ylös. Testin jälkeen havainnointi jatkuu, kunnes osallistuja lähtee testipaikasta, jolloin havainnointikin päättyy. Testin jälkeisen havainnoinnin tavoitteena on nähdä, vaikuttaako virtuaalitodellisuuden aiheuttamat muutokset vielä virtuaalitodellisuudesta poistumisen jälkeen, ja jos vaikuttaa niin miten kauan. Havainnoinnin tulokset kirjoitetaan ylös, jonka jälkeen ne digitoidaan.

Appendix 18. Ethical Review Statement

Ihmistieteellisen tutkimuksen eettinen ennakkoarviointi

Tutkimuksen nimi

Virtuaalitodellisuuden aiheuttaman pahoinvoinnin ehkäisy

Tutkimuksen yhteyshenkilö

Viljo Kankare

Tutkimuksesta vastaava henkilö

Olli Heimo

Käsittely ihmistieteiden eettisen toimikunnan ihmistieteellisten tutkimusten jaostossa

Tutkija on pyytänyt ennakkoarviointilausuntoa tutkimussuunnitelmansa eettisyydestä ja muista tutkimukseen liittyvistä riskeistä.

Turun yliopiston ihmistieteiden eettisen toimikunnan ihmistieteellisten tutkimusten jaosto on kokouksessaan 11.02.2025 käsitellyt hakijan pyynnön, tutkimussuunnitelman ja siihen liittyviä asiakirjoja. Toimikunta on pyytänyt hakijaa täydentämään hakemustaan. Hakija on toimittanut pyydetyt täydennykset.

Lausunto

Kun otetaan huomioon tutkijan pyyntö, mainitusta tutkimuksesta asiakirjoista saatava selvitys sekä Tutkimuseettisen neuvottelukunnan ohjeet ihmiseen kohdistuvan tutkimuksen eettisistä periaatteista sekä ihmistieteiden eettisestä ennakkoarvioinnista Suomessa (2019), toimikunta antaa puoltavan lausunnon. Toimikunnan käsityksen mukaan ennakkoarvioitavana oleva suunniteltu tutkimus on eettisesti hyväksyttävä.

Käsittelyyn osallistuneet henkilöt

Asian käsittelyyn ovat osallistuneet Janne Salminen toimikunnan puheenjohtajana sekä Mika Koivisto, Leo Lahti, Eriikka Paavilainen-Mäntymäki, Elsa Saarikkomäki, Helena Siipi, Marjaana Veermans toimikunnan jäseninä. Toimikunnan sihteerinä on toiminut Kirsi Klemelä ja henkilötietojen käsittelystä vastaavana asiantuntijajäsenenä Johanna Rauma.

Lisätietoja

Toimikunnan sihteeri Kirsi Klemelä,
sähköposti eettinen@utu.fi tai puh. +358 50 303 0346

Toimikunnan sihteeri Raakel Plamper,
sähköposti eettinen@utu.fi tai puh. +358 50 317 2608

Muutoksenhaku

Jos ennakkoarviointilausunnon pyytäjä ei hyväksy ihmistieteiden eettisen toimikunnan päätöstä tai lausunnon sisältämiä muutosehdotuksia, hän voi pyytää asiasta lausuntoa Tutkimuseettiseltä neuvottelukunnalta. Perusteltu lausuntopyyntö liitteineen tulee jättää kahden kuukauden kuluessa eettisen toimikunnan päätöksestä.

Lausunto on sähköisesti allekirjoitettu Turun yliopiston UTUsign-palvelussa.

Janne Salminen
Puheenjohtaja

Kirsi Klemelä
Sihteeri

Ethical review of humanities and social sciences research

Title of the research project

Contact person for the research

Viljo Kankare

Principal investigator of the research project

Olli Heimo

Handling the matter at the Humanities and Social Sciences Division of the Ethics Committee for Human Sciences

The researcher has requested an ethical review statement on the ethicality of the research plan and on other risks related to the research.

The Humanities and Social Sciences Division of the Ethics Committee for Human Sciences at the University of Turku has in its meeting on 11.02.2025 processed the applicant's request, the research plan, and the related documents. The Humanities and Social Sciences Division has asked the researcher to supplement the application. The researcher has submitted the requested amendments.

Statement

When considering the researcher's request, information about the research obtained from the delivered documents, and the national guidelines for the ethical principles of research with human participants and ethical review in human sciences, the Ethics Committee gives assent to the research. According to the Ethics Committee, the planned research project under the ethical review can be ethically approved.

Persons participating in the processing of the matter

The matter has been handled by Janne Salminen as the chair of the Committee and Mika Koivisto, Leo Lahti, Eriikka Paavilainen-Mäntymäki, Elsa Saarikkomäki, Helena Siipi, Marjaana Veermans as the members of the Committee. Kirsi Klemelä was the secretary of the Committee and Johanna Rauma the expert member on processing personal data.

More information

Secretary Kirsi Klemelä,

email eettinen@utu.fi or tel. +358 50 303 0346

Secretary Raakel Plamper,

email eettinen@utu.fi or tel. +358 50 317 2608

Appeals

If the person who has requested an ethical review statement does not accept the changes proposed in the statement or the decision of the human sciences ethics committee, they may request a statement on the matter from the Finnish National Board on Research Integrity (TENK). The request for a statement, including the grounds for requesting a statement, must be submitted within two months of the ethics committee's decision.

This document has been electronically signed with UTUsign.

Janne Salminen
Chair

Kirsi Klemelä
Secretary

Appendix 19: Signatures from Thesis Supervisors for the Ethical Review

Opinnäytetyön ohjaajan allekirjoitus lausuntopyyntöön tutkimuksen eettisyydestä

Opinnäytetyön tiedot:	
Opinnäytetyön nimi	Mitigating Motion Sickness in Virtual Reality
Opinnäytetyön tekijän nimi	Viljo Kankare
Opinnäytteen taso	☐ Kandidaatintutkielma ☒ Pro gradu ☐ Lisensiaatintyö ☐ Väitöskirja
Vakuutan, että seuraavat antamani tiedot ovat oikein:	
☒ Olen opinnäytetyön ohjaaja ☒ Olen tutustunut lausuntopyyntöön ja sen kaikkiin liitteisiin ☒ Tutkimuseettisen neuvottelukunnan ohjeen Ihmiseen kohdistuvan tutkimuksen eettiset periaatteet ja ihmistieteiden eettinen ennakkoarviointi Suomessa (TENKin ohje 2019) mukaisesti haen ennakkoarviointia yhdessä ohjattavani kanssa	
Opinnäytetyön ohjaajan allekirjoitus:	
Paikka ja aika Turku 27.01.2025	Opinnäytetyön ohjaajan allekirjoitus ja nimenselvennys Olli Heimo  Erikoistutkija

Opinnäytetyön ohjaajan allekirjoitus lausuntopyyntöön tutkimuksen eettisyydestä

Opinnäytetyön tiedot:	
Opinnäytetyön nimi	Mitigating Motion Sickness in Virtual Reality
Opinnäytetyön tekijän nimi	Viljo Kankare
Opinnäytteen taso	☐ Kandidaatintutkielma ☒ Pro gradu ☐ Lisensiaatintyö ☐ Väitöskirja
Vakuutan, että seuraavat antamani tiedot ovat oikein:	
☒ Olen opinnäytetyön ohjaaja ☒ Olen tutustunut lausuntopyyntöön ja sen kaikkiin liitteisiin ☒ Tutkimuseettisen neuvottelukunnan ohjeen Ihmiseen kohdistuvan tutkimuksen eettiset periaatteet ja ihmistieteiden eettinen ennakkoarviointi Suomessa (TENKin ohje 2019) mukaisesti haen ennakkoarviointia yhdessä ohjattavani kanssa	
Opinnäytetyön ohjaajan allekirjoitus:	
Paikka ja aika Turku 27.01.2025	Opinnäytetyön ohjaajan allekirjoitus ja nimenselvennys Taneli Nyyssönen  Projektitutkija

Appendix 20. The Experiment Starting Questionnaire

Participant number (ask supervisor) *	Your answer
State your age *	Your answer
State your sex *	☐ Male ☐ Female ☐ Other/Prefer not to say
Do you suffer from any serious physical, psychological or neurological conditions * (heart problems, epilepsy etc.)?	☐ Yes ☐ No
Are you sober? *	☐ Yes ☐ No
Past experience with virtual reality? *	☐ Never used ☐ Rarely used ☐ Often use ☐ Experienced user
How would you rate your susceptibility to motion sickness? *	1 2 3 4 5 Never feel motion sick ☐ ☐ ☐ ☐ ☐ Frequently feel motion sick
Submit Clear form	

Appendix 21. The Simulator Sickness Questionnaire

Participant number (ask supervisor) *

Your answer

Symptom *

	None	Slight	Moderate	Severe
General discomfort	☐	☐	☐	☐
Fatigue	☐	☐	☐	☐
Headache	☐	☐	☐	☐
Eyestrain	☐	☐	☐	☐
Difficulty focusing	☐	☐	☐	☐
Increased salivation	☐	☐	☐	☐
Sweating	☐	☐	☐	☐
Nausea	☐	☐	☐	☐
Difficulty concentrating	☐	☐	☐	☐
Fullness of head	☐	☐	☐	☐
Blurred vision	☐	☐	☐	☐
Dizzy (eyes open)	☐	☐	☐	☐
Dizzy (eyes closed)	☐	☐	☐	☐
Vertigo	☐	☐	☐	☐
Stomach awareness	☐	☐	☐	☐
Burping	☐	☐	☐	☐

Submit

Clear form

Appendix 22. Experiment Advert

Participate in a Virtual Reality Experiment!

Motion sickness in VR is a problem limiting the accessibility of the technology. This research project aims to find solutions to mitigate symptoms thus enabling a larger adoption of immersive technologies. We need **YOU** to help us!!!

Reasons to participate

- Getting to experience virtual reality
- Helping advance scientific knowledge
- Helping a student in need

Who Can Participate?

- Must be between ages 18-50
- No history of severe physical, neurological or psychological health conditions (heart problems, epilepsy, etc.)
- No prior experience in VR required!

What the experiment includes

- You will travel through a track in virtual reality using different motion sickness mitigation methods
- Track includes sections of varying intensity, ranging from walking to a rollercoaster
- Estimated total duration ~45-75 minutes
 - VR experience ~15-25 minutes
- Filling out a questionnaire and taking part in a short interview



Your contribution might help in making virtual reality more accessible for everyone!

Location:

University of Turku's Mixed Reality lab (room 453) at Agora building 4th floor



Thank you for your time, hopefully you'll consider joining!

Best regards
Viljo Kankare

Help us make VR more comfortable for everyone!

If you're interested or have any extra questions, email me at vvkank@utu.fi