Informatics

Design, Development and Evaluation of First-/Third-Person Hybrid Locomotion Techniques in Virtual Reality

DIPLOMARBEIT

zur Erlangung des akademischen Grades

Diplom-Ingenieur

im Rahmen des Studiums

Medieninformatik und Visual Computing

eingereicht von

Felix Ledóchowski
Matrikelnummer 01028318

an der Fakultät für Informatik
der Technischen Universität Wien
Betreuung: Thomas Grechenig
Mitwirkung: Christoph Wimmer

Wien, 21. Juni 2023

Felix Ledóchowski   Thomas Grechenig

Informatics

Design, Development and Evaluation of First-/Third-Person Hybrid Locomotion Techniques in Virtual Reality

DIPLOMA THESIS

submitted in partial fulfillment of the requirements for the degree of

Diplom-Ingenieur

in

Media Informatics and Visual Computing

by

Felix Ledóchowski
Registration Number 01028318

to the Faculty of Informatics

at the TU Wien

Advisor: Thomas Grechenig
Assistance: Christoph Wimmer

Vienna, 21st June, 2023

Felix Ledóchowski

Thomas Grechenig

Design, Development and Evaluation of First-/Third-Person Hybrid Locomotion Techniques in Virtual Reality

MASTER'S THESIS

submitted in partial fulfillment of the requirements for the degree of

Diplom-Ingenieur

in

Masterstudium Medieninformatik

by

Felix Ledóchowski
01028318

to the Faculty of Informatics
at the Vienna University of Technology

Advisor: Thomas Grechenig
Assistance: Christoph Wimmer

Vienna, 21.06.2023

Unterschrift Verfasser/in

Unterschrift Betreuer

Technische Universität Wien, Forschungsgruppe INSO
A-1040 Wien ▪ Wiedner Hauptstr. 76/2/2 ▪ Tel. +43-1-587 21 97 ▪ www.inso.tuwien.ac.at

Erklärung zur Verfassung der Arbeit

Felix Ledóchowski
Zirkusgasse 19/14, 1020 Wien

Hiermit erkläre ich, dass ich diese Arbeit selbständig verfasst habe, dass ich die verwendeten Quellen und Hilfsmittel vollständig angegeben habe und dass ich die Stellen der Arbeit - einschließlich Tabellen, Karten und Abbildungen -, die anderen Werken oder dem Internet im Wortlaut oder dem Sinn nach entnommen sind, auf jeden Fall unter Angabe der Quelle als Entlehnung kenntlich gemacht habe.

------------------------------- ---
(Ort, Datum) (Unterschrift Verfasser/in)

Acknowledgements

First I would like to thank Thomas Grechenig for giving me the chance to work on this topic, and grow with this opportunity. Great thanks also to Christoph Wimmer for supporting me all the way through this work, and his invaluable advice, and expertise.

Also I would like to thank all the test participants who found the time to take part in my experiments, and without whom the completion of this work would not have been possible.

Finally I would like to thank my friends and family for their patience and for supporting me in this journey.

Zusammenfassung

Viele neue Virtual-Reality-Fortbewegungstechniken wurden entwickelt, um den begrenzten VR-Tracking-Raum optimal zu nutzen und VR bedingte Übelkeit zu reduzieren. Die akademische Forschung konzentriert sich scheinbar hauptsächlich auf Techniken, bei denen User stehen und ihre Beine häufig bewegen müssen. Diese Arbeit betont den Bedarf an sitzenden Fortbewegungstechniken, die auch wichtige Eigenschaften wie sofortige seitliche Bewegung und die Fähigkeit zum Springen aufweisen, die bei der häufig verwendeten VR-Fortbewegungstechnik "Teleportation" fehlen.

Zwei neuartige Third-Person-Perspektive Fortbewegungstechniken wurden entwickelt. Die Hypothese hier ist, dass diese neuen Techniken es Usern ermöglichen, schnell und intuitiv auf jede gegebene Herausforderung zu reagieren und ein angenehmeres und immersiveres Erlebnis als Teleportation zu ermöglichen, ohne VR bedingte Übelkeit zu verursachen.

Das erste Steuerungsschema, „static camera“, verwendet vorab platzierte Kamerapositionen in einer Szene, von denen aus User ihren Avatar sehen können. Durch das betreten von vorplatzierten Volumes wechselt die Perspektive automatisch zu einem neuen Standort für eine bessere Sicht. User können jederzeit in die Ego-Perspektive wechseln.

Das zweite Steuerungsschema, "dynamic camera", verkleinert die virtuelle Szene aus einer Vogelperspektive. Beim Bewegen bewegt sich die Ansicht fließend mit dem Avatar, während nur ein kleiner Ausschnitt um ihn herum sichtbar ist. Hinter dem sichtbaren Teil der Szene wird ein karierter Hintergrund gezeigt, um die User in ihrer Perspektive zu verankern und so VR bedingte Übelkeit vorzubeugen. User können jederzeit auch in die Ego-Perspektive wechseln.

Eine User Study wurde ausgeführt, bei denen die Fähigkeiten der static camera, der dynamic camera und von Teleportation getestet wurden. Die Leistung wurde gemessen und die Präferenzen der Teilnehmer erfasst. Darüber hinaus mussten alle Teilnehmer einen Presence Questionnaire und einen Simulator Sickness Questionnaire ausfüllen.

Die User Study zeigte, dass es zwar kein Steuerungsschema gab, das den anderen allgemein als überlegen angesehen werden kann, dynamic camera jedoch für die Navigation bevorzugt wird, während Teleportation zu einer stärkeren Immersion führt. Beide Third-Person-Techniken sorgten für großen Spaß, wobei die Fähigkeit zu Springen besonders beliebt war. Es konnten keine statistischen Unterschiede in der Übelkeit oder Präsenz im Vergleich zur Teleportation festgestellt werden.

Abstract

Many novel virtual reality locomotion techniques have been developed to maximize the usage of limited VR tracking space while avoiding potential motion sickness. Modern academic research concerning these techniques seemingly focuses itself mostly on techniques that require the user to stand, and often move their legs. This work argues for a need for locomotion techniques that can be used entirely seated, and that the most commonly used VR locomotion technique teleportation is lacking in key factors, such as immediate lateral movement and the ability to jump.

Thus, two novel locomotion techniques featuring a third person perspective and a remote controlled avatar were developed. The hypothesis here is that these new techniques will allow users to quickly and intuitively react to any given challenges, and allow for a more enjoyable and immersive experience than teleportation, all without causing simulator sickness.

The first control scheme developed in this work is called static camera, as it uses preplaced camera locations in a scene, from which a user can see their avatar. By entering predesigned volumes, the perspective is automatically switched to a new location, to allow for a more advantageous view of the scene. Furthermore, the user can switch to a first person perspective at any time upon pressing a button.

The second control scheme developed is called dynamic camera. Here, the virtual scene is shrunk down when viewed from a third person perspective. When moving, the view smoothly moves with the avatar, while only a small cutout around it is visible. Behind the visible part of the scene a checkered box is shown to ground the user in their perspective, thus preventing motion sickness. The user can also switch to first person whenever desired.

Multiple trials were conducted testing static camera, dynamic camera and teleportation. Performance was measured and preferences of the users were recorded. Furthermore every test subject had to fill out a Presence Questionnaire and a Simulator Sickness Questionnaire.

Trials showed that while there was no control scheme that can be seen as universally superior to the others, dynamic camera seems to be preferred for navigation, while teleportation leads to higher immersion. Both third person techniques caused high levels of enjoyment when jumping was encouraged. No statistical difference levels in simulator sickness or presence compared to teleportation could be shown.

Keywords: *Virtual Reality; Third Person; Seated; Teleportation; Static Camera; SSQ; PQ*

Table of contents

List of Figures

List of Tables

1 Introduction

Development of Virtual Reality (henceforth referred to as VR) based solutions could arguably be traced back to the late 1800s with panoramic paintings [1]. Arguably the first head mounted displays featuring head tracking was created by Ivan Sutherland in the 1960s [2]. It needed to be ceiling mounted due to it being too heavy to be carried freely on a user's head, earning it the nickname "Sword of Damocles". Mass-market consumer VR as we know it today, featuring a head mounted display, 6 degrees of freedom tracking and a motion controller in each hand, started with the introduction of the HTC Vive and Oculus Rift. VR applications have been used in various industries, such as medicine [3], gaming and data visualization [4]. A lack of tracking space and the potential for motion sickness while using VR applications have led to the development of many novel locomotion techniques. The main aim of this thesis is to design and test solutions related to problems stemming from VR applications, specifically related to movement.

1.1 Problem Description

Virtual reality headsets allow users to experience a level of immersion unlike any visualization hardware before it. This however, comes at the price of conventional locomotion techniques such as continuous movement using an analog stick. A mismatch between visual information and vestibular input can lead to motion sickness [5] thus forcing VR applications, which require the traversal of a virtual space, to use unconventional movement techniques.

Therefore, the development of a VR locomotion technique should always consider the potential of cyber sickness caused by the relationship between a user's view of a virtual scene, and their movement in it. For this purpose various novel locomotion techniques will be tested and evaluated in order to assess the users propensity to cyber sickness and their general preferences.

In order to reach an audience as wide as possible, and to be inclusive of people with disabilities that prevent them from standing, only VR locomotion techniques which can be used while seated have been researched for the purpose of this work.

The desired outcome of this work is a locomotion technique that enables natural, continuous movement, that can react and interact with the environment, without causing motion sickness. One of the industries that these techniques would be beneficial for would be the gaming industry and potentially architectural visualization where continuous movement is of importance.

1.2 Motivation

One common locomotion technique in VR is teleportation [6]–[10], and other solutions exist, such as redirected walking [11]–[13], walking in place [14] and arm swinging [15]. These techniques mostly are based on the assumption that VR will be used standing up and often with enough room to walk around. From personal experience users prefer to use VR in a seated capacity, which is probably the reason why teleportation and rotating the view with snap turning has become the standard, as it allows for such a position. However, teleportation has its own limitations, such as not allowing true continuous movement, making it hard to quickly move backwards or sideways, and lacking the ability to jump.

From previous work (such as the development of locomotion techniques) and personal purposes, many VR applications and games have been tested, which use many different locomotion techniques, conventional or otherwise. Often these solutions only seem to meet the need for seated use half way, especially when requiring quick lateral movement or reaching higher spaces.

Academia seems to concentrate its efforts more on VR with a larger tracking space available, which might not necessarily be the future, if VR is to go truly mainstream, as not every user will have such space available at all times.
Furthermore, there is the question of accessibility. A wheelchair bound user does not have the luxury of using VR from an upright standing position. Therefore, for VR to be truly accessible this problem needs to be addressed.

Hence, the aim of the thesis is to create a versatile, comfortable traversal technique of VR scenes from a seated position. This would also would help to increase the acceptance of VR and improving accessibility for all.

1.3 Objective

VR is commonly is used from a first person perspective. It stands to reason that seeing a given virtual scene from the same perspective as the avatar the user inhabits would lead to higher immersion than seeing the same avatar from outside. After all, this is how humans naturally perceive the world. Furthermore this perspective allows users to manipulate objects in the environment using motion controllers in a similar manner how they would using their hands. However, this immersion is immediately broken when the user is required to traverse the virtual environment by either teleportation, or motion sickness inducing continuous movement.

This work suggests that a combination of third and first person perspectives can lead to a more immersive and motion sickness free experience. For this purpose two novel locomotion techniques, combining first and third person perspectives have been developed.

These techniques are:

- Static camera: the third person view is preset by the designer of the virtual scene for each room or location. The user can switch to first person at any time, but can only move in third person. The switch is almost instantaneous.
- Dynamic camera: the third person view moves with the user's avatar while they traverse the environment, but during movement only a small cut-out of the environment is visible, while the rest of the environment is barely visible. The user can rotate their view continuously with a similar cut-out view. While seeing the scene in third person, the environment is miniaturized. Transitioning to first person gradually expands the environment to a 1:1 size, while smoothly translating the view to that of the avatar. This is also done in a cut-out view to preclude motion sickness, without causing undue amounts of VR or motion sickness.

The main hypothesis for this work is that above mentioned techniques will outperform default teleportation in user acceptability, trial performance and immersion, without causing undue amounts of VR or motion sickness.

1.4 Overview of Thesis

Chapter 2 provides a general and a systematic overview of the work done in this area, addressing the question of which third person techniques perform best.

The design and implementation of the work, will be explained in chapter 3. A detailed explanation of the interaction design, technical design and implementation will be given.

The methodology and trial design is presented in Chapter 4. Here three different testing scenarios with three variants each are included.

Chapter 5 describes statistical and qualitative results of the user trials and analyzes user behavior during the trials.

Chapter 6 discusses these results and compares them to other existing locomotion techniques.

Finally, the summary and the way forward are discussed in chapter 7.

2 Related Work

Before starting the design and implementation of the novel movement techniques, first an overview of existing VR locomotion techniques was established. Then a systematic literature review [16] was conducted to find out what has been done in the area of combining third person and first-person perspectives in VR.
This has led to the implementation of an entirely new camera perspective system.

2.1 Overview of VR Locomotion techniques

Limited tracking space and the possibility of motion sickness in Virtual Reality lead to the development of many unique locomotion techniques. There have been efforts to categorize these techniques. VR Locomotion in the New Era of Virtual Reality : An Empirical Comparison of Prevalent Techniques by Boletsis et al [17] splits these methods into four base categories: motion based, room-scale-based, controller-based and teleportation based as can be seen in Figure 1.

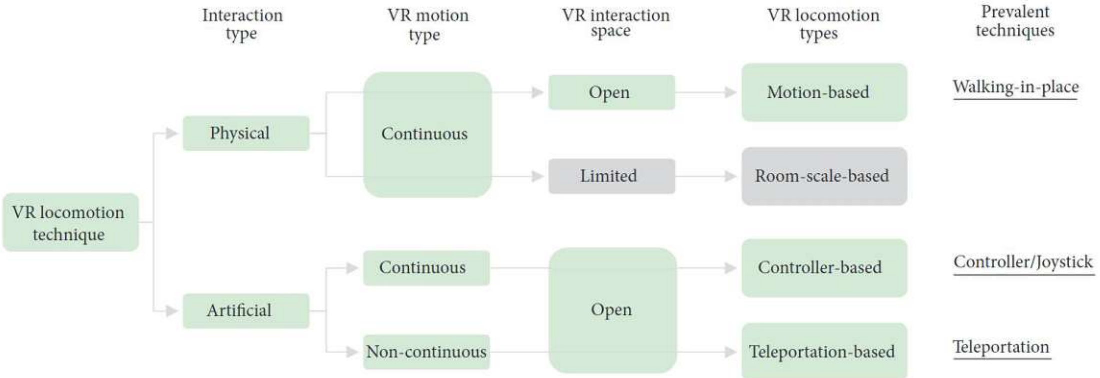


Figure 1: Topology of VR Locomotion techniques according to [17]

A Typology of Virtual Reality Locomotion Techniques by Boletsis et al [18] suggests a further split for VR Locomotion with a Physical Interaction Type, by splitting the Open VR interaction space further down into Continuous and Non-continuous VR motion types (see Figure 2). This results in the following VR locomotion types:

- Motion-based: Here continuous movement is triggered by utilizing some kind of physical movement such as arm swinging or walking in place.

- Motion-based Teleporting: Teleportation is triggered by physical such as hand gestures, lifting their feet or moving their head.
- Roomscale-based: The user can move around the VR environment by physically around the tracking space, but is limited to by the given physical space.
- Controller-based: Continuous movement can be triggered using a controller. This can be done for example using joysticks, buttons or chair peripherals.
- Controller-based Teleporting: Similar to controller-based, but instead of continuous movement the user is instantaneously teleported to a desired location.

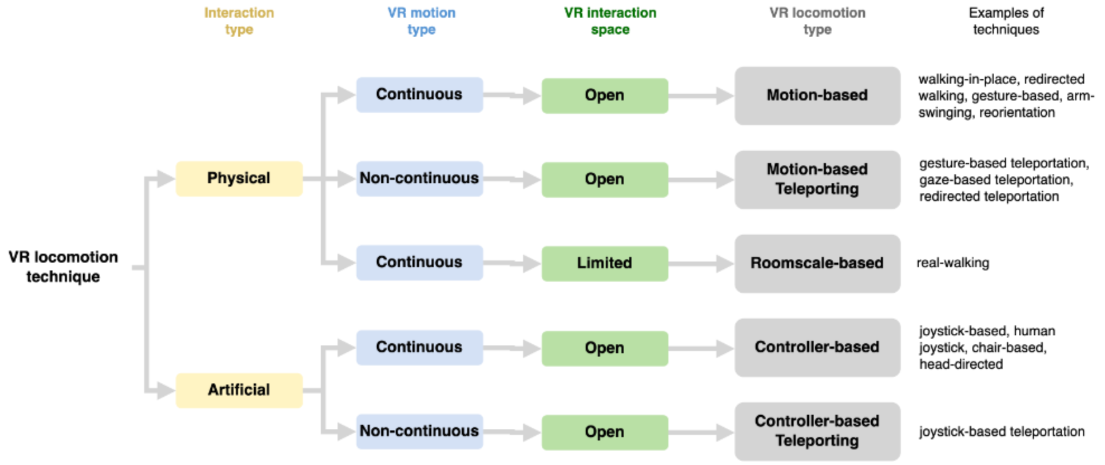


Figure 2: Updated typology of VR locomotion techniques according to [18]

Literature review of locomotion techniques in virtual reality by Cherni et al [19] suggests an entirely different taxonomy of locomotion techniques after collecting a total of twenty-two locomotion techniques. Here techniques are split into Non-Natural, Semi-Natural, Walk simulation, and Leaning-based, which in itself is split into Arm-based motion capture, Head-based motion capture and Trunk-based motion capture (see Figure 3).

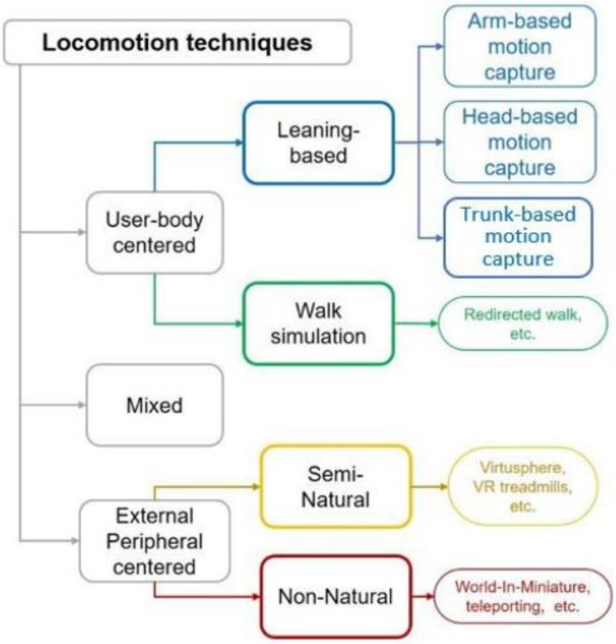


Figure 3: Virtual reality locomotion taxonomy according to [19]

2.1.1 Motion-based

Walking in place techniques are the most utilized in academia [18]. This is a technique whereby a user can move across a virtual environment by stepping in place [20]. Examples of this are: A Walking-in-Place Method for Virtual Reality Using Position and Orientation Tracking by Lee et al [14], which seeks to improve step recognition by utilizing position and orientation tracking, and On Your Feet! Enhancing Vection in Leaning-Based Interfaces through Multisensory Stimuli by Krujiff et al [21], wherein the experience is enhanced by the usage of a custom-designed foot haptics system.

An alternative to walking in place is arm-swinging [15] wherein a user locomotes by swinging their arms and standing in place. Such physically intensive input methods can find applications in the realm of Exergames [22].

These walking in place techniques are often combined with leaning-based rotational controls, which can show performance similar to analog stick controls [23].

Another method is to maximize the available tracking space by manipulating the users viewing angle, movement speed and various visual cues. This technique is called Redirected Walking [11], [13], [24]–[29]. When using this technique the user is naturally walking through the tracking space. By manipulating the rotation the user is looking in they are subtly manipulated to walk at an angle rather than straight. So while the user is thinking they are walking in a straight line they are actually walking in a curve, thus making them believe they are walking through a larger space than the tracking space should permit.

This effect can be further amplified by applying it during interactions in the VR environment such as with doors [30]. Similarly, the location of the user in virtual space can be manipulated, such as while jumping [31], while walking [32], [33], or even blinking [34].

2.1.2 Motion-based Teleporting

Advancements in motion tracking allow users to use complex gestures as a means to generate an abstract effect such as teleportation, without the need for handheld controllers featuring buttons. Teleportation meanwhile allows users to get around obstacles which regular room-scale based tracking cannot get around. Force-based foot gesture navigation in virtual reality [35] for example allows users teleportation by lifting their heels.

In more recent times VR headsets have started to integrate advanced hand tracking solutions allowing individual fingers to be recognized by software [36]. This opens up new input methods in virtual reality [37]. Controlling Teleportation-Based Locomotion in Virtual Reality with Hand Gestures: A Comparative Evaluation of Two-Handed and One-Handed Techniques by Schäfer et al [6] suggests four different techniques where users can teleport through an environment using only hand gestures.

2.1.3 Room scale-based

Modern VR devices allow tracking of the user in 6 degrees of freedom, meaning location and rotation can be tracked. The users movement is mapped 1:1 from the physical space to the virtual space. All tracked body parts, usually hands and head, are replicated in VR. This means that movement is limited to the physical tracking space available.

Different solutions [38], [39] for tracking can be summarized into two types:

Outside-in: The user’s headset and/or controllers are tracked from an outside sensor. For example, older Oculus Headsets featured a table mounted camera tracking infra-red LEDs, which are installed on the HMD and controllers.

Inside-out: The sensors are installed on the HMD or controllers themselves and track the world around them. This can be done with preplaced markers in the environment around the user, such as with the HTC Vive [40] which uses devices placed in the room, called “lighthouses”. These devices send out infrared signals at precise time intervals. The emitted infrared signals are intercepted by infrared sensors mounted on the HMD and controllers, thus allowing to calculate their location and rotation in space.

The currently most popular approach is marker-less inside-out tracking used in Headsets such as the Oculus Rift S [41]. In this case head mounted cameras determine the user's location through the utilization of computer vision algorithms.

2.1.4 Controller-based

Controller based locomotion controls rely on an extra input device such as joysticks. While this does not seem as natural as techniques such as Walk in Place or Redirected Walking, naturalism in locomotion techniques might not always be desirable [42].

Using a joystick for continuous locomotion comes natural to users who have had experience using similar control schemes outside of virtual reality [17], but can cause higher amounts of nausea during movement. There are different approaches to reducing nausea, the most common one being reducing the field of view [43]–[49]. Another approach is to apply a depth of field blur to make objects blurrier the further they are to the user [50]–[52]. Adding an object to focus on, such as a virtual nose attached to the user's face [53] or a target reticule [54], can also help with reducing a feeling of illness during movement.

Many locomotion techniques can be further enhanced by allowing the user to rotate on the spot using a joystick. This is useful for scenarios where users cannot rotate on the spot, such as when the tracking solution does not allow for such movement, or when seated on a non-swiveling chair. There are different approaches to this, such as Continuous Turning, Discrete Turning and Field-of-view Reduction during Continuous Turning by Sargunam et al [55].

What also should not be overlooked is development in VR hardware as a means to improve avoidance of VR sickness. WalkingVibe [56] is a device that can be attached to a Virtual Reality Headset, which utilizes two small vibration motors to simulate tactile feedback of walking through an environment. Combining this with continuous artificial movement significantly reduced VR sickness and discomfort.

Similar advancements have been made in the realms of galvanic stimulation [57]. A lightweight wearable device is attached to a user's neck which stimulates the user's senses with electrical, caloric and bone conduction [58].

A comparatively low tech solution is to simulate airflow by mounting a fan in front of the user, which was shown to be a promising solution in Reducing Virtual Reality Sickness for Cyclists in VR Bicycle Simulators by Matviienko [59].

2.1.5 Controller-based teleporting

Controller based teleportation [7] has become a widely used solution in Virtual Reality. It has been shown that teleportation allows users to both cause less nausea and move faster than joystick based and walking in place locomotion techniques and was also experienced as just as intuitive as these two techniques [8]. Teleportation could be further improved by adding the ability to both choose the location and rotation the user will have upon teleportation [9], although some users might find this addition to be less intuitive [7]. While teleportation is often implemented by selecting the desired location using an arc projection emitted from a motion controller [8], occasionally a menu based solution is preferable [60], where users can choose from a list of predesigned locations to give them the optimal locations and rotations for a given scenario.

2.2 Systematic literature review

The aim of a systematic literature review is to generate a fact-based and balanced overview of a given subject. This becomes increasingly necessary, as the body of available work in the space of human computer interaction is in constant growth. To achieve this, a systematic methodology is used involving these five steps as defined in Evidence-Based Software Engineering for Practitioners [61] :

1. Specification of research question: The first step in conducting a systematic literature review is to clearly define the research question or problem that the review will address. This will help to guide the search for relevant literature and ensure that the review is focused and relevant.
2. Identification of relevant studies: The next step is to conduct a comprehensive search for relevant literature. This typically involves searching multiple databases and sources, such as academic journals, conference proceedings, and technical reports, using a combination of keywords and other search criteria.
3. Selection of relevant studies: Once the search is complete, the next step is to select the studies that are relevant to the research question or problem. This typically involves reading the abstracts and titles of the studies, as well as the full text of any studies that appear to be relevant, in order to determine their relevance and inclusion in the review.

4. Detailed examination of the selected works: Once the relevant studies have been identified, the next step is to extract and analyze the data from each study. This typically involves creating a structured data extraction form that allows for the consistent and systematic extraction of data from each study. The extracted data is then analyzed in order to identify patterns, trends, and gaps in the existing research.
5. Synthetization of the findings: The final step in the systematic literature review process is to synthesize the findings from the analysis of the data. This typically involves summarizing the key findings and conclusions, highlighting any inconsistencies or gaps in the existing research, and providing recommendations for future research directions.

Since there is less research material available than, for example medicine, where the systematic literature review originally stems from, we cannot afford to be too stringent with the search terms [61]. Otherwise, relevant works might be ignored.

2.2.1 Specification of research question

Since this work mostly concerns itself with the combination of a third and first person view in a seated position, the research question was defined as follows:
"How do traversal techniques combining a first- and third-person view, preferably usable in a seated position, perform in comparison to each other."

2.2.2 Identification of relevant studies

Google Scholar [62] and the ACM-Database [63] were used to search for relevant material. Some general Google searches were also made to see if some related work was done outside of academia.
The following keywords were used when searching: "Seated, VR, Virtual Reality, third person, first person, VR sickness, virtual environments." Approximately 30 different studies were looked at. Most of them were discarded, resulting in the nine studies collected here, as the rest had only small to no relevance to the given research question.

No work was found featuring a VR locomotion technique that both allows switching between a first and third person perspective, and being able to use it in a seated position.

Only three studies were found that concerned themselves with the ability to switch between a first and third person perspective: Outstanding: A perspective switching technique for covering large distances in VR games by Cmentowski et al [64], Out-of-body Locomotion: Vectionless Navigation with a Continuous Avatar Rep-resentation by Griffin et al [65] and Characterizing first and third person viewpoints and their alternation for embodied interaction in virtual reality by Galvan Debarba [66].

Thus, the search was expanded to works that feature at a minimum a third person perspective. Even this gave little results so techniques such as handheld world in miniature teleportation were also considered, although they are arguably not a third person locomotion technique, and more of a first person teleportation type.

2.2.3 Selection of relevant studies

After a comprehensive exploration of the given search space the following nine works have been selected:

Study and purpose	**Locomotion technique**
WIM: Fast locomotion in virtual reality with spatial orientation gain & Without motion sickness [67]	Teleportation by placing an avatar on a handheld miniature version of the environment.
Navigation and locomotion in virtual worlds via flight into hand-held miniatures [68]	Picking up and moving around an avatar in a handheld miniature representation of scene. Two variations: View flies with avatar while being dragged and flying to location after having placed the avatar.
Characterizing first and third person viewpoints and their alternation for embodied interaction in virtual reality [66]	Movement was enabled by providing the user with a motion capture suit both in third- and first-person perspective. Users can switch between perspectives at the press of a button.
TPVR: User Interaction of Third Person Virtual Reality for New Presence and Experience [69]	Leap motion hand-based tracking. Environment is viewed in miniature from above. A destination location for your avatar can be picked by tapping on the environment with the index finger.

Outstanding: A Perspective–Switching Technique for Covering Large Distances in VR Games [64]	The environment is viewed from a third person perspective in miniature. At any time the user can switch to a first person perspective. The transition between perspectives is gradual. An avatar can be moved through the environment in third person perspective using analog controls. A further button press moves the view closer to the avatar to catch up to it.
3PP-R: Enabling Natural Movement in 3rd Person Virtual Reality [70]	Environment is shrunk and concatenated by a sphere mask. The area hovers in front of the players face. Users can rotate the environment by rotating their head. The play area moves with the avatar. A fixed checkered plane is set beneath the area to prevent motion sickness. Player can be moved by both physical movement and analog stick controls. Interactions are gesture based (punching, swinging from pole). There is no way to switch to a first-person perspective.
Memories for third-person experiences in immersive virtual reality [71]	View is set above and behind the avatar and moves with them. Avatar is continually moved using keyboard controls.
Out-of-body Locomotion: Vectionless Navigation with a Continuous Avatar Representation [72]	User can change to a static behind the shoulder top down third person perspective. The viewpoint can be switched back to first person either by pressing a button or breaking line of sight.
The labors of Theseus: how we designed a 3rd person VR experience [73]	A combination of fixed predetermined camera locations and following an avatar from an over the shoulder view. The avatar is moved using analog stick controls.

2.2.4 Detailed examination of the selected works

The following subchapter will explore the locomotion techniques researched in the Systematic literature review and their relevance to this work.

2.2.4.1 World in miniature

World in miniature (WIM) [67] (see Figure 4 for example from the paper) has been shown to be the fastest locomotion technique, at least in comparison to first person teleportation and continuous movement in first person. Furthermore, it was found that WIM enabled better spatial knowledge than strictly first-person perspectives, even with the addition of a mini-map. It is suggested in the paper that WIM works best in combination with continuous movement in first person for adjustments in smaller spaces. Immersion was not measured in the paper, but WIM showed a statistically significant improvement in motion sickness over continuous motion.

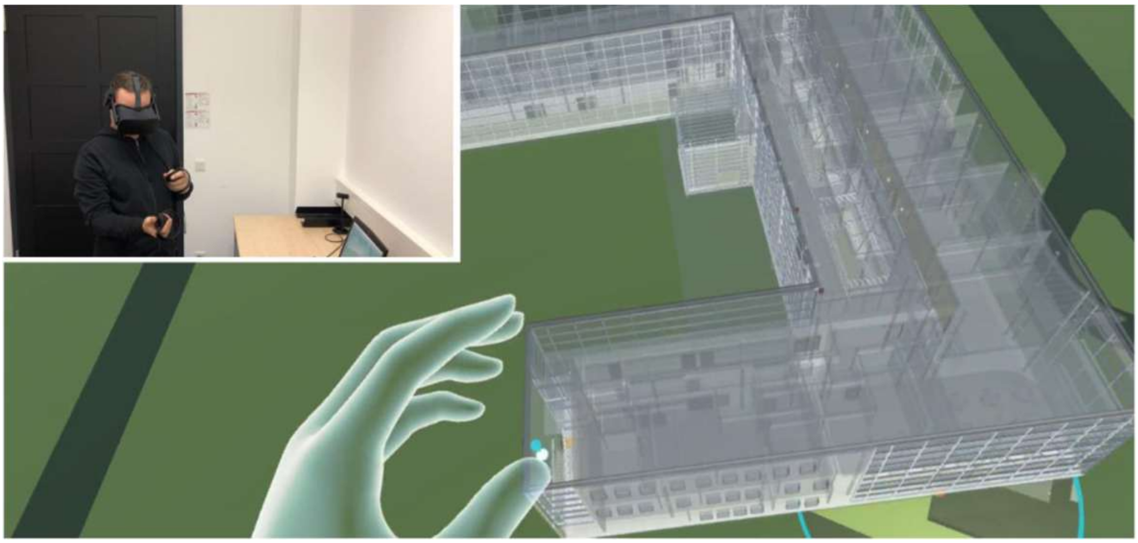


Figure 4: World-in-Miniature (WIM) using a pick&drop gesture for re-locating oneself in a miniature copy of the virtual environment [67]

2.2.4.2 Navigation and Locomotion in Virtual Worlds via Flight into Hand-held Miniatures

Navigation and Locomotion in Virtual Worlds via Flight into Hand-held Miniatures by Pausch et al [68] used a similar approach to WIM featuring a hand mounted miniature environment, but instead of choosing a location and instantly teleporting there, instead an avatar is picked up and placed at the desired location. Two different methods were used for transitioning to the new location: live updating the location of the user with the movement of the avatar, and moving the user to the chosen location after having placed the avatar using a slow-in-slow-out animation.

Life updating the viewpoint led to users getting disoriented. Using an animation also led to confusion, causing users to lock their view to the miniature until the transition ends, or to quickly lower the miniature after placing the avatar to regain orientation before the animation begins.

2.2.4.3 Characterizing first and third person viewpoints and their alternation for embodied interaction in virtual reality

Characterizing first and third person viewpoints and their alternation for embodied interaction in virtual reality by Galvan Debarba et al [66] focuses on the feeling of embodiment in VR using a third person perspective and the ability to switch to a first-person perspective. No movement technique like teleportation or similar was used, just a full body tracking suite. Experimentation showed that the feeling of ownership over a body viewed in third person could be enhanced when given the option to switch between a first person and third person view.

2.2.4.4 TPVR: User Interaction of Third Person Virtual Reality for New Presence and Experience

TPVR: User Interaction of Third Person Virtual Reality for New Presence and Experience by Kim et al [69] implements a finger gesture-based traversal and menu system both from a third person miniature and first-person perspective. The differing viewpoints required entirely different input methods. While the in the third person perspective the avatar and view location is translated by tapping the desired location (see Figure 5), in first person spreading all fingers and holding the user's hand in front of their face translates them forward. Further input methods such as selecting multiple items in the scene and opening and using menus were implemented to use the strengths of each viewpoint. The paper concludes that enhanced presence can be enabled from both a first and third person perspective, as long as the interactions are designed to take advantage of that perspective.

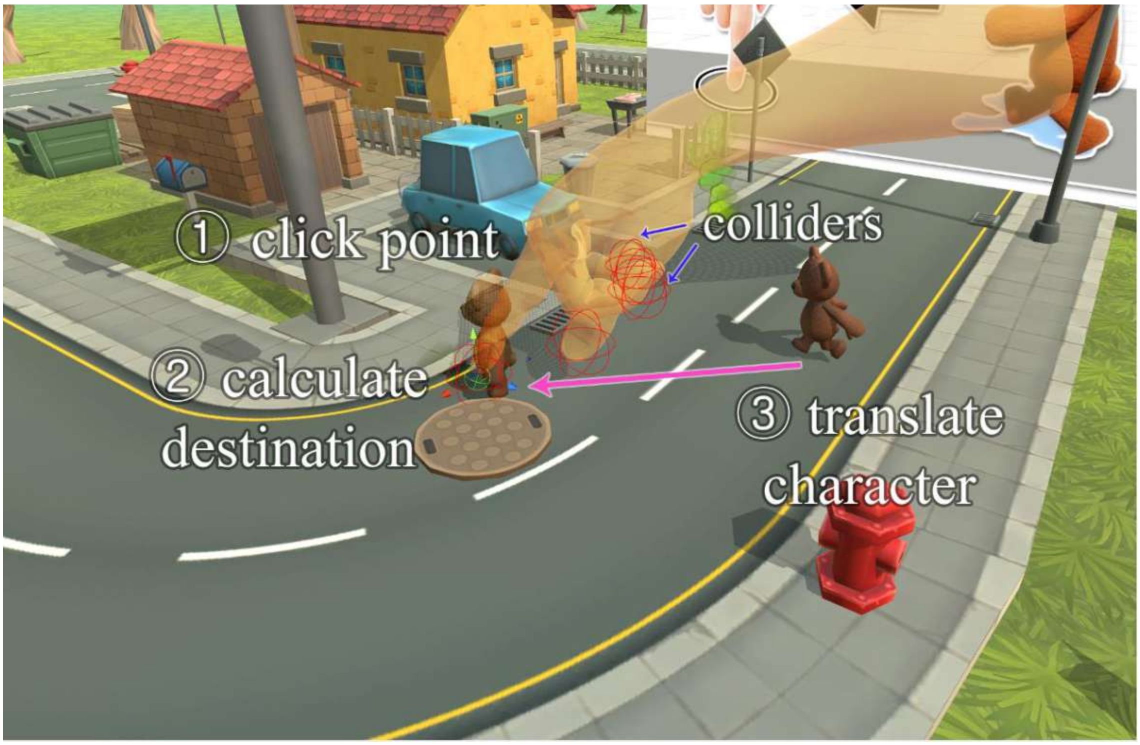


Figure 5: Procedure of processing virtual character translation using hands [69]

2.2.4.5 Outstanding: A perspective-switching technique for covering large distances in VR games

Outstanding: A perspective-switching technique for covering large distances in VR games by Cmentowski et al [64] tries to solve the challenge of open world traversal in VR. Teleportation over long distances can be tiring, thus a third-person god-mode perspective was implemented in which the user can point to a location using motion controls to make an avatar move there (see Figure 6). At any time the user can switch to a first person perspective with a button press. The transition from third to first person follows an arch during which the environment grows to a 1:1 scale. The paper claims this transition technique causes no cybersickness. When switching back to a third person view this animation is played in reverse, starting from the back of the user's head outward. If the avatar moves too far away from the third person perspective another button press allows the user to "catch up", thus moving the view closer. During an explorative study forced switching was added which automatically transitions the user to a first-person perspective at important locations. Users described the technique as "natural" and "surprisingly intuitive". Interestingly, users expected the avatar to continue moving when switching to a first-person view while the avatar is moving to a chosen location. Since continuous movement in a first-person perspective would cause cybersickness, the avatar instead stops during the transition. Users enjoyed being constrained by a full body representation in the form of the avatar making travelling "a realistic and believable process". At the same time users did not perceive the avatar as their own body, instead describing it as an "NPC entity" operated from a "god-mode". A suggestion given was that the perspective switching technique should be used in conjunction with classic teleportation for precise adjustments. During the explorative study the test environment and the scale in the third person perspective was adjusted to allow locomotion unobstructed by trees and other view obstructing objects.

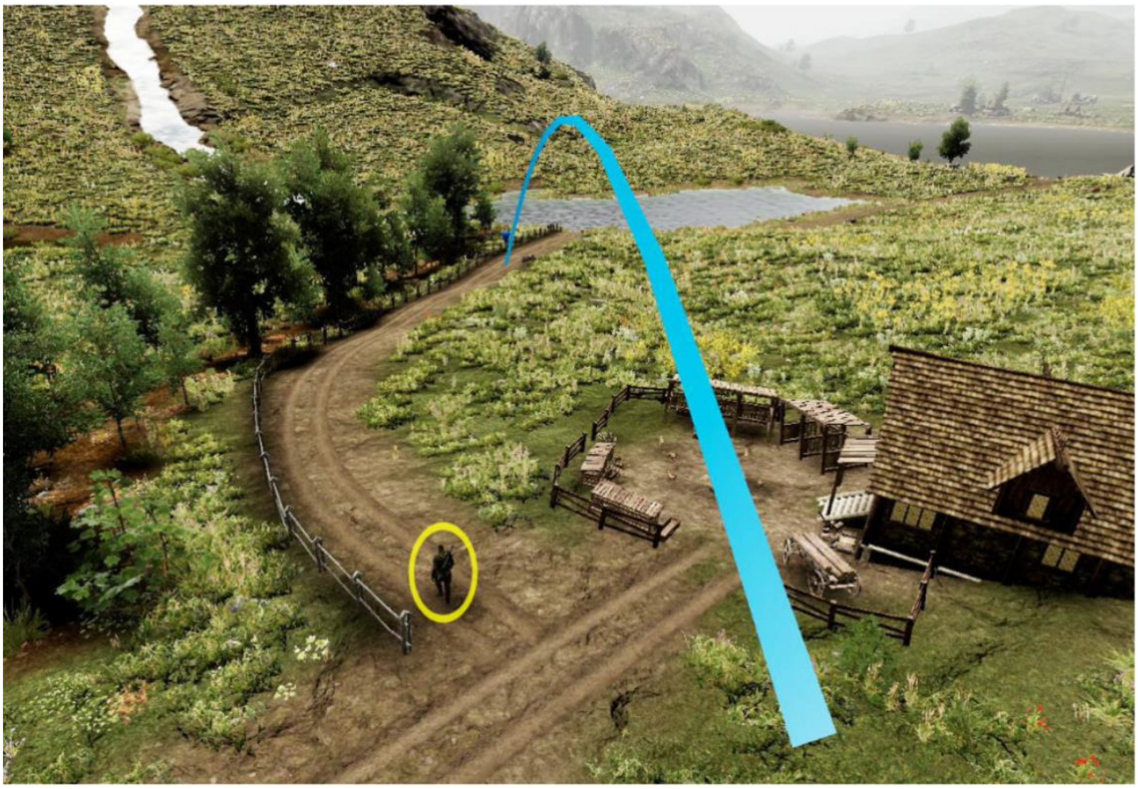


Figure 6: Setting a navigation target in third-person perspective [64]

2.2.4.6 3PP-R: Enabling Natural Movement in 3rd Person Virtual Reality

3PP-R: Enabling Natural Movement in 3rd Person Virtual Reality by Evin et al [70] fixes a miniature cutout of a scene in front of the user's face. When the user rotates their head an avatar representation of the user standing in the middle of the cutout rotates with them, so that it always faces in the same direction as them. Meanwhile the rotation of the scene stays static, thus making the world rotate around the avatar, as seen in Figure 7. The user can move through the scene using a combination of motion tracking in the 3D scene and analog stick controls, moving the cutout of the scene with the avatar. To give the user the impression of being stationary, rather than moving through a scene, a non-moving background is displayed around the cutout environment. This allows users to freely explore an environment from a third person perspective with very low cybersickness. Furthermore, the third perspective allows both replication of motion controls like hand movements and displaying animations such as running and jumping, and reactions to the environment like making the avatar fall over after getting hit by an obstacle. 3PP-R caused no or very little simulation sickness during an explorative study.

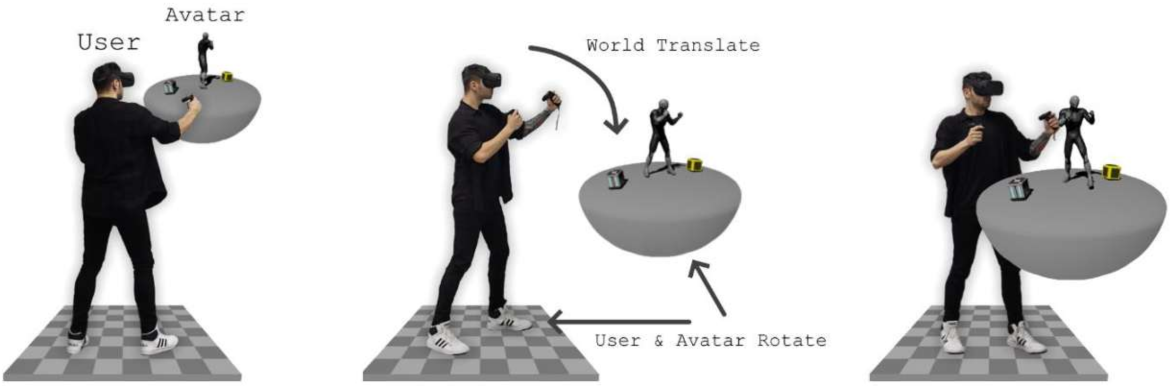


Figure 7: Visualization of 3PP-R [70]

2.2.4.7 Out-of-body Locomotion: Vectionless Navigation with a Continuous Avatar Representation

Out-of-body Locomotion: Vectionless Navigation with a Continuous Avatar Representation by Griffin et al [72] allows the user to switch between a first- and third person perspective. Locomotion is only allowed in the third person view. The view's location in the third-person perspective stays static, only updating when switching back and forth from a first-person perspective. When the user breaks line of sight, the view is automatically updated to a first-person perspective. The goal of this work was to develop a new locomotion technique that requires fewer perspective changes than teleportation while keeping the camera perspective static, thus preventing cybersickness. This goal was achieved according to the user study conducted in this work where significantly fewer "teleports" were needed in the third person technique rather than teleportation, which participants found more efficient. Furthermore, the study found "no significant difference between out-of-body locomotion for learnability, accuracy, likeability, disorientation and VR sickness." It is suggested in this work that such an approach would be well suited to a multiplayer environment, where teleporting avatars can seem jarring from an onlooker's perspective, but no tests concerning multiplayer were conducted.

2.2.4.8 The labors of Theseus

The labors of Theseus: how we designed a 3rd person VR experience [73] is a blog post concerning itself with how the camera for the third-person VR game Theseus was developed. For this the developers of the game came up with the so called Mixed-Camera System. This system allows the designers to either use a fixed view perspective for some scenes, and a player character following perspective for scenes where movement speed is limited. The developers found the main thing to consider during level design was the placement of cameras. Since user's head movement cannot be "forced" to look at a certain direction, rooms structure and camera placement therein had to consider the head rotation as it was when exiting the previous room.

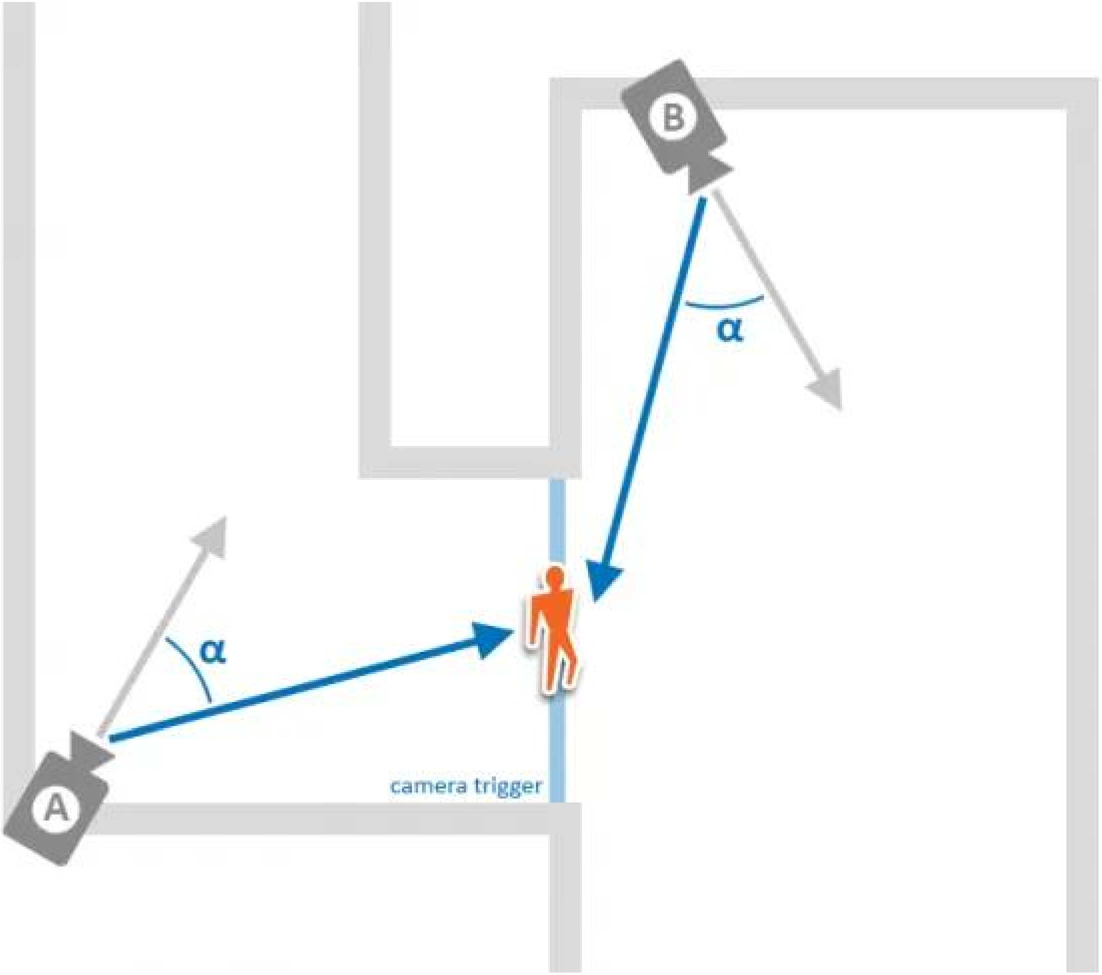


Figure 8: Example of optimal room design in Theseus.

Consider the schematics in Figure 8: The user will, upon leaving the room on the left have rotated their head to the right, as seen on camera A shown in Figure 8. When entering the next room the user hits a camera trigger, thus changing the view to camera B. This camera must be placed in such a way, that the same head rotation keeps the player avatar in view.

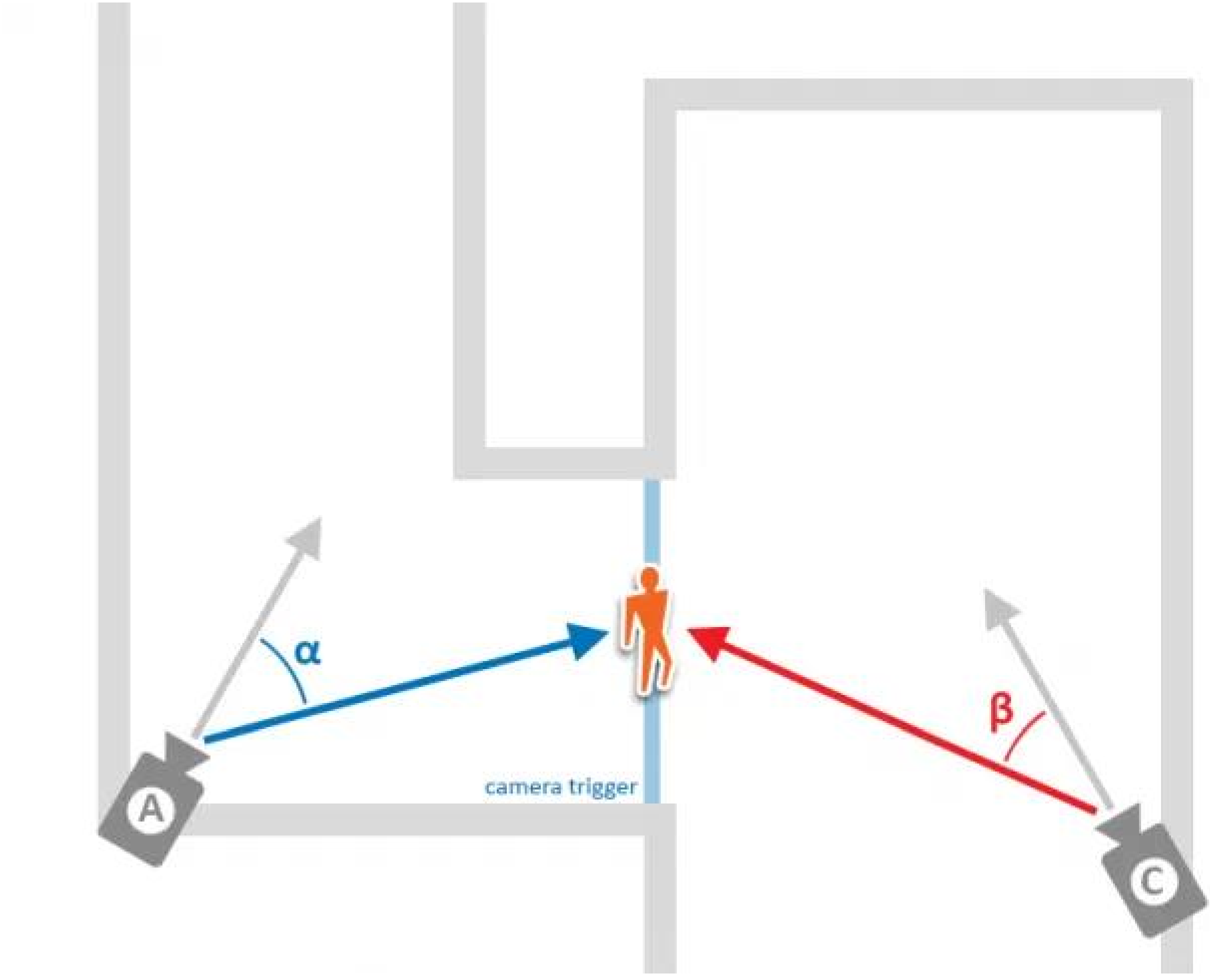


Figure 9: Example of incorrect camera placement.

In Figure 9 an example of an incorrect camera placement can be seen. Upon entering the room on the right and switching to camera C the user would be looking to the right along the wall, rather than the left where the player character is actually located.

2.2.5 Synthetization of the findings

There seems to be four different approaches to viewing an environment using a third person perspective:

- Manipulating a hand-mounted miniature environment, thus allowing to see the scene from a third- and first-person perspective at the same time [67], [68]
- Looking down onto a miniature environment [64], [69], [70]
- Continuously moving with the avatar from a behind the shoulders perspective [71], [73]
- Fixed predetermined view locations [66], [73]

Actual movement can be split into four methods:

- Teleportation by selecting a location in a miniature environment [67]
- Gradually moving by choosing a location in a miniature environment [68], [69]
- Continuous movement using an analog stick or keyboard [64], [70], [71], [73]
- Movement using motion tracking [66], [70]

Only two works investigated the ability to switch between a first- and third-person perspective [64], [66].

None of the papers concerned themselves with seated use but most of them, given an option to rotate the current view, could definitely be used this way.

Since this work tries to tackle the challenge of quick horizontal movement, works allowing for such movement were considered for implementation. Here 3PP-R [70] was of particular interest since it’s view of the scene and direct analog stick controls allow for precise movement. Outstanding [64] on the other hand seemingly gave the best overview of a given VR scene, and the ability to switch to a first person view gave it an edge over other solutions.

Thus a combination of 3PP-R [70] and Outstanding [64] led to the development of the dynamic camera solution used in this work, combining the scene cutout of 3PP-R and the ability to switch to a first-person perspective from Outstanding. Further additions were: the ability to rotate the scene using the right stick rather than the user’s head to allow seated use, a very faded out scene being visible while moving and the entire scene being visible when standing still.

3 Design & Implementation

In this chapter the design and implementation of the three control schemes used in this study will be discussed. All locomotion techniques will be based in the Non-Natural Locomotion techniques environment (see Figure 10).

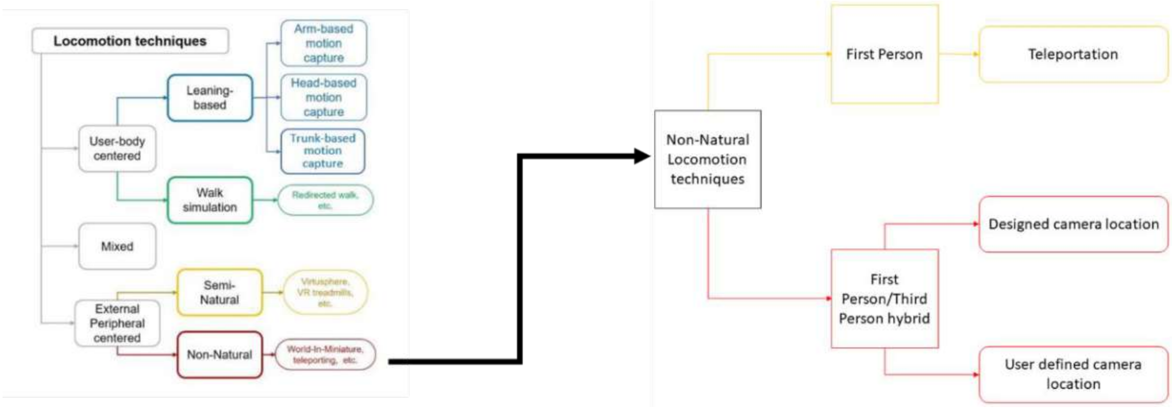


Figure 10: Locomotion Technique Design Space

3.1 Interaction Design

This subchapter will be split into the design of the static camera, dynamic camera and teleportation.

3.1.1 Teleportation

The design of the teleportation locomotion technique was kept as closely as possible to default as is used in most VR applications. Teleportation is initialized by holding the stick on the right motion controller forward. At this moment a colored arch appears at the tip of the motion controller pointing downwards.

Figure 11: Teleportation implementation with arch and valid location

Using an arch rather than a straight line allows users to teleport on top of elevated surfaces out of sight. If the endpoint of the arch points to a valid location a blue circle is shown, denoting the location the user will reach upon teleportation (see Figure 11). Letting go of the right analog stick triggers a fade out animation, where the user's view gradually turns black, then triggers the teleportation, almost invisible to the user, and then fades back in again at the new location. Moving the right stick left or right causes the user to snap rotate by 45 degrees, allowing them to rotate on the spot without having to rotate their body, thus making seated play possible.

3.1.2 Static camera design

The original inspiration for the static camera locomotion technique were classic 32-bit era video games such as Resident Evil, that used fixed camera perspectives through which an avatar would move. At the time this was done to get around hardware limitations by using prerendered backgrounds. This precluded lateral movement of the view of the scene, as that would not be compatible with the unchanging nature of a prerendered background. Similarly in VR the viewpoint of the user generally cannot be moved without causing motion sickness. Thus, the solution of static camera angles offers itself well for a third person approach in VR.

3.1.2.1 Camera placement and transitioning between scenes

The most basic approach of the static camera technique can be explained as follows:
The scene is viewed from a predetermined location and angle in the scene. An avatar representation allows the user to move around the scene. When the avatar touches a predesigned trigger, the

view transitions to a new camera angle and location to give a better view of the current avatar position.

The classic static camera angles of older video games cannot be mapped 1:1 onto VR. On a TV screen the designer can decide exactly where the user can look at all times. In VR the user cannot be constrained in such a way, as locking the user's view in a given direction would be antithetical to the virtual reality experience. However, the initial view the user has when entering a new scene can be chosen, for at least the yaw rotation, as rotating the user's view up or down would give the impression of a tilted scene. Rotating the users view to a fixed rotation is not the silver bullet it might be expected to be, as in VR you also have to consider the user's current head rotation. Consider the following scenario: A user moves their avatar from the left side of the room to the right side through a door. They follow the avatar with their head and end up looking to the right when they move the avatar to a new room. This triggers a camera transition to a new view location and rotation. If this location was not carefully chosen the user might now end up staring at a wall or away from the avatar, and force the user to look around the scene to find the avatar again. One solution for this problem, which was investigated in this work, was inspired by the developers of the video game Theseus [73]. Their approach was to design camera placement in such a way, that on transition between scenes the user would end up looking at the avatar's location while keeping the head rotation. This works reasonably well, in enclosed spaces and especially if you have the freedom to design the environment around this technique.

Finding ideal camera locations and triggers thereof was usually possible in the interior navigation map as will be described in chapter 4.6.2, however was very cumbersome in the exterior navigation map (chapter 4.6.3). Finding the right angle was impossible, since the user could approach a trigger from any angle in an open environment. In addition, unlike Theseus, the static camera solution described in this work also implements the ability to switch between third and first person. This could lead to problematic scenarios such as: the user moves the avatar, from their perspective, to the right (see Figure 12). They then switch to first person perspective, and then look left. Now, were they to switch back to a third person perspective, they would end up looking away from the avatar, and would be forced to look around the scene to find the avatar again.

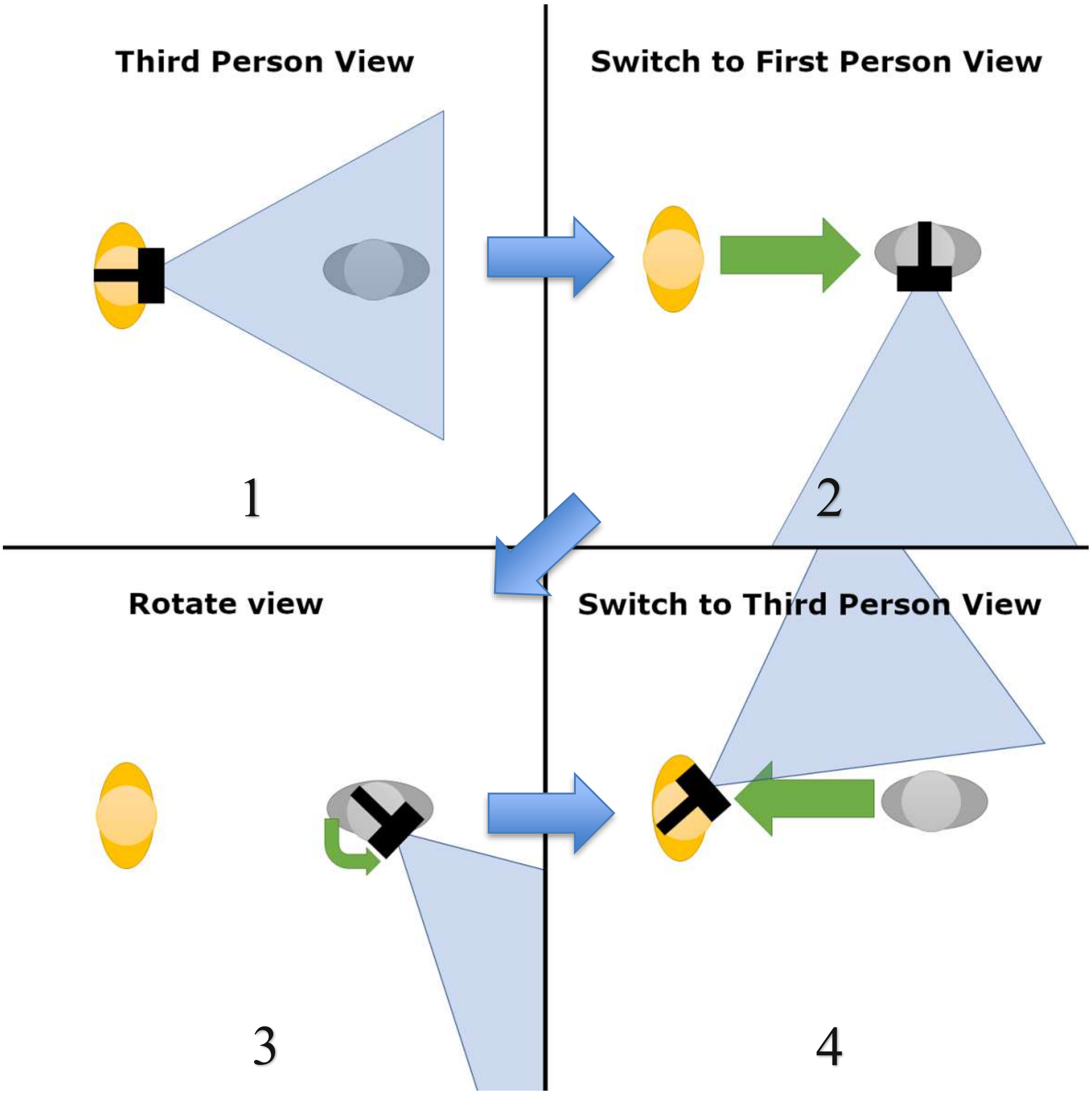


Figure 12: Example of confusion that might occur when switching between first and third person. The grey figurine represents the third person avatar, and the yellow figurine represents the view the user has when in third person view.

This was mitigated with the implementation of an arrow that points to the avatar when the user looks away from it. To further mitigate the disorientation problem, a fast transition animation between first and third person was implemented, wherein the user's perspective quickly moves in and out of the avatar's head. This animation had to be fast and short enough as to not cause motion sickness. Through preliminary user testing this was settled on just 0.2 seconds. However, these mitigation measures did not entirely solve the issue.

In the end the solution proposed here was twofold: auto rotation to the avatar and the ability to manually rotate the view by the user.

First: when transitioning from first person back to the third person view, the view is automatically rotated to the avatar during the transition, thus making the avatar the first thing the user sees (see Figure 13).

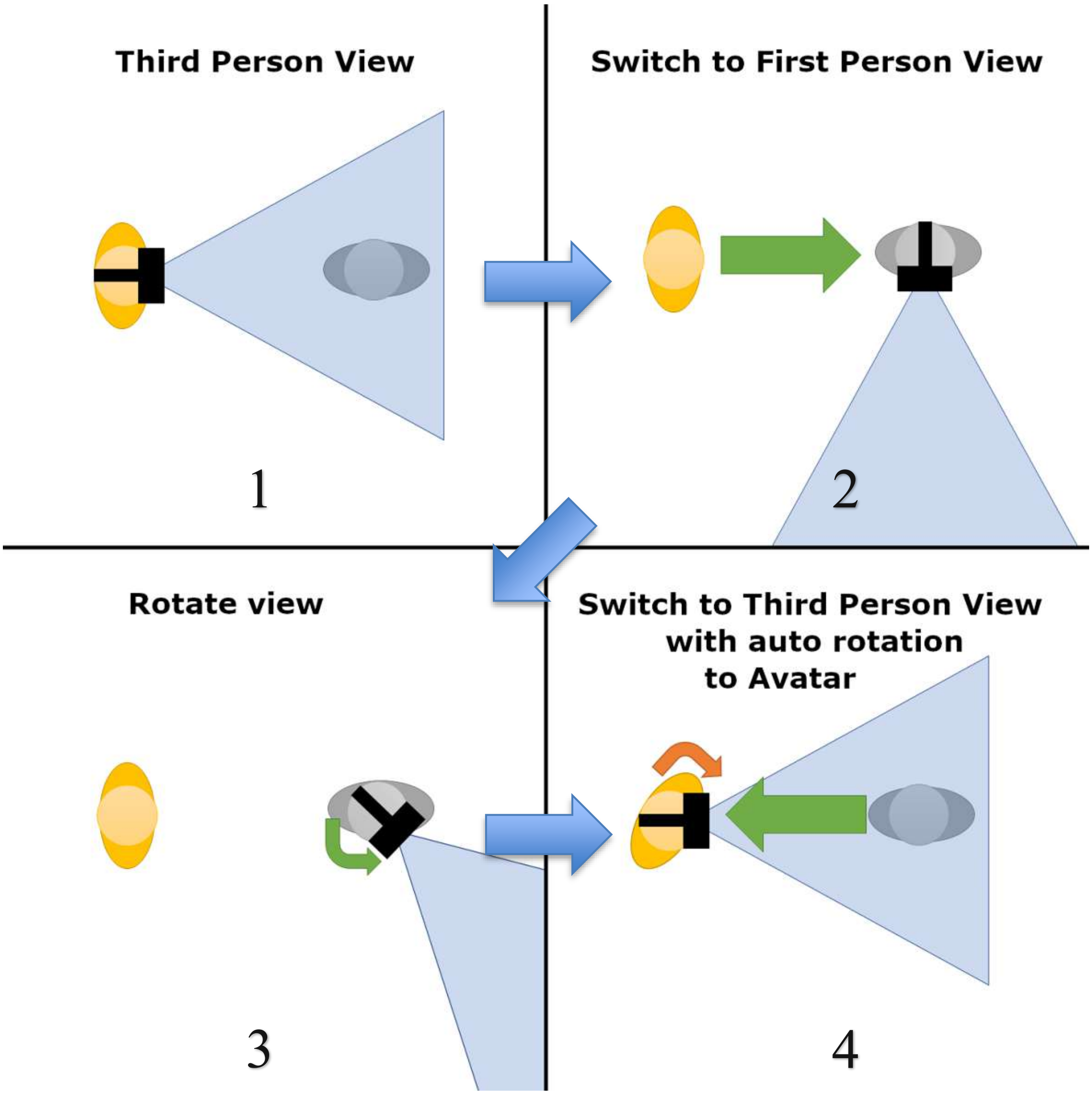


Figure 13: Switching back to third person view auto rotates the user to always look at the third person pawn.

This might lead to scenarios where the avatar could be moved to a location where the users head movement could not follow. The solution implemented involves both letting the user rotate their view in 15 degree steps and also auto rotating the view when the user moves the avatar outside their potential field of view.

Finally, a slow motion effect was added when transitioning positions, allowing the user to reorient themselves in hectic scenarios requiring quick reaction time.

3.1.2.2 Character movement

Most modern video games and VR applications use camera relative movement controls: if the user were to press a direction on the analog stick, the avatar would rotate to that direction and start moving in that direction relative to the user's view of the scene. This comes natural if the view of the user is directly behind the avatar and follows it. Often this is combined with the ability to rotate the view around the avatar. When using fixed camera angles, a few issues arise: changing camera angles when transitioning between scenes causes the directional inputs to change relative to the camera. If, for example, the camera changes to the opposite view, forward becomes backwards, left becomes right, that is a general inversion of controls takes place relative to the previous perspective. Therefore, confusion is caused for the user, especially if the change of view comes suddenly and unexpectedly. In worst cases the user will end up running back the way they came, causing another camera change back to the initial view, thus compounding the confusion. In order to mitigate this issue the following adjustment was implemented for the static camera control scheme: directional controls from the previous camera angle are retained when changing views, and are only updated when the user points to a new direction, or stops the avatar. This fixes the issue of immediately going an unintended direction when changing camera angles.

Another VR specific peculiarity is that when using camera relative controls, the direction the avatar moves will also change when rotating the user's head, as that changes the view of the scene. Some VR games, such as Chronos keep the relative controls to the user's view, and only update the relative controls once the user stops their movement input. This can help mitigate the unexpected change of direction the user might experience when rotating their head. Such adjustments were considered during development of the static camera control scheme, but were deemed unnecessary during preliminary testing.

In older video games, so called tank controls were often used in combination with fixed camera angles. The name tank controls stems from the way the character is controlled, which is similar to the controls of a tank. In an application featuring tank controls, the user's avatar will generally move in the direction that they are facing, instead of the direction that the camera is facing. For example, pressing up on the analog stick will make the avatar move forward from its perspective rather than the user's. Pressing left or right on the analog stick will make the avatar rotate in place, similar to a tank. The main advantage of this control scheme is that pressing a direction will stay consistent between camera transitions, offering itself to the static camera control scheme. The main disadvantage of this control scheme is the lack of the ability to move sideways, from the perspective of the avatar. This could be solved by adding yet more buttons dedicated to strafing, but that would overcomplicate the control scheme even more. In general, tank controls are now barely in use anymore as they are deemed unintuitive and cumbersome.

A third option for movement controls, beside camera relative and tank controls, would be to point to a location, and have the avatar move there by its own automatically. This technique is used by Outstanding [64] and many other games. Choosing a location once could potentially solve the problem of disorientation when changing camera angles as the chosen location stays consistent between camera angles and does not have to be readjusted manually. The process of choosing a location itself would be slower than directly controlling the avatar and would get less precise the further the avatar is away from the user's view.

3.1.3 Dynamic camera

The dynamic camera control scheme was created on the basis of both Outstanding [64] and 3PP-R [70] combining their advantages. Over the course of development of this work, Outstanding was reimplemented to be compared to the static camera control scheme. The comparison offered itself, as it also featured a third person camera and the ability to switch to a first person perspective.

3.1.3.1 Reimplementing Outstanding

The Outstanding VR locomotion technique (see chapter 2.2.4.5) combines a miniature overview of a scene, a third person avatar and a manual gradual switch to the avatar's perspective.
A few issues arose during preliminary testing. Gradual transitioning from a miniature overview scene to a 1:1 first person immediately caused motion sickness. Outstanding suggests that a combination of 10x scale in third person, a 45° angle down to the player avatar, a 0.5 seconds transition, and camera movement along a curve downwards, will prevent any motion sickness. This was reimplemented as closely as possible while comparing video footage of Outstanding [74], yet transitioning between views still caused motion sickness during preliminary testing.

Another perceived shortcoming was the need for a "Catching Up" feature. If the user moves their avatar too far away from the user's view, it might become necessary to move the view closer again. Outstanding allows this using the so called "Catching Up" feature, where the view gets brought closer when pressing a button. The need for this, especially in bigger scenes, was felt as cumbersome by test subjects, as the users defaulted to using it every few steps. This made the experience feel choppy and unrealistic, similar to teleportation.

A seemingly essential missing feature not mentioned in Outstanding, was the ability to rotate the view around the avatar during traversal. The only way for the user to achieve this without such a feature, would be to transition into first person, rotate their view in the desired direction, then transition back out again in a new direction. This was found to be extremely cumbersome.

Finally, the avatar in Outstanding is controlled using an arched pointer, similar to common teleportation techniques. Controlling the avatar in such a way becomes harder the further it moves away from the user's view.

The main advantages of Outstanding over the static camera control scheme are the ability to freely choose where to place the third person view, a greater ease of achieving an overview of a given scene thanks to the shrunken scale in third person, and very little confusion during the transition from third and first person and back. In the static camera control scheme it is easy to lose track of the avatar when transitioning back out to the third person view, meanwhile in Outstanding, the comparably slower transition allows the user to reorient themselves around the avatar.

3.1.3.2 Taking lessons from 3PP-R

3PP-R [70] fixes all of the issues of Outstanding, but brings limitations of its own. 3PP-R allows a view following the avatar, without motion sickness, thus eliminating the need for a "Catching Up" mechanism. This is achieved by shrinking the environment by a scale of 1:50, similar to Outstanding, and showing only a cutout around the user's avatar, with a 28 cm radius. Furthermore, a static Independent Visual Background in the form of a checkered plane beneath the cutout was implemented to ground the user's view on an unmoving background. Independent Visual Backgrounds, or IVB for short, have been shown to drastically reduce motion sickness when in combination with independently moving scenes [75]. Cutting out the environment solves motion sickness, but also very much limits it's uses in larger environments.

3.1.3.3 Combining and improving on Outstanding and 3PP-R

By combining Outstanding and 3PP-R, this work proposes a superior control scheme to both. As a first step, the scaled down environment from a third person perspective is kept with a scale of 1:10.

Movement using an analog stick is used similar to 3PP-R, but without mapping the avatars location to the HMD's location in the tracking space.

The entire virtual environment is visible, just as in Outstanding, unless any movement happening not caused by the user's actual head movements. So when moving the avatar using analog stick controls or transitioning between perspectives, the environment is extremely faded out except for a radius around the avatar. Behind the transparent environment an Independent Visual Background, in the form of a checkered floor, ceiling and walls are visible. How this looks in action can be seen in Figure 14.

Figure 14: Dynamic camera scene visible while standing still in the top image and faded out while moving in the bottom image.

The opacity of the background should be adjusted per scene, as darker scenes seemingly needed a lower opacity to not cause motion sickness. Generally an opacity between 0.1 and 0.15 was used, where a value of 1 means full opacity and a value of 0 means the environment is entirely invisible. Through extensive testing it was concluded that a visible radius of 35 cm around the avatar does not cause any or minimal motion sickness during movement. For transitioning from third person to first person and back, the radius had to be cut down even more to just about cover the floor under the avatar. This was done since the perspective transition also changes the scale, thus, from the perspective of the user, growing the environment around them. An example of such a transition can be seen in Figure 15)

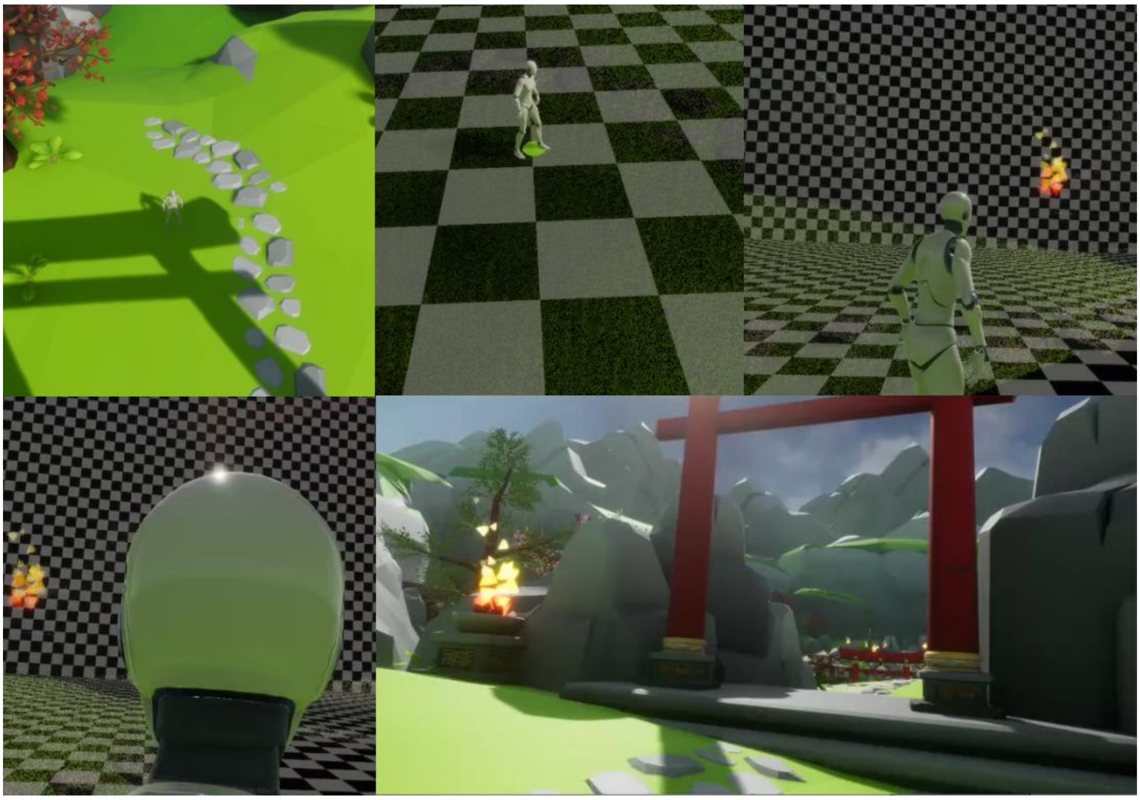


Figure 15: Transition from third person view to first person view using dynamic camera.

It was found during initial testing that leaving some elements always visible, even during movement did not cause any additional motion sickness, as long as they were not larger than the avatar. This made it possible to keep the avatar, the objectives and some of the obstacles to stay visible while the rest of the environment could stay quasi invisible. Having some things "more" visible than others really helped users quickly orient themselves in the environment and understand how to reach their objectives during preliminary testing. See Figure 16 for an example of such selective visibility.

Figure 16: Selective visibility during movement when using dynamic camera

In the dynamic camera implementation, the avatar's location is always anchored in front of the users default sitting position, rather than being attached to the user's head, as it is in 3PP-R. Moving and rotating a fully visible scene with the user's head could cause considerable motion sickness. Furthermore leaving the scene static allows the user to peer away from the avatar and inspect the environment. Instead, a continuous rotating camera using the left analog stick, similar to modern 3D video games was implemented. Fading out the surrounding environment, similarly to when moving the avatar, allows the rotation of the user's view without causing considerable motion sickness, despite rotation being one of the stronger causes of VR sickness than translational movement [5].

To quickly reorient the player towards their avatar, in case they somehow got turned away from it, a "growing" animation is played whenever a transition from translucent to an opaque level is needed. The environment gradually grows from the avatar out into the scene. From observing this effect the user can intuitively reconstruct the avatar's location.

The transition from third person to first person is kept similar to Outstanding, with some adjustments. In Outstanding the switch from third person to first person would ignore the avatar's rotation, as rotating to the avatar's viewpoint would also require rotating the user's view. This would cause strong VR sickness. However, since we hide most of the surrounding environment and instead allow the user to anchor themselves in the non-rotating Independent Visual Background we can gradually rotate the view to exactly where the avatar is looking all while doing a smooth transition (see Figure 15).

Similar to static camera, time is slowed down during the transition between perspectives to allow users to readjust in case quick reactions are required.

3.2 Implementation

3.2.1 Teleportation

The teleportation technique implementation was based on the VR sample project included with Unreal Engine Version 4.27. It works by calculating a projectile path from the user's hand. The endpoint of the arch checks if the location hit corresponds with a location of a previously calculated Navigation Mesh. A Navigation Mesh (example seen in Figure 17) or nav mesh for short, defines an area where characters are allowed to move in a scene. It is calculated by defining an area using a volume in the scene and setting the size of a character. Every location in the volume that is not too steep and can be reached by a character without colliding with any other objects will be marked as valid. This makes it possible to define areas the user can teleport to without accidentally clipping through a wall.

Figure 17: Navigation Mesh in outdoor test level highlighting navigable area with green.

3.2.2 Static camera

To allow the automatic switching of camera locations between areas, specific volumes had to be placed in the scenes and camera locations (see Figure 18). Placement of volumes in an enclosed space is somewhat intuitive, as it one camera location per room is usually enough to capture the entirety of it. But on occasion a single location is not enough, as for example a hallway with doors on all sides, or a room that goes around a corner.

Figure 18: Placement of volumes and corresponding cameras.

The avatar was based on the default third person template from Unreal Engine 4.27, which featured animations for walking, jumping and idling. An orbiting camera system was included that needed to be replaced with the static camera system. A new animation was added for levels featuring targets to shoot, wherein the character aims their pistol to mirror the stance the user should take.

3.2.3 Dynamic camera

To achieve the cutout effect, a material function was implemented and applied to every material in the scene. A material defines the visual look of an object in a scene. Material functions define reusable functionality. By defining radius and a location the materials using the cutout shader can determine which parts should be rendered fully. The areas outside the radius are rendered by applying the DitherTemporalAA Function provided by Unreal Engine 4.27. This gives materials a dithered semitransparent look when it is set to masked. A masked material allows hiding certain parts of an object using a texture mask, which defines which areas should be visible and which should not. An example of what this looks like can be seen in Figure 19.

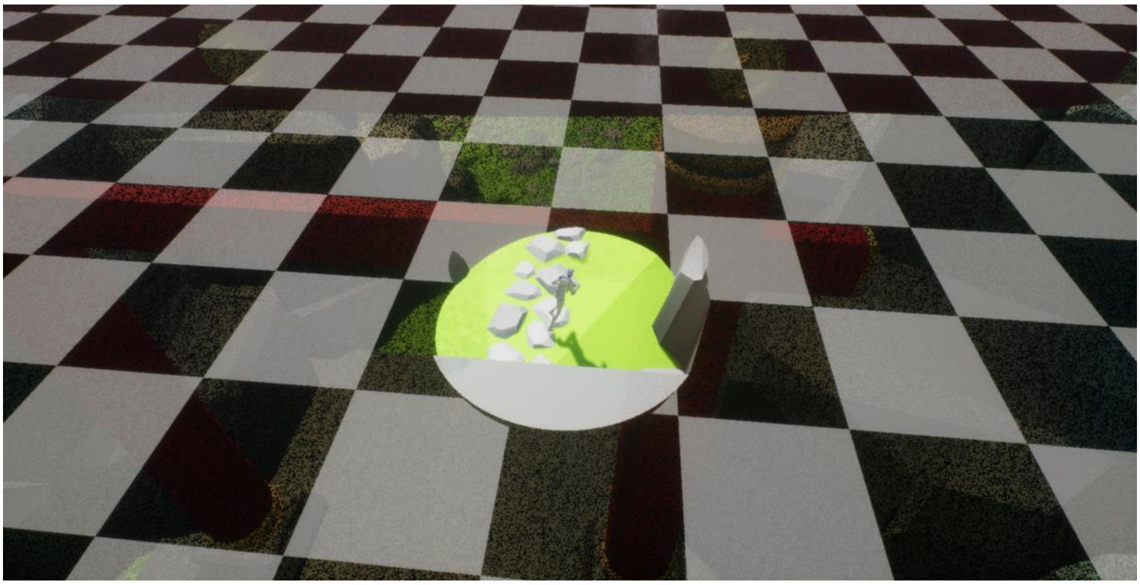


Figure 19: Avatar surrounded by dithered masked material

4 Methodology and Study Design

4.1 Problem Definition

The goal of the user study was to evaluate the comfort, usability, preference and performance of three movement techniques. As part of this thesis two novel techniques were developed in prototypical fashion: static camera views and dynamic camera. A third movement technique, teleportation, was taken from the Unreal Engine 4.27 Virtual Reality sample. This technique was adapted to have a fade effect between changing locations to bring it more in line with teleportation techniques in commercial products, and to somewhat limit the speed at which the user can move through the scene. Since these techniques are in a prototypical state, they were assessed using a formal formative evaluation approach. 12 test subjects were selected for a within-subject assessment. Thus, every test subject used each control scheme on every type of trial.

Concretely the following six questions were to be answered during the trials:

- Is the control scheme intuitive?
- Does it cause disorientation?
- Does it cause physical illness?
- What control scheme allows the user to react the fastest to a given scenario?
- How do the participants perform in comparison to the other control schemes?
- What control scheme does the participant prefer for a given scenario?

The static camera and dynamic control schemes were designed to fix two perceived problems of the teleportation control scheme:

- A lack of continuous movement.
- Slow reaction time when quick lateral movement is required.
- A sense of disorientation when teleporting between locations
- No ability to jump

4.2 Metrics and Measurement

Both quantitative and qualitative data were gathered during the tests.

Qualitative Data

- Observation about different approaches to completing a given task depending on the given control scheme.
- Comments given by the testing participants during the trials.
- Screen recordings of trails

Quantitative Data

- Time taken until completion of a given task
- Times "damaged" by a projectile or enemy
- Simulator Sickness Questionnaire
- Presence Questionnaire

4.2.1 Simulator Sickness Questionnaire

The Simulator Sickness Questionnaire, or SSQ for short, was developed to ascertain the reaction users have to virtual reality, and other simulations, in regards to motion sickness and other related discomforts. The SSQ, which is now widely in use in academia [76] was created by Kennedy et al. in 1993 [77]. It encompasses 16 items concerning different types of symptoms such as fatigue, eye strain, and vertigo, which are rated "None", "Slight", "Moderate" or "Severe".

These items are added up into 3 categories Nausea, Oculomotor and Disorientation, which are then added up for a Total Score according to the following formulas:

$$\text{Nausea} = (\text{Score added up from all Nausea items}) \times 9.53$$
$$\text{Oculomotor} = (\text{Score added up from all Oculomotor items}) \times 7.58$$
$$\text{Disorientation} = (\text{Score added up from all Disorientation items}) \times 13.92$$
$$\text{Total Score} = \sum (Nausea\ items + \text{Oculomotor items} + \text{Disorientation items}) \times 3.74$$

4.2.2 Presence Questionnaire

The Presence Questionnaire used was created by Bob G. Witmer and Christian J. Jerome in 1998 [78] and further refined in 2005 [79]. The goal of this survey is to measure the sense of presence or immersion in a virtual environment. It encompasses 24 questions, two of which concern themselves with haptics, which were ignored as they were not the focus of this study. Each question is rated on a 7-point scale. After a survey, these questions are then added up into the following subcategories: Realism, Possibility to act, Quality of interface, Possibility to examine, Self-evaluation of performance and Sounds.

4.3 Test Subjects

To facilitate a full balancing of the three testing conditions [80], a sample size of six or full multiple thereof was required. In total, 12 test participants were recruited for the study.

Participants who had at least some video game experience were selected, as all control schemes, including teleportation, require some understanding of controller type input devices and movement in 3D. Furthermore, the trials could be quite intense and needed some dexterity in input, thus, requiring some experience for the trials to be completed in a timely manner.
VR experience was chosen to vary from none to extensive to see if previous experience in VR would influence preferences in control schemes. The avatar uses right handed animations, thus right handed users were preferred for testing. Participants needed to be over 18 years to be able to give consent for testing. Furthermore, age recommendations by Meta for the Quest Headset are 13+ [81]. Participants were required to not have color blindness as some trials required picking differently colored objects in scenes, and to give everyone a similar experience.

An effort was made to have an equal representation of genders with 5 out of the 12 participants being female (see Table 1).

12 persons where tested with a mean age of 30.2 and a standard deviation of 1.5.

User	Age	Gender	Wears glasses	Virtual reality experience	Video game experience
1	32	Male	Yes	Moderate	Extensive
2	32	Male	No	Extensive	Extensive
3	27	Female	No	None	Minimal
4	30	Male	Yes	None	Extensive
5	29	Female	No	Moderate	Moderate
6	32	Male	No	Extensive	Extensive
7	30	Male	No	Minimal	Extensive
8	30	Male	No	Minimal	Extensive
9	30	Female	Yes	None	Moderate
10	30	Female	Yes	Minimal	Extensive
11	29	Female	Yes	Moderate	Extensive
12	31	Male	Yes	Moderate	Extensive

Table 1: Test user data

4.4 Material and Facility

4.4.1 Hardware, Software

The chosen device for this study was the Oculus Quest 2, which at the time of writing, was the most commonly used VR Headset [82]. The Oculus Quest 2 enables full six degrees of freedom motion tracking of both the headset and two motion controllers, without the need for external markers or tracking devices. This allows for a quick and easy setup. Tracking is achieved using machine vision software looking for points of reference in the room around the user. The Oculus Quest 2 features four cameras for tracking, a 1920 x 1832 per-eye resolution, up to 120hz refresh rate and 90° field of view. A high end PC (11th Gen Intel(R) Core(TM) i7-11700K @ 3.60GHz, 32GB RAM, NVIDIA RTX 3090) was used to run the user study application. The Oculus Quest 2 was connected to the PC using a USB 3.0 cable.
For screen recording Nvidia ShadowPlay [83] was used.

4.4.2 Test Environment

A secluded and relatively calm room was selected as test location to avoid distractions during the procedures. Furthermore, the room was well lit with artificial light as per Oculus recommendations. The test participants were seated on a wooden chair with no arm rests to allow a free range of arm and head movements. A non-swiveling chair was purposefully chosen to force users to use the in-application solutions for rotation. The Oculus VR guardian was deactivated as collisions with the real life environment would be impossible due to requiring the participant to stay seated.

4.5 Trial design

Three trials were implemented using a different type of environment each. Each one gives the user a harder challenge than the previous one, and also focus on a different type of navigation. The first trial acts as an introduction to the control schemes, the second one focuses on indoor navigation and the last one on outdoor navigation. Since there are three different control schemes to test out, this means every user has to do each trial three times, thus making for nine trial runs per user in total. To counter a learning effect a 3x2 Latin Square Design [80] was used (See Table 2). The test subject would start with one control type, go through all trials, fill out a presence questionnaire and a simulation sickness questionnaire, then start over again with the next control scheme. All trials which feature finding objects in a scene have three different locations for these objects to further balance against a learning effect.

Test Subject	Control scheme #1	Control scheme #2	Control scheme #3
TP1	SC	DC	T
TP2	SC	T	DC
TP3	DC	T	SC
TP4	DC	SC	T
TP5	T	SC	DC
TP6	T	DC	SC

Table 2: Control scheme order (static camera = SC, dynamic camera = DC, teleportation = T)

During the trials the facilitator took notes of any comments uttered by the test participants. The VR view of the participants was recorded for further analysis.

4.5.1 Basic trials map

The first map has a blocky non-naturalistic design to be easily readable. Before starting the trial the test subject is instructed on how to use the current control scheme and what the goal of the current trial is. Challenges consist of quickly navigating an area, target acquisition and generally pushing the advantages and disadvantages of each control scheme to their limit. The area is designed as a linear path that is blocked by gates that require the user to gather a given amount of collectibles. There are two types of collectibles: green ones that need to be touched to be picked up, and blue ones that need to be shot. At the start of the trial the user is placed in an empty field with one collectible of each type (see Figure 20). This is to give the user time to get to grips with the controls in a relatively simple area. The trial starts once both collectibles are picked up.

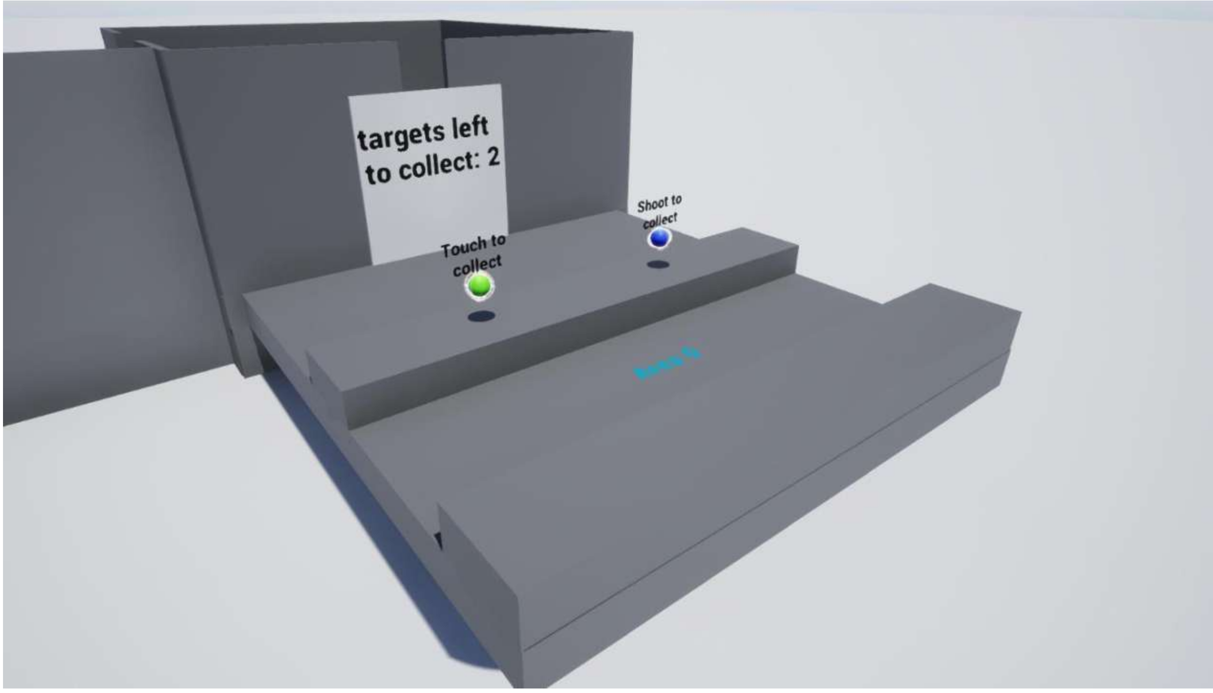


Figure 20: The starting area of the basic trial.

The first area (see Figure 21) requires shooting four targets, and then another 4 targets to get to the next area. In the first sub-area targets are spread horizontally, requiring some lateral movement and understanding of the area, while the second sub-area relies entirely on target acquisition.

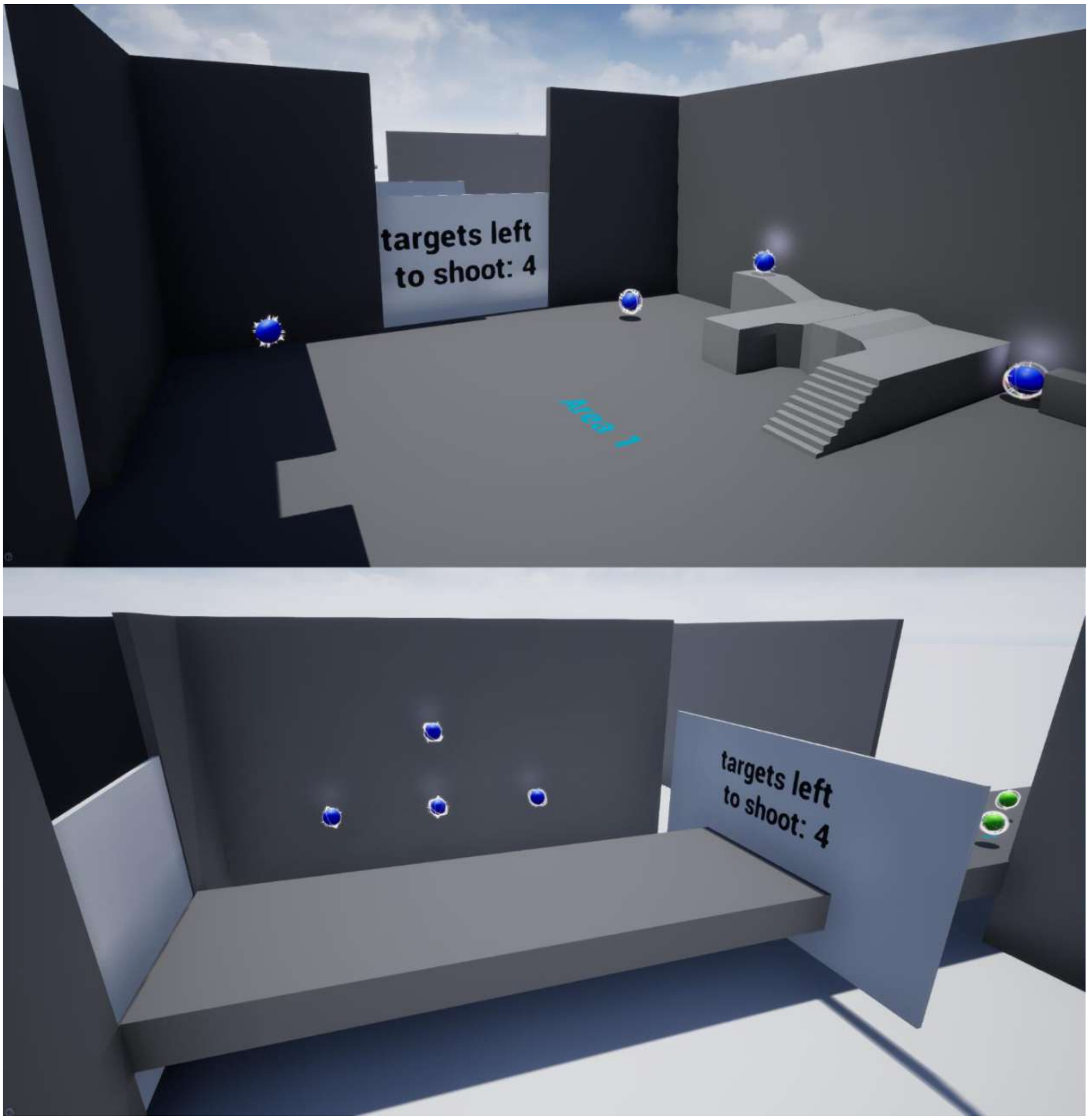


Figure 21: Area 1 featuring targets to shoot to get to the next area.

The second area (see Figure 22) focuses on continuous horizontal and vertical movement. The goal here is to collect green orbs by touching them. In theory, an avatar that can continuously move should have a clear advantage since they can pick up a row of orbs by just moving in a single direction. Meanwhile using teleportation the user would have to point and teleport to each orb individually to pick them up. Furthermore, a small gap obstructs the path to further collectibles. A third person view allows them to continuously move towards their destination and jumping over the gap in one move. Using teleportation the user has to teleport to the edge of the gap, and then teleport over to the other side. Additionally, this part of the trial features a staircase-like structure. Since the third person view has an overview of the area, the user can immediately tell where they need to jump from and where to move next. The first person teleportation user has to slowly ascertain the situation and find the correct teleportation arc to get on top of the staircase structure.

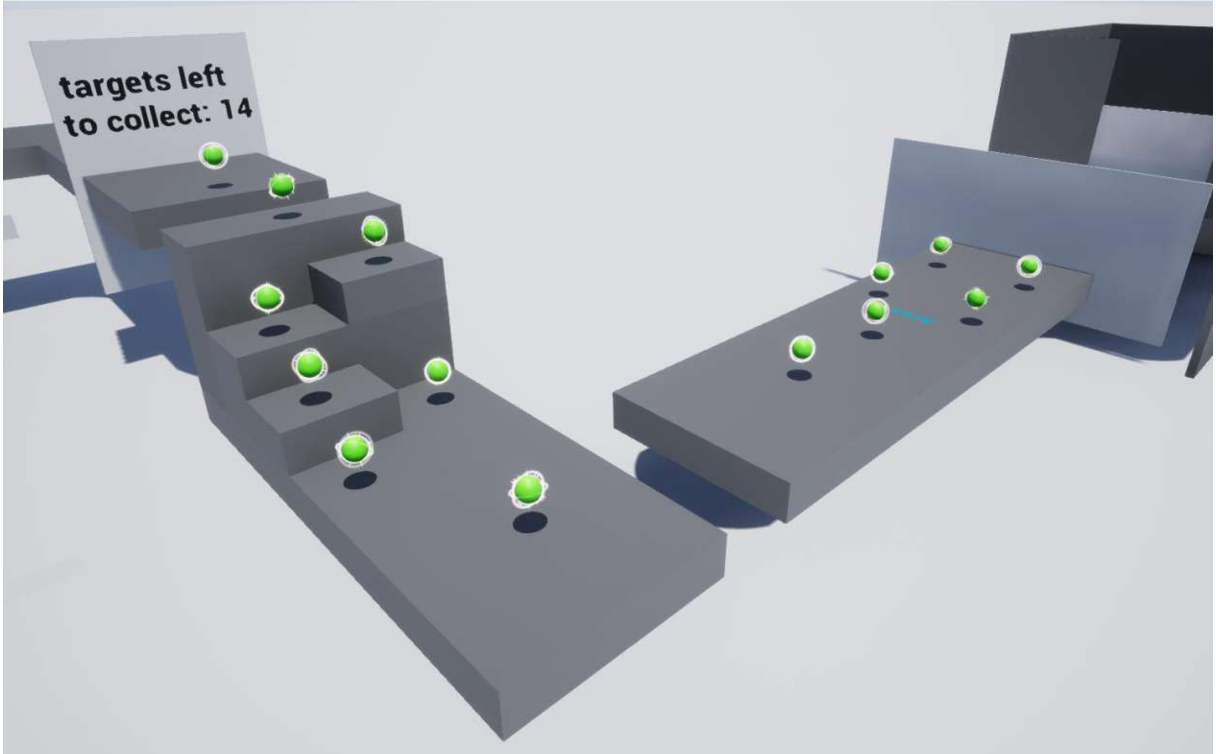


Figure 22: Area 2 featuring challenges for continuous horizontal and vertical movement.

The final area, as seen in Figure 23, features moving glowing obstacles for the user to dodge. They come both from the side and the front. An avatar controlled from the third person should have a clear advantage since it can quickly move laterally and also jump over obstacles. The trial concludes when the last collectible has been picked up. Completion time and the times the test participant collided with the glowing obstacles are recorded on finishing the trial.

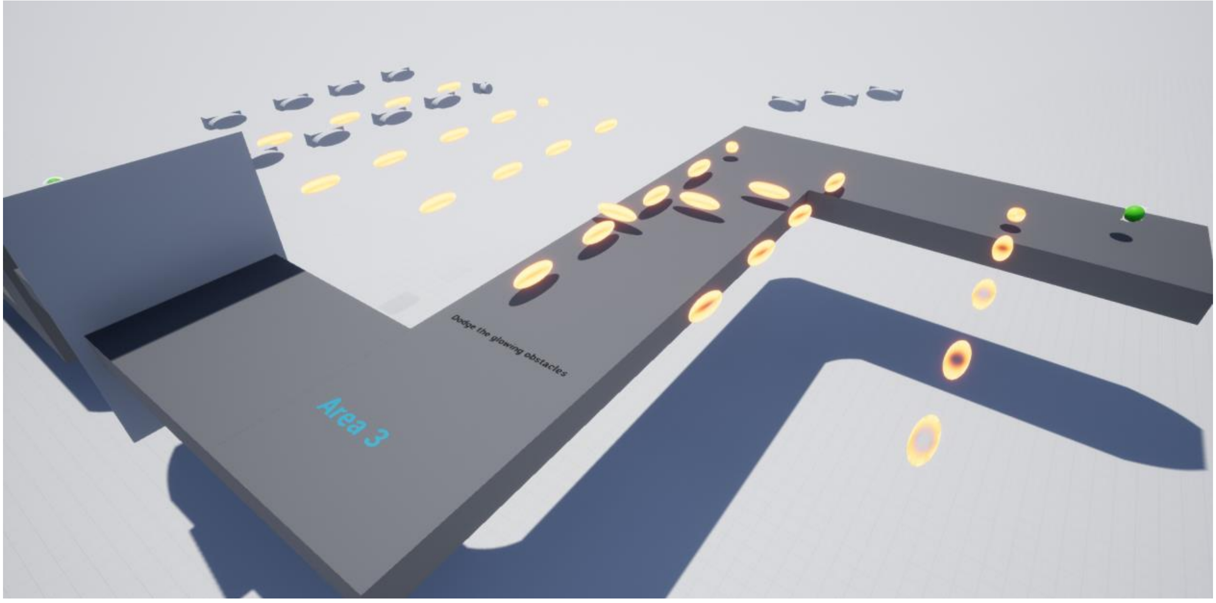


Figure 23: Area 3 requiring the user to dodge glowing obstacles

4.5.2 Interior navigation map

The second trial is set in and around a realistic house scene (See Figure 24). The goal here is to collect orbs by shooting them with a pistol. This trial was designed to test interior navigation, memorization of locations, situational awareness and interacting with the environment. To combat a learning effect, three different variants of collectible locations were created for each control scheme.

Figure 24: Outside the house scene.

Every time an orb is collected an enemy (see Figure 25) spawns. Collecting more orbs increases the number of enemies spawned, one enemy per orb collected. Touching an enemy will make it explode and make an invisible counter go up. The user is otherwise not affected. Enemies emit loud footsteps to make it clear when one is close by.

Figure 25: The player avatar running away from two enemies

Every time an orb is collected a message pops up informing the user on how many orbs are left to be collected. Before starting the user is given four tips:

- Enemies can be easily defeated by being shot in the head.
- They only spawn when collecting orbs.
- There is a maximum of one orb per room.
- There is one orb outside.

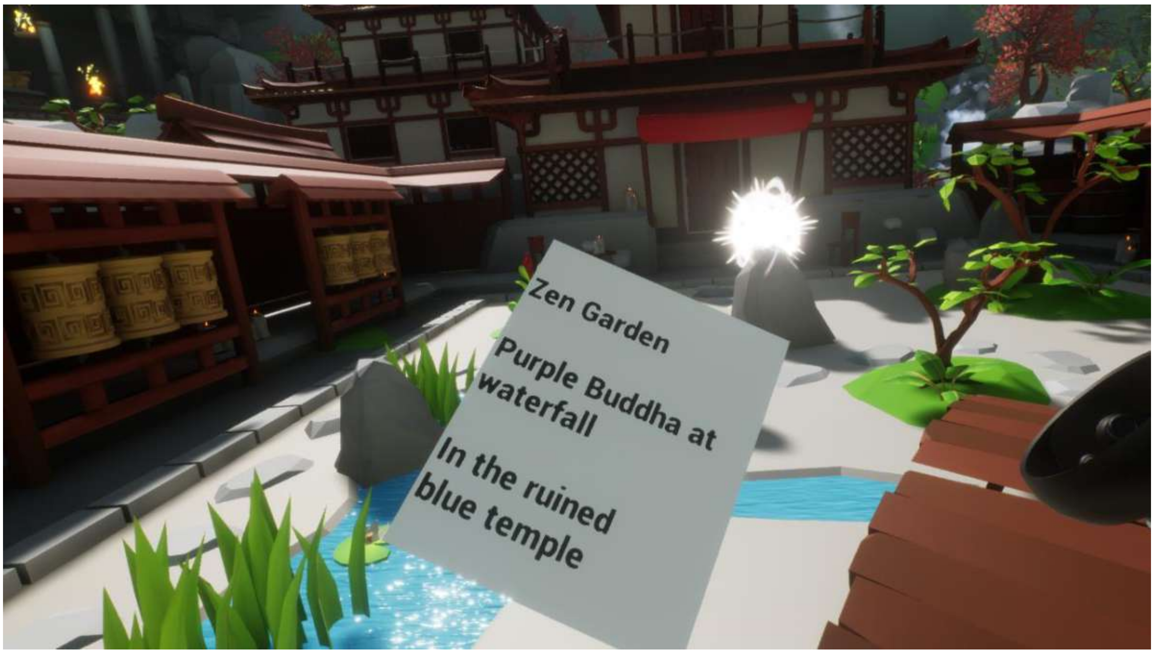
The test concludes when all orbs have been collected. Upon completion, the amount of time required to finish the trial and the times the test participant has been hit by the enemy are recorded.

4.5.3 Exterior navigation map

The third and final trial requires the user to navigate a large exterior map (see Figure 26).

Figure 26: An overview of the exploration scene.

To complete the trial the test subject needs to collect glowing orbs. A description of the location of these orbs can be viewed on the users left hand (see Figure 27). This requires the user to swap to a first person view. Orbs can also only be picked up in a first person view.



Zen Garden

Purple Buddha at waterfall

In the ruined blue temple

Figure 27: A user looking at a list containing all collectible locations. A collectible is visible in the background

This trial was designed to test outdoor navigation, transitioning between outdoors and indoors, sense of directions, recognizing elements in the environment.

Three different sets of collectibles were created to combat a learning effect when redoing this challenge with different types of controls. Each set contains one collectible located in an interior area. While using the dynamic camera, destination locations will not be faded out to make navigation easier.

The trial concludes when all collectibles have been gathered. The time to completion is noted in the end.

5 Evaluation Results

In this chapter, statistical and qualitative results for each trial variant are recorded and described. The qualitative results subchapter goes into further detail on preferences, comments and observations.

5.1 Statistical Results

Jamovi [84], an open-source statistical analysis software, version 2.3.21 was used for statistical analysis.

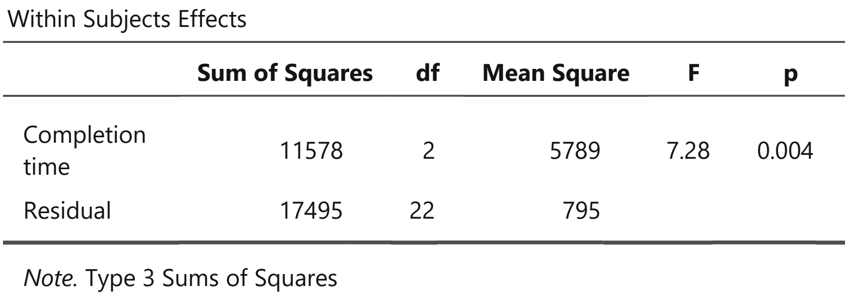
5.1.1 Performance

A repeated measures ANOVA was performed to compare the effect of three different control schemes on time to complete a trial, and times hit by obstacles.

5.1.1.1 Basic trials map

Time to completion and times hit by obstacles were measured in the basic trials map.

There was a statistically significant difference in completion time between at least two groups (F(11, 2) = [7.28], p = [0.004]) when testing in the basic trials map (see Table 3)



Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Completion time	11578	2	5789	7.28	0.004
Residual	17495	22	795		

Note. Type 3 Sums of Squares

Table 3: Repeated Measures ANOVA for completion times in basic trials map

Post hoc testing (see Table 4) highlighted a statistically significant difference between dynamic camera and teleportation for completion time (t=-3.2040, p=0.021).

Participants were faster using dynamic camera compared to teleportation ($\overline{DC}$ =105,75s, $\overline{T}$=144.00s) (see Figure 28). No significant statistical differences could be found between static camera versus dynamic camera (t=0.0581, p=0.998), and static camera versus teleportation (t=-2.6513, p=0.054).

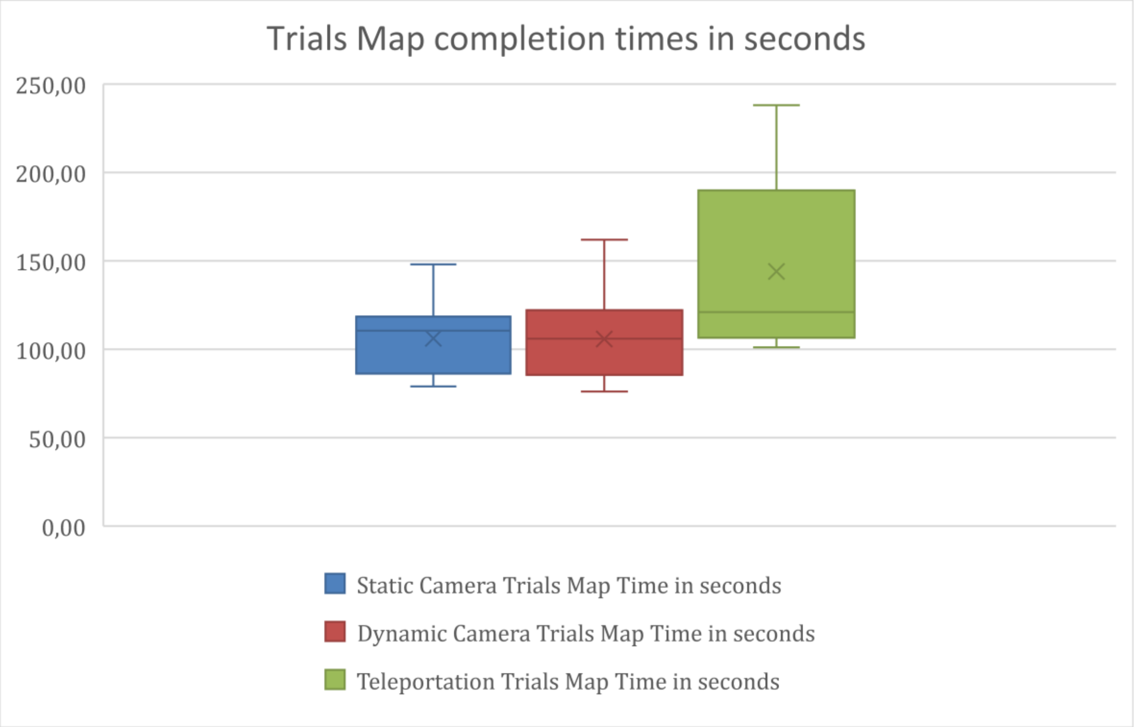


Figure 28: Trials Map completion time box plot

Post Hoc Comparisons - RM Factor 1

Comparison							
RM Factor 1		**RM Factor 1**	**Mean Difference**	**SE**	**df**	**t**	**p_{tukey}**
Static Camera	-	Dynamic camera	0.417	7.17	11.0	0.0581	0.998
	-	Teleportation	-37.833	14.27	11.0	-2.6513	0.054
Dynamic camera	-	Teleportation	-38.250	11.94	11.0	-3.2040	0.021

Table 4: Post Hoc Tests for completion times in basic trials map

A significant difference (see Table 5) in times hit by an obstacle could be shown between at least two groups in basic trials map (F(11, 2) = [4.67], p = [0.020]).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Times hit	11.7	2	5.86	4.67	0.020
Residual	27.6	22	1.26		

Note. Type 3 Sums of Squares

Table 5: Repeated Measures ANOVA for times hit in basic trials map

Participants were observed to get hit less (see Figure 29) on average when using the static camera versus teleportation on the basic trials map ($\overline{SC}$ =0.92 times hit, $\overline{T}$ =2.17 times hit). Post hoc testing (see Table 6) showed that the difference was significant (t=-2.916, p=0.035).
No significant difference could be shown between static camera and dynamic camera users (t=-0.192, p=0.980) and between dynamic camera and teleportation (t=-2.310, p=0.096).

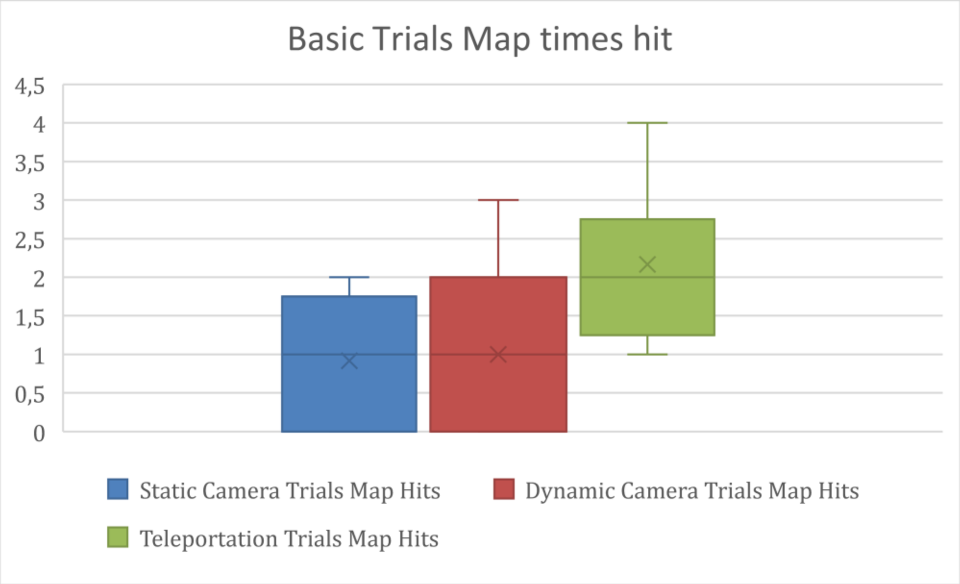


Figure 29: Trials Map times hit time box plot

Post Hoc Comparisons - RM Factor 1

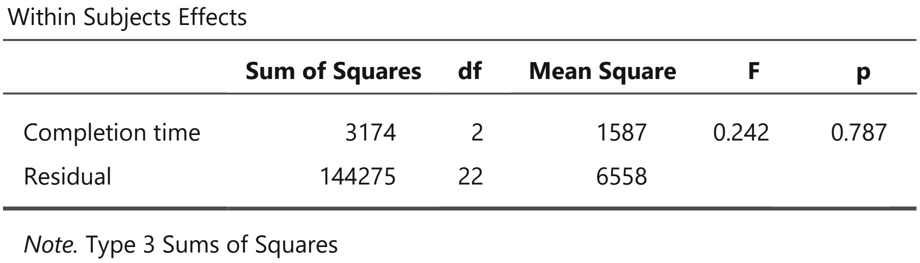
Comparison							
RM Factor 1		RM Factor 1	Mean Difference	SE	df	t	p_{tukey}
Static camera	-	Dynamic camera	-0.0833	0.434	11.0	-0.192	0.980
	-	Teleportation	-1.2500	0.429	11.0	-2.916	0.035
Dynamic camera	-	Teleportation	-1.1667	0.505	11.0	-2.310	0.096

Table 6: Post Hoc Tests for completion times in basic trials map

5.1.1.2 Interior navigation map

Time to completion and times hit by enemies were measured in the interior navigation map.

No statistically significant difference in completion time between at least two groups (F(11, 2) = [0242], p = [0.787]) when testing in the interior navigation map (see Table 7) could be found.



Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Completion time	3174	2	1587	0.242	0.787
Residual	144275	22	6558		

Note. Type 3 Sums of Squares

Table 7: Repeated Measures ANOVA for completion times in interior navigation map

Participants were faster on average using dynamic camera compared to teleportation ($\overline{\text{DC}} = 198.33s$, $\overline{\text{T}} = 218.08s$) (see Figure 30), but not to a significant degree.

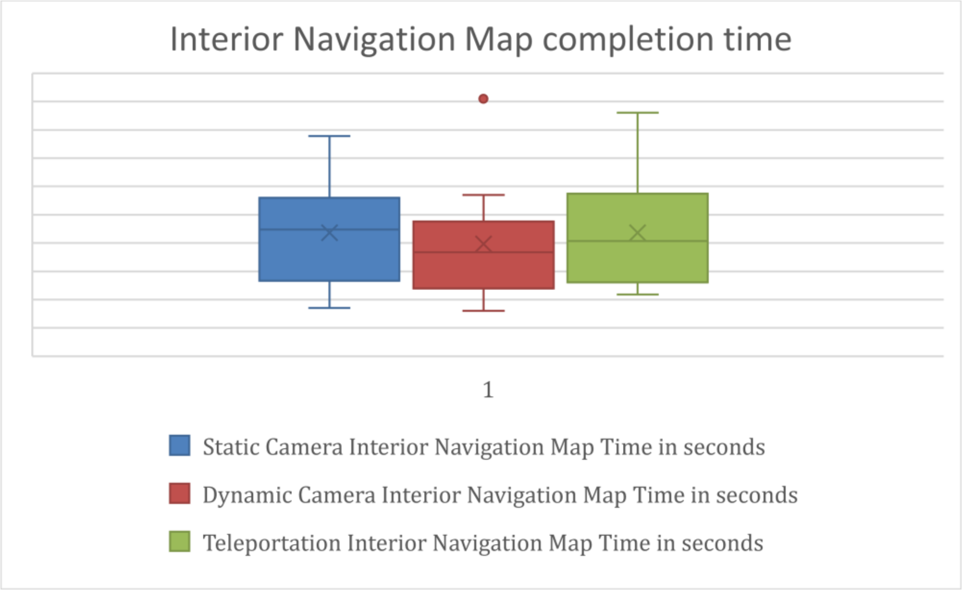


Figure 30: Interior Navigation Map completion time box plot

No significant difference (see Table 8) in times hit by an obstacle could be shown between at least two groups in interior navigation map (F(11, 2) = [0.149], p = [0.863]).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Times hit	0.222	2	0.111	0.149	0.863
Residual	16.444	22	0.747		

Note. Type 3 Sums of Squares

Table 8: Repeated Measures ANOVA for times hit in interior navigation map

On average participants collided more often with enemies when using static camera than when using dynamic camera or teleportation ($\overline{\text{SC}} = 0.92, \overline{\text{DC}} = 0.75, \overline{\text{T}} = 0.75$), but not to a statistically significant degree (see Figure 31).

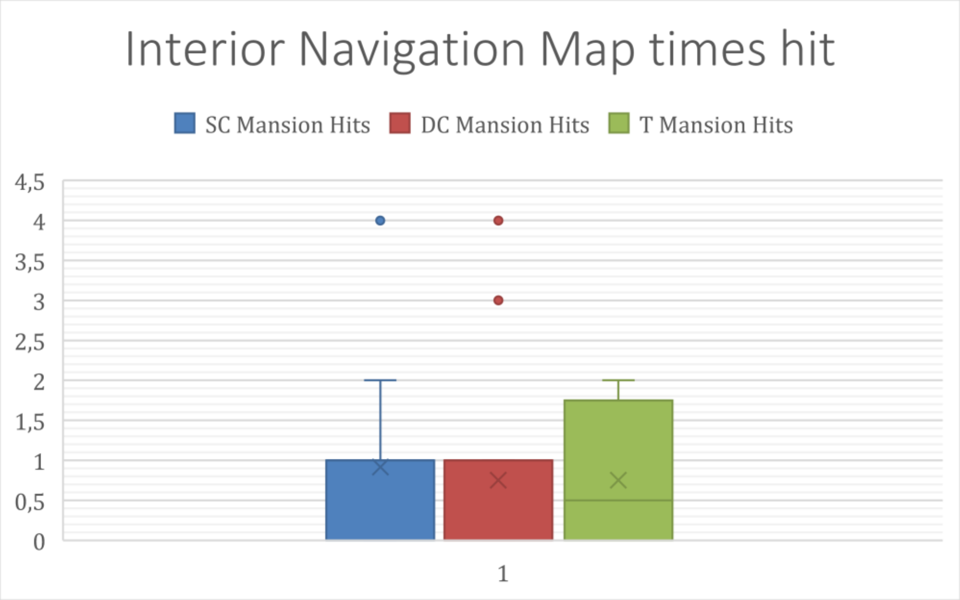


Figure 31: Interior Navigation Map times hit time box plot

5.1.1.3 Exterior navigation map

Only completion time was measured in the exterior navigation map.

No significant difference (see Table 9Table 8) in completion times could be shown between at least two groups in exterior navigation map (F(11, 2) = [0.804], p = [0.460]).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Completion time	3561	2	1780	0.804	0.460
Residual	48726	22	2215		

Note. Type 3 Sums of Squares

Table 9: Repeated Measures ANOVA for completion times in exterior navigation map

Participants were faster on average using both static camera and dynamic camera compared to teleportation ($\overline{\mathrm{SC}} = 133.08\mathrm{s}, \overline{\mathrm{DC}} = 139.92\mathrm{s}, \overline{\mathrm{T}} = 156.75\mathrm{s}$) (see Figure 32), but not to a significant degree.

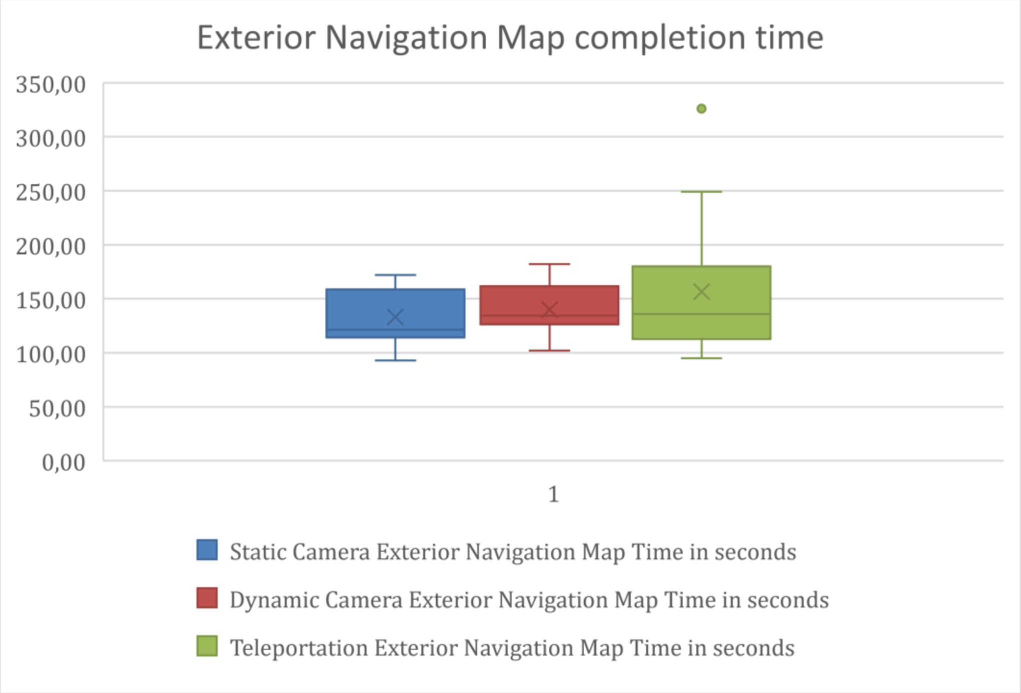


Figure 32: Exterior Navigation Map completion time box plot

5.1.2 Presence Questionnaire

No significant difference for any category could be shown between any of the control schemes. A comparison between control schemes can be seen in Figure 33.

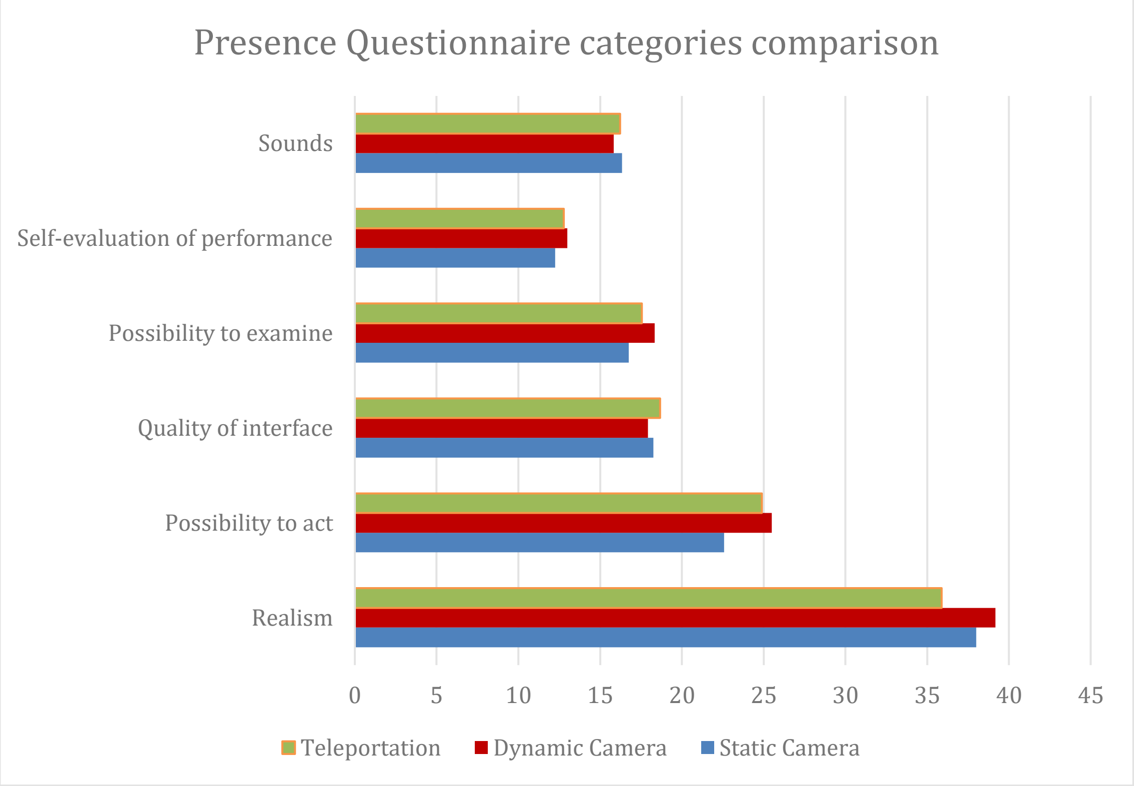


Figure 33: Presence Questionnaire categories comparison. Higher values represent better responses.

No significant difference (see Table 10) in preferences could be shown between at least two groups in category Realism (F(11, 2) = [2.19], p = [0.136]). Dynamic camera was considered more realistic, but not to a significant degree (see Figure 34).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Score	121	2	60.3	2.19	0.136
Residual	607	22	27.6		

Note. Type 3 Sums of Squares

Table 10: Repeated Measures ANOVA for PQ category Realism

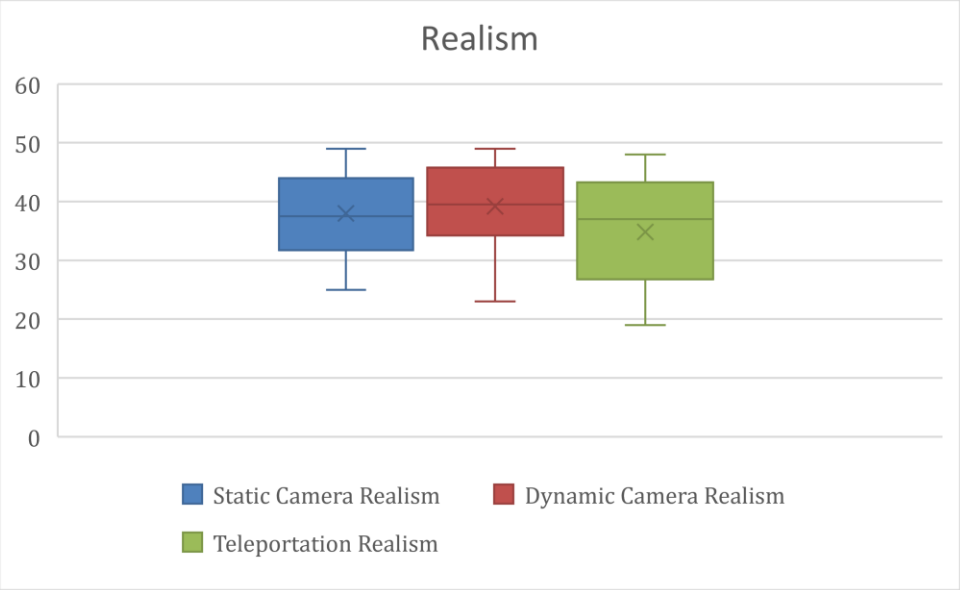


Figure 34: PQ Realism Box Plot. Higher values represent better responses.

No significant difference (see Table 11) in preferences could be shown between at least two groups in category Possibility to act (F(11, 2) = [3.08], p = [0.066]). Dynamic camera ranked higher in category Possibility to act, but not to a significant degree (see Figure 35).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Score	58.4	2	29.19	3.08	0.066
Residual	208.3	22	9.47		

Note. Type 3 Sums of Squares

Table 11: Repeated Measures ANOVA for PQ category Possibility to act

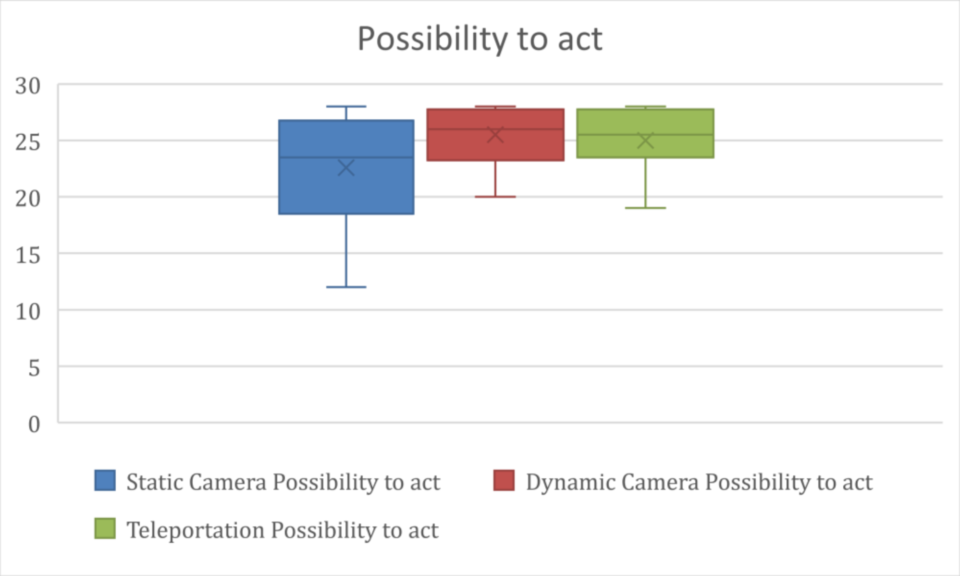


Figure 35: PQ Possibility to act Box Plot. Higher values represent better responses.

No significant difference (see Table 12) in preferences could be shown between at least two groups in category Quality of interface (F(11, 2) = [0.591], p = [0.562]). Teleportation ranked highest in category Quality of interface, but not to a significant degree (see Figure 36).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Score	5.17	2	2.58	0.591	0.562
Residual	96.17	22	4.37		

Note. Type 3 Sums of Squares

Table 12: Repeated Measures ANOVA for PQ category Quality of interface

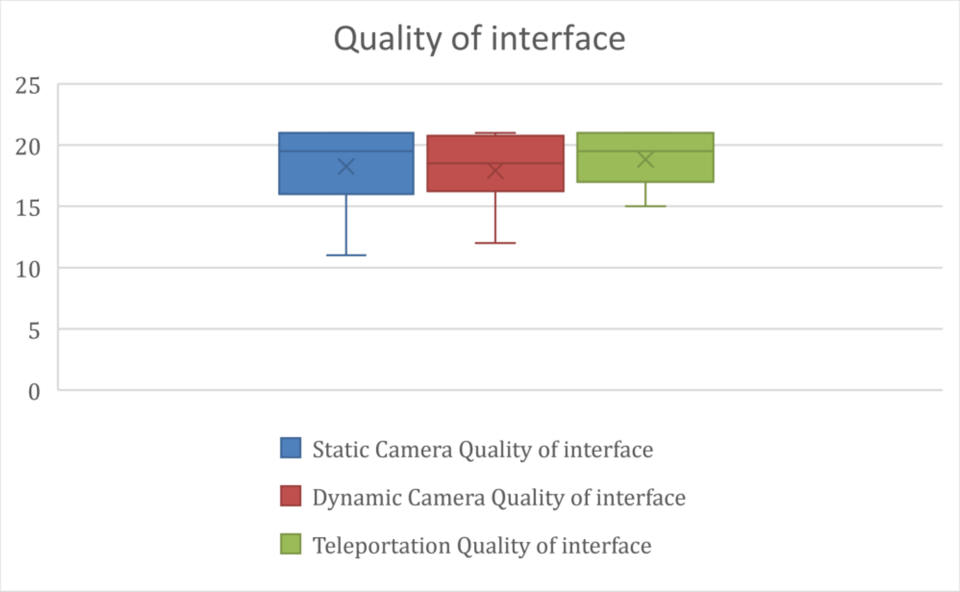


Figure 36: PQ Quality of interface Box Plot. Higher values represent better responses.

No significant difference (see Table 13) in preferences could be shown between at least two groups in category Possibility to examine (F(11, 2) = [1.60], p = [0.225]). Dynamic camera ranked highest in category Possibility to examine, but not to a significant degree (see Figure 37).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Score	15.4	2	7.69	1.60	0.225
Residual	105.9	22	4.82		

Note. Type 3 Sums of Squares

Table 13: Repeated Measures ANOVA for PQ category Possibility to examine

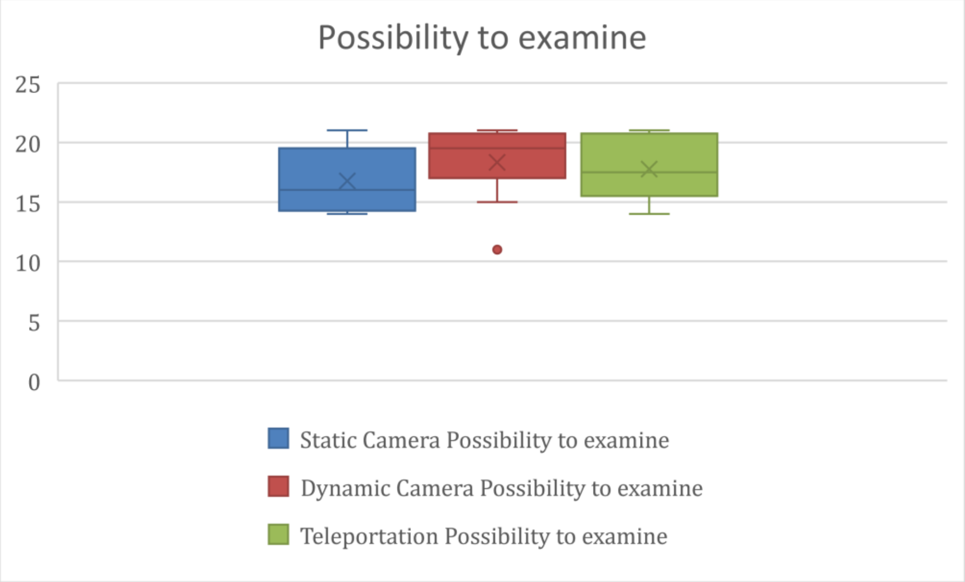


Figure 37: PQ Possibility to examine Box Plot. Higher values represent better responses.

No significant difference (see Table 14) in preferences could be shown between at least two groups in category Self-evaluation of performance (F(11, 2) = [0.773], p = [0.474]). Dynamic camera ranked highest in category Self-evaluation of performance, but not to a significant degree (see Figure 38).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Score	3.72	2	1.86	0.773	0.474
Residual	52.94	22	2.41		

Note. Type 3 Sums of Squares

Table 14: Repeated Measures ANOVA for PQ category Self-evaluation of performance

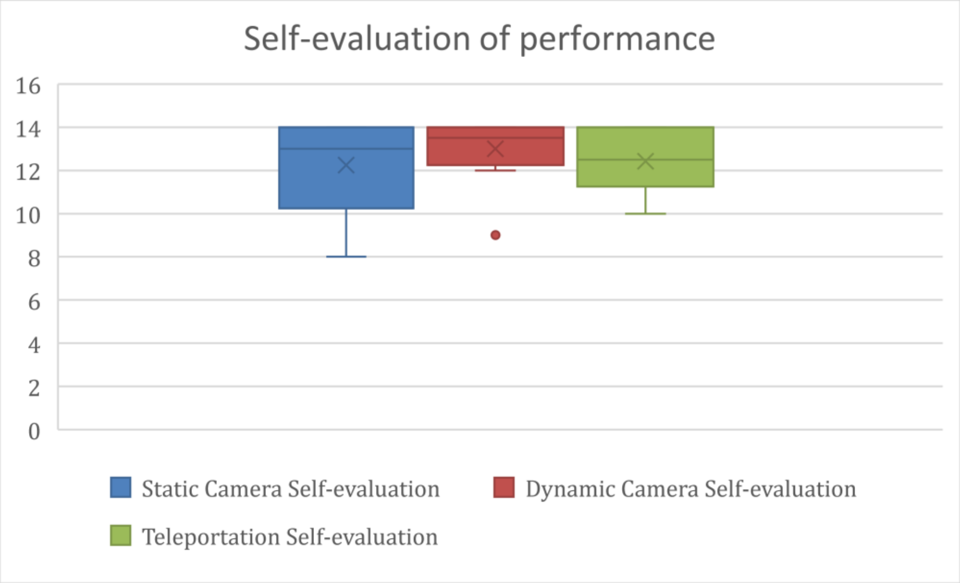


Figure 38: PQ Self-evaluation of performance Box Plot. Higher values represent better responses.

No significant difference (see Table 15) in preferences could be shown between at least two groups in category Sounds (F(11, 2) = [0.217], p = [0.806]). Static camera ranked highest in category Sounds, but not to a significant degree (see Figure 39).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Score	2.39	2	1.19	0.217	0.806
Residual	120.94	22	5.50		

Note. Type 3 Sums of Squares

Table 15: Repeated Measures ANOVA for PQ category Sounds

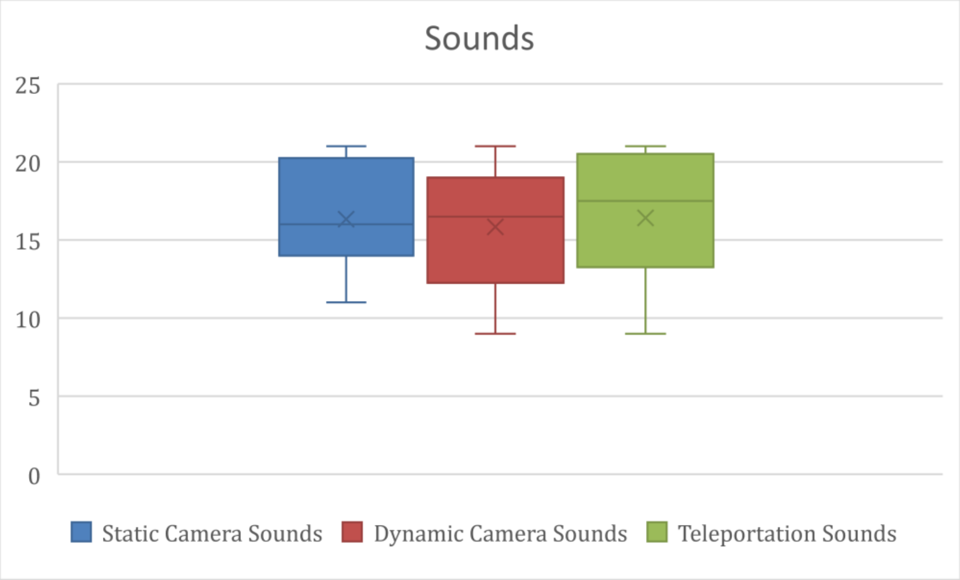
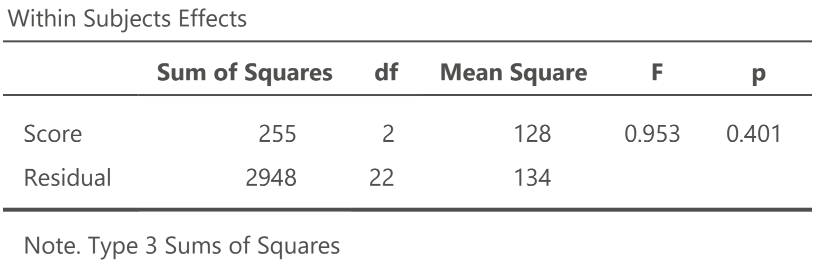


Figure 39: PQ Sounds Box Plot. Higher values represent better responses.

No significant difference (see Table 16) in preferences could be shown between at least two groups in category Total (F(11, 2) = [0.953], p = [0.401]). Dynamic camera ranked highest in category Total, but not to a significant degree (see Figure 40).



Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Score	255	2	128	0.953	0.401
Residual	2948	22	134		

Note. Type 3 Sums of Squares

Table 16: Repeated Measures ANOVA for PQ category Total

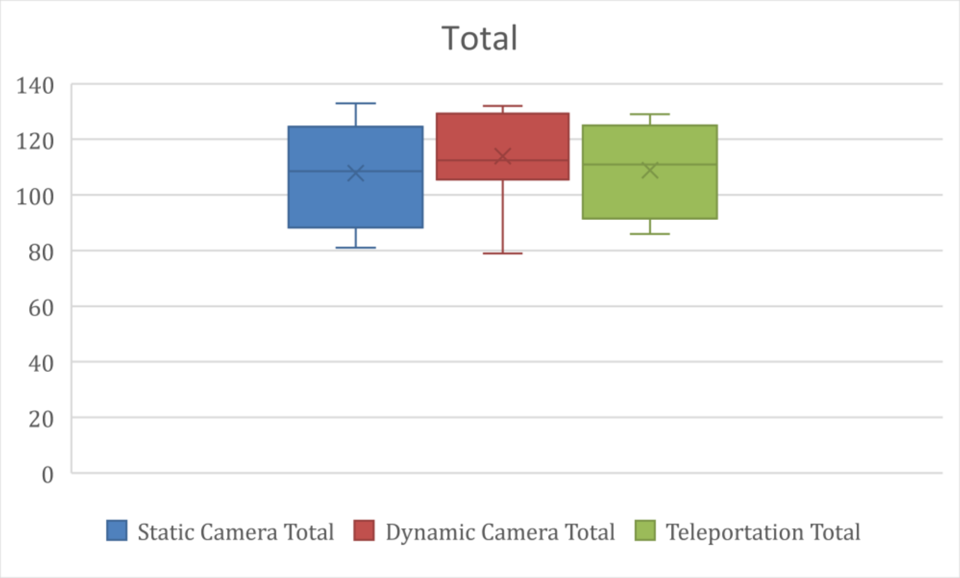


Figure 40: PQ Total Box Plot. Higher values represent better responses.

5.1.3 Simulator Sickness Questionnaire

While dynamic camera seemed to cause higher amounts of motion sickness (see Figure 41), no significant difference for any category or total score between any control scheme group could be found (F(11, 2) = [1.93], p = [0.169] (see Table 17).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Score	807	2	404	1.84	0.183
Residual	4834	22	220		

Note. Type 3 Sums of Squares

Table 17: Repeated Measures ANOVA for SQ category Total

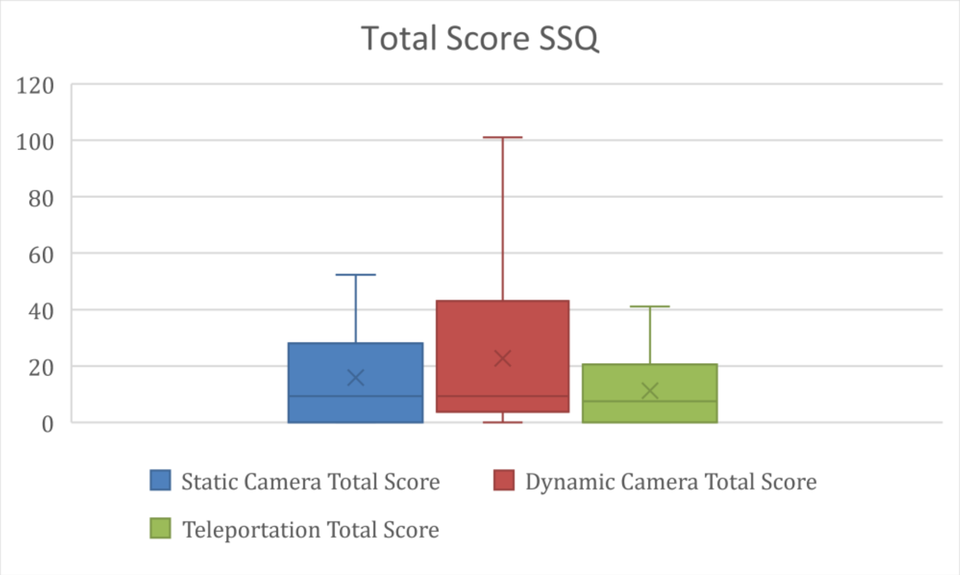
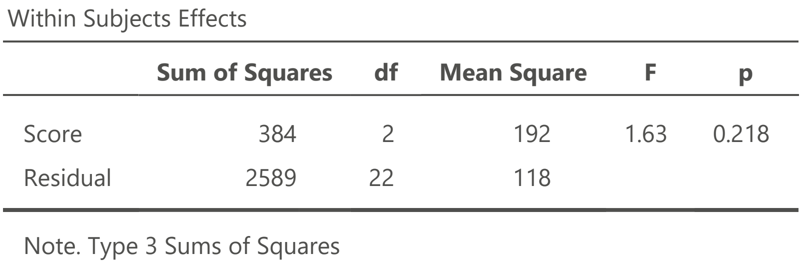


Figure 41: SSQ total score box plot. Higher score means higher motion sickness.

There was no statistically significant difference in category Nausea between at least two groups (F(11, 2) = [1.63], p = [0.218]) (see Table 18). Teleportation ranked best in category Nausea, but not to a significant degree (see Figure 42).



Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Score	384	2	192	1.63	0.218
Residual	2589	22	118		

Note. Type 3 Sums of Squares

Table 18: Repeated Measures ANOVA for SQ category Nausea

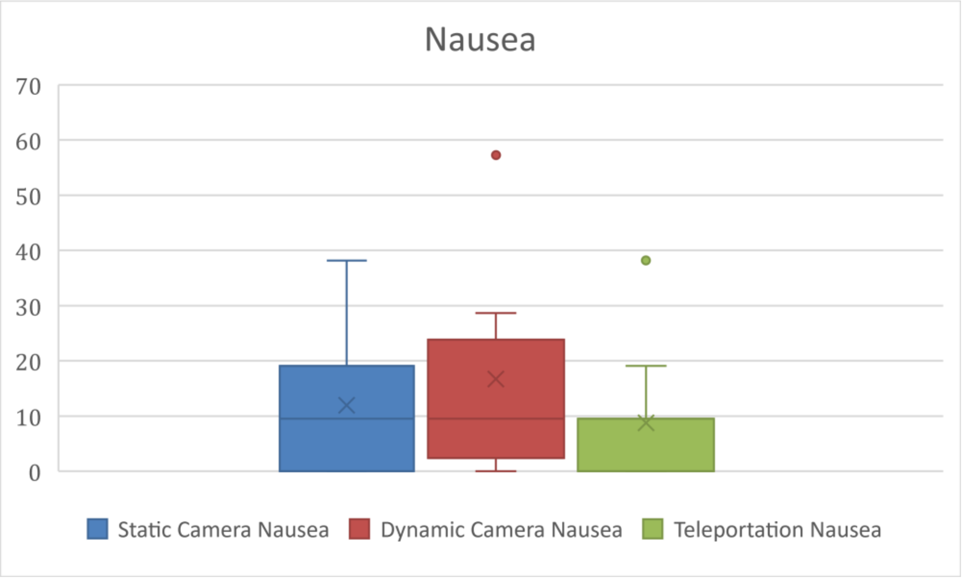


Figure 42: SSQ Nausea box plot. Lower score means better result.

There was no statistically significant difference in category Oculomotor between at least two groups (F(11, 2) = [1.06], p = [0.362]) (see Table 19). Teleportation ranked best in category Oculomotor, but not to a significant degree (see Figure 43).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Score	345	2	172	1.06	0.362
Residual	3562	22	162		

Note. Type 3 Sums of Squares

Table 19: Repeated Measures ANOVA for SQ category Oculomotor

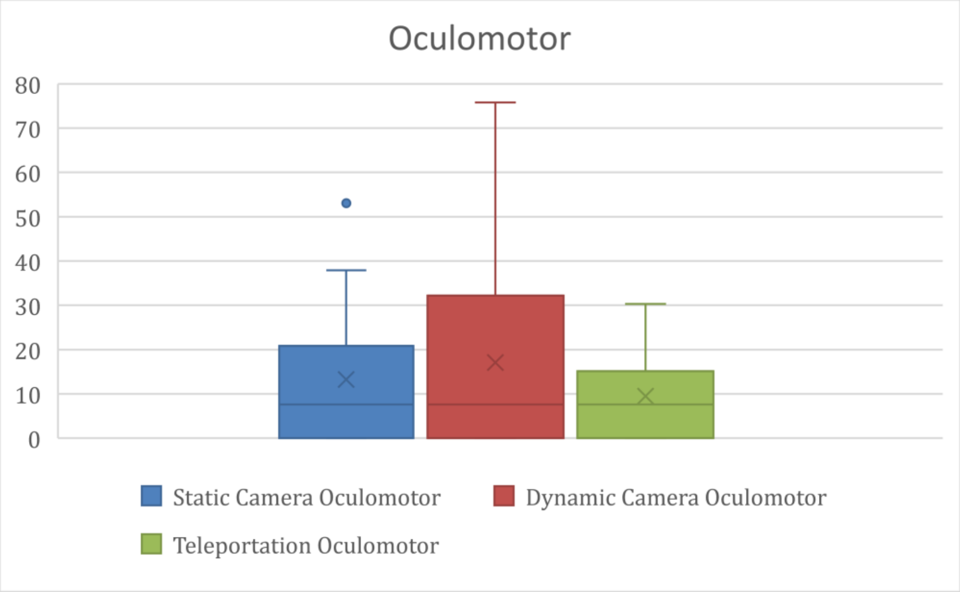


Figure 43: SSQ Oculomotor box plot. Lower score means better result.

There was no statistically significant difference in category Oculomotor between at least two groups (F(11, 2) = [1.84], p = [0.183]) (see Table 20). Teleportation ranked best in category Oculomotor, but not to a significant degree (see Figure 44).

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p
Score	1884	2	942	1.84	0.183
Residual	11292	22	513		

Note. Type 3 Sums of Squares

Table 20: Repeated Measures ANOVA for SQ category Disorientation

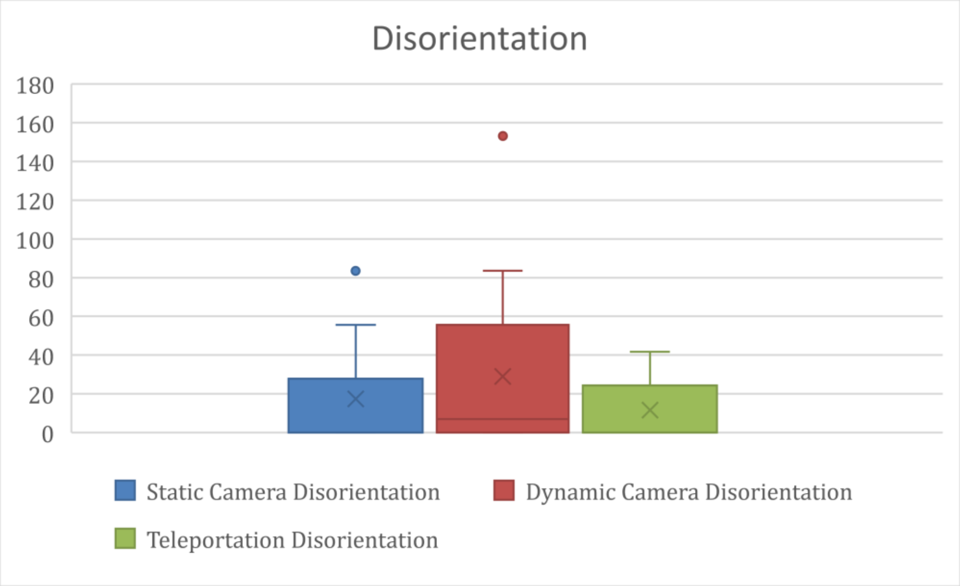


Figure 44: SSQ Disorientation box plot. Lower score means better result.

5.2 Qualitative Results

5.2.1 Preference Rankings

After completing all the trials with all control schemes, participants were asked the following questions: 1. What was their favorite control scheme; 2. Which one they felt most competent with; 3. Which one was the most immersive; 4. Which one they felt was best for navigation; 5. Which one was their least favorite. This was done since different camera types offer different advantages depending on requirements and desired qualities. While the trials should theoretically give an answer in what situation a control scheme performs better, how users feel about them is of equal or maybe even higher importance.

In general, users felt the most competent while using teleportation and dynamic camera. Only two out of the 12 participants preferred static camera over the others for navigation (see Figure 45).

When considering immersion, teleportation has the clear advantage with seven participants preferring it over the other control schemes. Four participants chose static camera as the most immersive while, only one user chose dynamic camera as the most immersive (see Figure 45).

Only one participant picked static camera as best for navigation, and only three chose teleportation for this category. The clear winner here is dynamic camera with eight out of 12 feeling that this control scheme had the advantage over the others for actual navigation (see Figure 42).

These results suggest that while dynamic camera does not allow for high levels of immersion, if the main challenge to overcome is navigation, this control scheme might be preferred over teleportation, as users felt equally competent with both, but more competent when navigating.

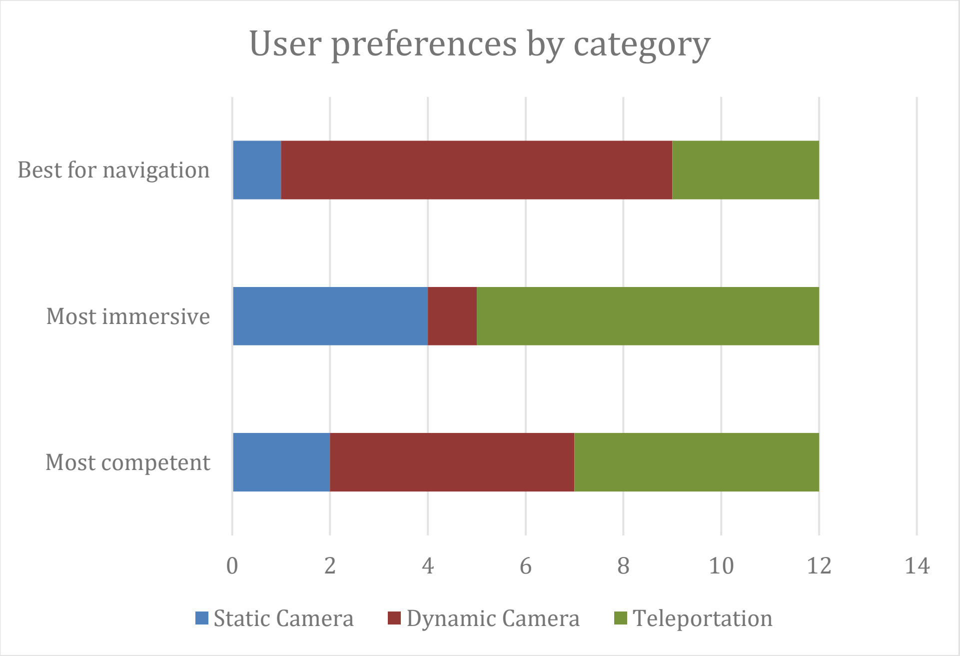


Figure 45: User preferences by category. X axis represents amount of users.

When checking general preferences, no clear winner could be determined. While five out of 12 users picked static camera as their favorite, putting it as the highest rated of the schemes, this advantage is only one higher than teleportation at four users and two higher than dynamic camera with three users (see Figure 46).

Interestingly, when looking at least favorite the situation is exactly reversed with teleportation being the most disliked, followed by static camera. On the other hand, dynamic camera resulted in being both the least liked and disliked (see Figure 46). Overall this suggests that the dynamic camera was the least polarizing and might be considered a safe and versatile choice.

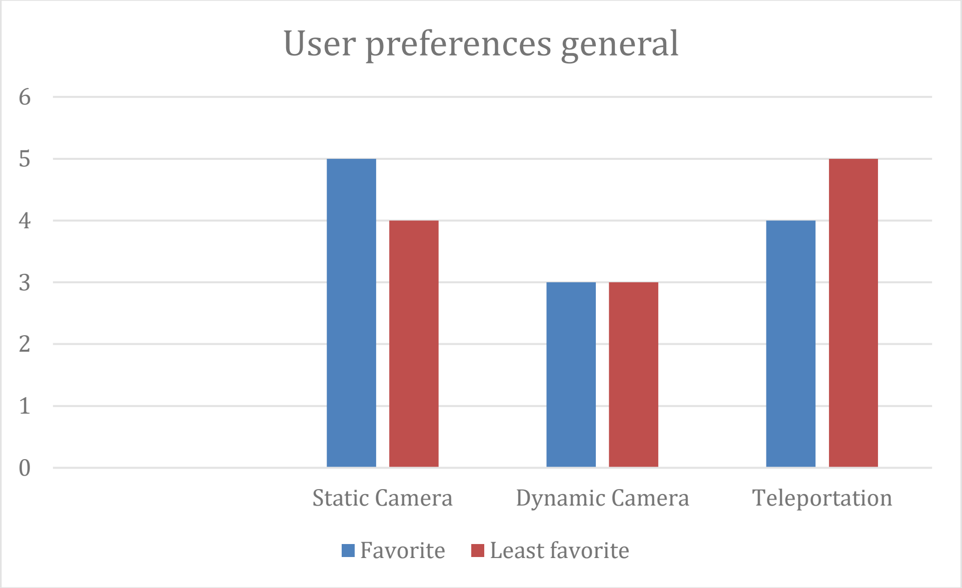


Figure 46: User preferences in general. Y axis represents amount of users

When looking at individual preferences in Table 21, it is possible to see that rarely does a user consider one control scheme for all scenarios. Only one user preferred teleportation over all the other control schemes, while the others always felt that at least one differing control scheme was preferable in one category to what was chosen in the other categories.

No divide between preferring a first person perspective over a third person perspective, or the other way round, can be seen. Users who picked dynamic camera as their favorite would also on occasion pick static camera as their least favorite, and vice versa.

Name	**Favorite**	**Most competent**	**Most immersive**	**Best for navigation**	**Least favorite**
1	T	DC	T	T	SC
2	SC	DC	SC	DC	T
3	T	T	SC	T	DC
4	T	T	T	DC	SC
5	T	T	T	T	SC
6	DC	DC	T	DC	SC
7	DC	T	DC	DC	T
8	SC	DC	T	DC	T
9	SC	SC	SC	DC	T
10	DC	DC	SC	DC	T
11	SC	SC	T	DC	DC
12	SC	T	T	SC	DC

Table 21: User preferences table

5.2.2 Participant improvement suggestions, comments and complaints after completing trials

After all trials in all control schemes were completed, the participants were asked if they had any suggestions on how to improve the given control schemes.

5.2.2.1 Comments on static camera

Reactions to the static camera were polarizing. Some users considered it to feel more natural and made them want to follow paths laid out in the environment, especially in the exploration scene, as it gave them more the feeling of actually moving through the scene and persisting there, as opposed to teleportation where no feeling of movement was felt. One user suggested the feeling of more natural movement was enhanced when compared with the same the same task using teleportation. One user felt it gave a good overview of the environment. Another user pointed out if you are familiar with classic Resident Evil, then one will know what to expect. One other user felt that the transition from third person to first person was equally non-confusing between static camera and dynamic camera, despite the transition in the latter being slower and including rotation. The addition of the arrow pointing to the avatar's location when looking away was seen as helpful by those that noticed it. One user observed the existence of the arrow, but not the connection to the avatar location.

A common complaint was that the camera changes were felt as too sudden, as there was no warning when they were to happen. Confusion increased specially when camera angles would rotate to almost 180 degrees when compared to a previous angle.

Suggested improvements were to better design levels around the static camera control scheme, such as making rooms larger, and placing exits so that only one camera placement is needed to see all of them. One participant suggested to give the user the ability to choose the location of the camera themselves, but could not explain how this could be achieved.

5.2.2.2 Comments on dynamic camera

In general, dynamic camera was preferred for scenarios that required quick reactions and immediate movements. It was often considered to be the most intuitive control scheme, as it most closely resembled modern 3D video game controls. Some considered it to give a good overview, but only while standing still. The general consensus was that dynamic camera is a good fit for the Basic trials map and the interior navigation map, but not for the exterior navigation map.

The transition from third person to first person was felt as not confusing and generally allowed users to quickly adjust to the switch. Once again movement felt more natural when compared to teleportation, leading to more frequently following laid out paths, rather than pointing at a destination and heading straight for it.

A general complaint was a lack of immersion. One user even initially thought the trial was broken, saying "This is not supposed to look like that, right?".
A common complaint was a lack of overview during movement, making users think they are basically running blind.

Dynamic camera did cause more motion sickness compared to the other control schemes. Some users felt light to intense motion sickness during movement, but interestingly not when transitioning between first and third person views. This motion induced sickness seemed to be scene-dependent, as one user commented that the interior navigation scene caused no motion sickness. Another user suggested concentrating on the circle of visible area around the avatar helped with motion sickness, rather than the checkered background.
One user complained that the fade-in effect was too jarring, as it could, depending on the scene, rapidly change light intensity. Another user felt that this fade-in effect was what caused the feeling of sickness. Similarly to static camera and teleportation one user felt it hard to position themselves when picking up an item by hand was required.

A frequent suggestion was to make the visible area during movement larger when using the dynamic camera. When hearing the explanation that enlarging the visible area would lead to increased motion sickness one user suggested giving the option to the user themselves to increase or decrease the size of the visible area to find the sweet spot between a good range of visibility and minimized VR sickness. Some users even suggested giving the option to always show the entire scene when using dynamic camera, for those who can handle it. A creative suggestion by one participant was to, rather than fade out the entire scene, show it in a wireframe fashion, or at least show the essential path this way (see Figure 47 for what this could look like).

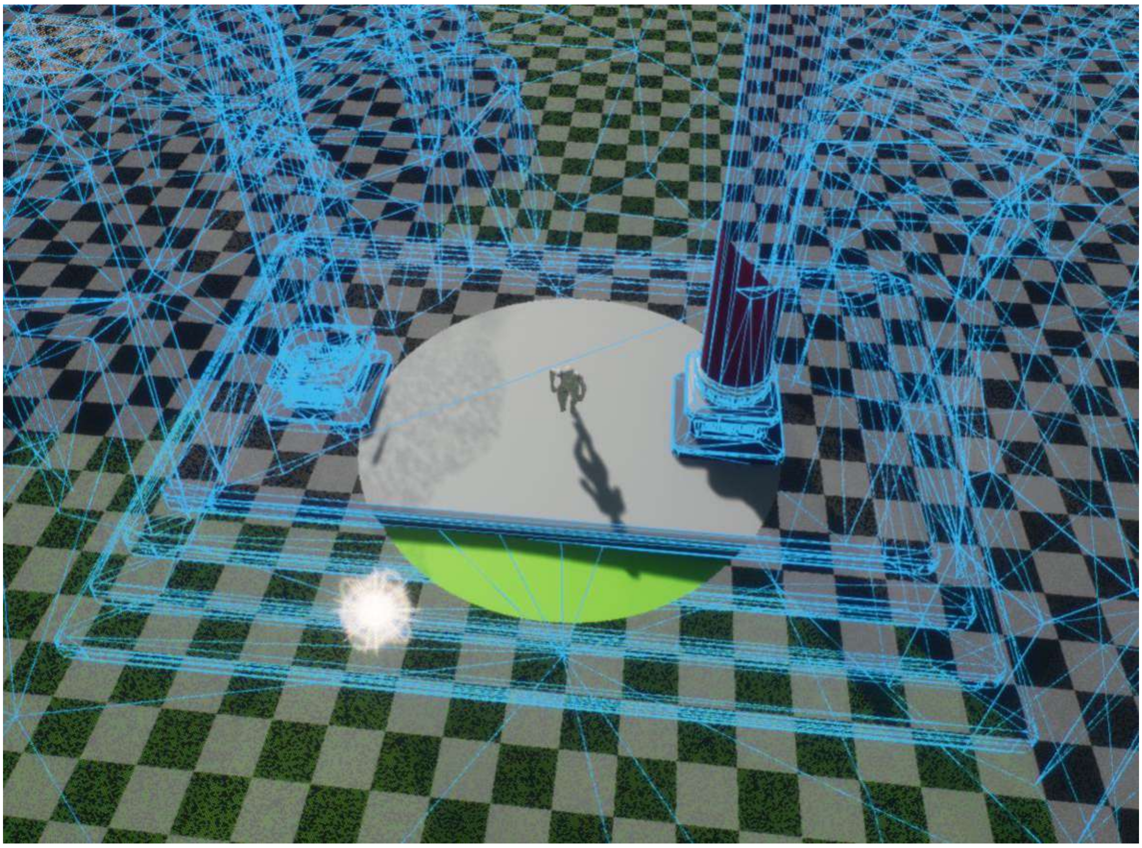


Figure 47: Dynamic camera with wireframe mode

One user complained about the time from hiding the scene to showing it in its entirety was too slow, and should be made shorter or removed entirely to make quick reorientation easier, especially in the exterior navigation map.

Common improvement suggestions were made concerning the Independent Visual Background [75]. The checkered background was considered as unfitting to the Interior and exterior navigation maps, as they featured more realistic environments. Suggestions ranged from naturalistic gardens to scary interiors or the same scene again but not shrunk down as replacements for the checkered background.

5.2.2.3 Comments on teleportation

Few comments on teleportation were given on teleportation after completing the trials, as improving it was not the focus of this study. Still many users commented on the unnaturalness of the control scheme, especially in comparison to the third person variants. A common wish was for the ability to teleport slightly further.

5.2.3 Participant comments and observations during trials

All trials were recorded with the consent of the participants for later analysis. Participants were encouraged to comment their experiences.

5.2.3.1 Static camera

Initial reactions to the static camera control scheme varied from intense aversion to what could be perceived as high levels of immersion. Camera angle changes were felt as intense, with users sometimes exclaiming “Woah” or similar when switching for the first time. Interestingly, this feeling of intensity would change depending on the scene and distance to the avatar. One user mentioned a higher level of discomfort when seeing the avatar from afar at the start of the interior navigation map, and then feeling at ease upon entering the building.

Users often struggled to adjust the direction they were running in after a camera change, especially when walking through doors. Occasionally participants interpreted camera changes as inverting the controls. There were also complaints about the camera suddenly rotating, and being too far away from the avatar. One user wished to be warned before camera angle changes and be told where the new view would move to. Occasionally, there were attempts to move the camera closer behind the character. Users likened the confusion these camera changes cause to classic Resident Evil games. One participant argued that, while this type of control scheme might not work for every type of game, it might work for some. The exterior navigation map for example was felt as a good instance for where static camera is superior to teleportation, since it gave a better overview of the scene. One user who had previously done the trials using the dynamic camera did ask if there was a way to see all the collectibles, similarly to how you could while moving when using dynamic camera.

Interestingly, the auto rotation to the avatar was not seen as jarring and caused users to barely manually rotate the view themselves, as after switching to a new perspective a good enough view was usually given. Just the initial switch to a new location seems to cause irritation.

Switching between first and third person was also felt as intense, with fast zoom in and out animation. One user said that it felt barely bearable, but later felt no more sickness when doing it. Some users saw the slow motion effect when switching as annoying at first, but later appreciated it when fighting enemies in the interior navigation map. The idea to only have slow motion when entering first person, and not when switching back to third person was mentioned by one user. Having to switch to first person to pick up the collectibles in the exterior navigation map was seen as unnecessary by some, especially after not having had to do so in the Basic trials map. One user wished the view would not change to the direction the avatar was currently pointing, but rather kept the one they currently had in the third person view.

One participant mentioned they would be totally lost without the blue arrow pointing to the avatar.

The fact users can't move in first person when using static camera was not always intuitive, with participants often asking if there was a way to do so.

The interior navigation map especially caused participants to compare it to Resident Evil. One user even wished for the tank controls used in this franchise. Some participants mentioned an increased feeling of horror when using static camera, especially because of the obfuscating nature of fixed camera angles. Another user became especially nervous when hearing the approaching enemies, while not being able to pinpoint their location yet. One user, who had previously gone through this part of the trial with a different control scheme mentioned not being able to imagine how this is supposed to work with the static camera control scheme.

Interestingly, the ability to jump seemed to be a big factor to the level of enjoyment, when compared to teleportation. Users who previously had to go through the trials using teleportation, especially valued the newfound ability. Giving participants the possibility to jump led to new behaviors, when compared to teleportation, such as constantly jumping everywhere, to the point they occasionally forgot what their objective was. Users tried to use new techniques, self-described as “Mad tech” where they tried to jump over rooftops and fences in the exterior navigation map. Participants would jump in the air, switch to first person midair and shoot an objective, with one user exclaiming “I'm so badass!” while doing so. With the ability to jump and an avatar controlled from a third person perspective came also new challenges, such as the possibility to fall from a platform. In the Basic trials map there are gaps users have to jump over. Failing to do so would cause the avatar to respawn before the gap, requiring users to time their jumps correctly. Being able to fall made users also worry more about staying on a platform, as they now were able to fall off a platform, unlike when using teleportation.

Generally, having an avatar representation in the scene seemed to cause higher immersion for scenarios requiring a lot of movement, such as when collecting a lot of collectibles in a row, dodging projectiles or fleeing from enemies. Just the act of moving through a scene would cause participants to occasionally hum along with their movements.

5.2.3.2 Dynamic camera

Initial reactions to using dynamic camera ranged from confusion, to immediate feelings of sickness. Only when starting to properly engage with the controls and the given tasks, did participants start to see the advantages of this control scheme over teleportation and static camera.

A lot of participants reported slight feelings of sickness when moving through the scene, that seemingly quickly started to recede as the trials went on, with the exception of one user who always felt motion sickness. That one user interestingly also gets motion sickness from looking at regular 2D screens showing similar experiences. One user reported that the interior navigation map especially caused little to no motion sickness. Participants commented on using different techniques to stave off the feeling of sickness by, for example, focusing on objectives which were always fully visible, or on the small area of always visible space.

Switching between first and third person seemingly caused little to no motion sickness, as opposed to movement and rotation. One participant even shouted “Oh cool!” when trying it for the first time. Switching between viewpoints seemingly never caused any confusion as users always knew where their avatar was and the fluent transition giving them enough time to reorient themselves. On the other hand, the lack of an ability to move in first person was missed by some. Similarly, users wished for the ability to shoot while in third person, as they would occasionally get in scenarios where switching to first person and then aim at an enemy was seen as too slow.

Generally the fact that most of the scene is faded out when moving was met with confusion. Comments ranged from “Why can’t I see anything?”, to “Oh my god, what is happening”. Users complained about not being able to see where they are going. The fact that the scene is fully visible when standing still was sometimes forgotten by users, who had to remind themselves of the possibility. The desire to just always see the entire scene was often mentioned, as stopping to see the entire scene was seen as irritating. Generally users who got no motion sickness from using dynamic camera were eager to try it again, but with the entire scene visible.

The fade-in effect when stopping was seen as weird and too slow by some users. Shrinking the environment, on the other hand, was appreciated by many. Especially, the interior navigation map gave users a dollhouse-like look, making users think about what other genres would be possible with such a perspective.

The checkerboarded background used as an Independent Visual Background [75] was seen as quite immersion breaking. While it was generally accepted as a necessary evil to avoid motion sickness, something more appropriate for a given scene was wished for.

The ability to see collectibles and enemies through walls while moving was seen as very helpful, to the point of feeling like it is cheating. Users would comment on how the blurred out landscape was too opaque to make out anything, but the objectives still being visible allowing them to navigate regardless. Occasionally, this would cause moments of euphoria, with users excitedly pointing out collectibles in the scene. One user thought the ability to see objectives through walls was cheating, and then refused to use them to plan a route, only checking the environment when it is fully visible while standing still or in first person. The ability to see enemies and objectives at the same time occasionally led to users being more reckless than with the other control schemes, causing them to run into enemies. One user noted however, that this might be due to them having done a similar trial with another control scheme.

Similarly to static camera, scenarios where a third person controlled avatar excels at were noticed. This was especially observed while dodging projectiles in the Basic trials map. Having the view move with the avatar made users seem more attached to it, and also gave them finer control. Users had no trouble going through doorways, and since there were no sudden camera changes unlike static camera, users always knew exactly where the avatar would move. The ability to smoothly rotate the view was hugely useful for participants and appreciated, when they did not forget they had the ability to do so. One participant, who had little gaming experience, did complain about the relatively complicated controls, saying that they were way too complex for someone not already familiar with such control schemes. Once again, being able to jump at any time was appreciated, but used less frequently since users had trouble looking ahead were they were going to land. One user tried jumping over a fence repeatedly and eventually gave up, saying “Ok, I’ll stop being lazy”.

Moreover, similarly to static camera, users would on occasion follow the laid out path more, both because of a higher feeling of immersion, and because it would help with the lack of visibility.

5.2.3.3 Teleportation

Similarly to static camera teleportation was met with strong reactions, both positive and negative. This seemingly had no connection to the familiarity from previous VR experiences participants might have had. Reactions ranged from relief to strong annoyance and dread of how the coming challenges will have to play out. Many users complained about the artificiality of this control scheme, possibly highlighted when compared to the other control schemes, if they were tried first.

The main frictions between teleportation and the given challenges appeared in the Basic trials map. Having to pick up collectibles one at a time, by manually aiming the teleportation arch at them, then letting go to teleport there was considered as a slow and arduous process. Users often had difficulty understanding where, in relation to the orb they would land, having to orient themselves with the shadow the orbs cast (see Figure 48). Even so, participants would sometimes have their aim slightly off, forcing them to rotate their view around, or lean forward in their chairs, or in the worst case scenario, teleport again to get to a more advantageous location. This challenge showed that while participants might have understood the basics of movement when using teleportation, they had often difficulty grasping how precise aiming at locations worked.

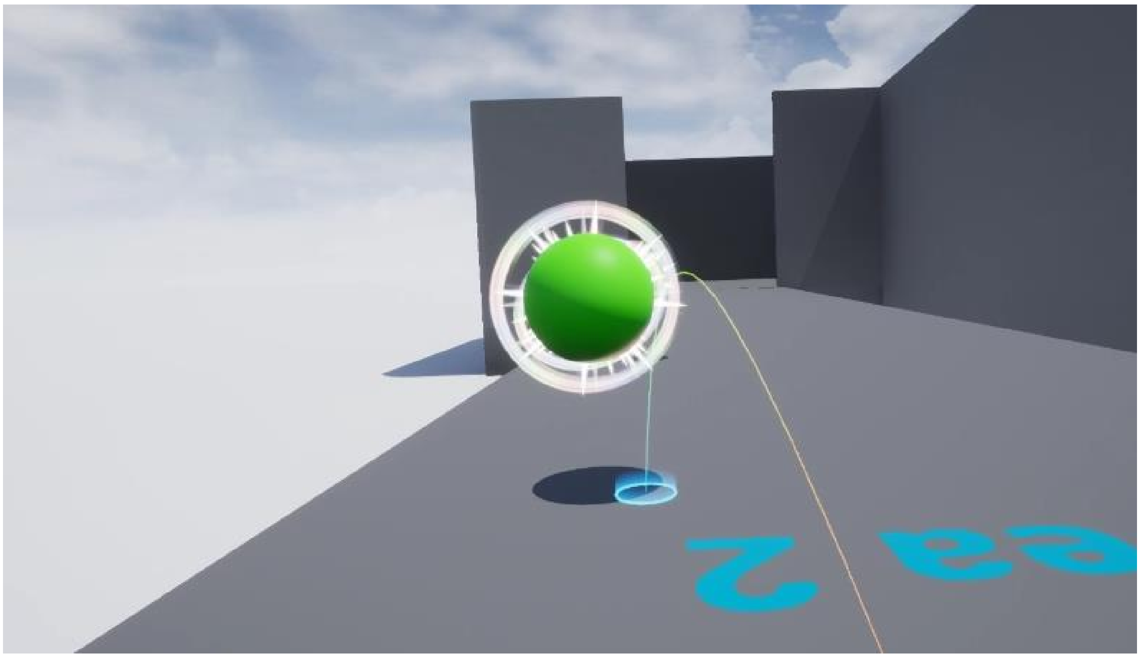


Figure 48: A user trying to align themselves with a collectible to pick it up using teleportation

Occasionally users would think that they picked up a collectible without actually having done so, and then continuing on, only to realize at a locked gate that they have to turn around for some of the collectibles they missed. Some users expected that teleporting would simulate in-between transitions. For example, they would aim past a collectible and expect it to be picked up. This would make picking up collectibles easier and faster, but would make dodging obstacles harder, and might be confusing as to when and where they got hit.

In general having to dodge moving obstacles caused users a lot of trepidation. When faced with this challenge, users often uttered sentences of hopelessness as how to get through this challenge unharmed.

Challenges that required users to get on top of heightened elevation or get over a gap also caused a lot of confusion. Users would sometimes assume that it is not possible to climb on top of a block, or back up a little to make aiming easier. When having to jump over a gap, they would often try aiming over it, realize they were too far, then move to the very edge of the gap and then try again. In these scenarios, often a longer range for teleportation was requested by the users. Participants would also request an ability to jump for these scenarios.

The interior exploration map did seem to cause higher levels of immersion, as users were occasionally hesitant to enter the building, in fear of enemies. Especially, being in the dark and hearing the enemies approaching caused participants to be frightened. Suddenly seeing an enemy approaching made users occasionally yelp. On the other hand, teleportation also caused users to occasionally teleport into enemies by accident, which seemed to cause more frustration rather than immersion. Furthermore, when an enemy managed to reach them from behind, the ensuing explosion effect would cause similar feelings of confusion, as if the cause of this event was out of their hand. Users would also on occasion do "unrealistic" maneuvers such as teleporting through stair railings, to skip climbing stairs (see Figure 49).

Figure 49: User skips stairs by aiming between stair railings

Users who previously used one of the third person perspectives missed the overview ability, especially when trying to find collectibles in the scene. Some users considered it way harder without the ability to survey the scene from above, making them question where to go. This was especially true for the exterior navigation map, with users seeing the given task as "impossible". One user who had trouble finding the last collectible in the interior navigation map described their experience as "horrible".

Interestingly, once users found their destination when surveying their environment, they would go in a straight line towards their goal. This was achieved by teleporting on top or through obstacles, where the geometry permitted. One user commented that teleportation here felt like cheating. Teleporting many times in a row, as was required in the exterior navigation map, since objectives were far apart, caused some agitation among participants. One user likened the feeling to looking at a slide projector presentation or a particularly low framerate movie.

6 Discussion

This study set out to create virtual reality control schemes that work both in seated use, and cause none to very little motion sickness. With some exceptions and a few adjustments, this goal has been achieved by both static camera and dynamic camera.

The main hypothesis for this work was that dynamic camera and static camera will outperform the teleportation locomotion technique, as it is commonly used in many VR experiences, in user acceptability, trial performance and immersion.

When looking at user preferences, no singular VR control scheme was seen as superior in every way to others. But if you concentrate on certain scenarios, and focus on particular qualities, some control schemes can be seen as preferable.

Dynamic camera seems to be preferred over both static camera and teleportation for navigation. The significantly faster completion times of the basic trials map when using dynamic camera support the preference of the users. Especially scenarios that require immediate movement were felt as a lot easier when using this control scheme. While the results of the SSQ did not show any significantly stronger aversion to dynamic camera then other control schemes, feelings of sickness, at least initially were noticed during trial runs. Some users reported these feelings subsiding in the darker interior exploration map, implying that lighting playing a larger role then initially assumed. Dynamic camera was also seen as the least immersive, pertaining mostly to the Independent Visual Background. While finding a more thematically fitting background might heighten immersion, it will most likely not be able to beat out teleportation due to its miniature and cut out view during movement. Navigation was felt as most competent in the interior navigation map, as it was a smaller exploration space, where the small visible area during movement mostly sufficed. Having some parts of the environment visible at all times did not seem to affect VR sickness in any way, allowing perhaps future work to build on this quality with, for example, showing the environment in a wireframe fashion, as suggested by one of the participants.

Static camera was not seen as superior in any category, but still was picked as most favorite, but not by a significant degree, but also almost an equal amount as least favorite. This shows that while this control scheme has unique qualities not covered by the given categories, there is room for growth. Participants often had trouble with rapid camera position changes, as they came frequently when not expected. This could be solved by establishing fixed rules, such as one camera position per room, and camera transitions only when leaving a room. Users would also get turned around when changing camera positions, especially when the new location made the view rotate 180 degrees, making them accidentally run back to where they came. Having the analog sticks temporarily use the directions from the previous view rotation alleviated this problem, but did not entirely solve it. Perhaps removing controls from the user when entering a new area, making the avatar move by themselves to the new one, while accompanied by fade in effect could fix this problem. This would give users time to let go of the controls and readjust to a new scene. Fading to black and then fading the scene back in upon reaching the next destination, similarly to the fade effect when using teleportation, could also alleviate the feeling of dizziness some users had when changing scenes with large lighting differences. Analyzing user behavior shows that keeping users in one scene for as long as possible seems to be preferable. Users were significantly better at dodging moving obstacles when compared to teleportation. Looking at this particular scenario shows that good immediate navigation is definitively possible using static camera when the level design is built around it. In this case, that means having only one camera location and rotation per scene, and having the user stay as long as possible in that scene. Having the camera automatically rotate to the avatar when it moves out of head rotation range was never seen as an interruption and almost imperceptible.

Switching to first person seemed intuitive for participants and did not cause any motion sickness even for those users that felt some when using dynamic camera. Using it the first time was felt as intense and exciting, and became almost second nature over the course of the trials. Future works using perspective switches should think about when first person is truly necessary, as not all interactions are necessarily improved by first person. Interestingly both types of perspective switching, the fast zoom in used with static camera and the slow rotation zoom in from dynamic camera both resulted in no to little motion sickness. Since dynamic camera requires the world to be faded out, which results in a loss of immersion, perhaps the technique used in static camera is preferable overall.

The greatest success the third person techniques had over teleportation was the ability to jump. This brought users a lot of joy, and made challenges that were slow and cumbersome when using teleportation, fast and fun. It entirely changed user behavior in larger scenes as users happily jumped over obstacles and made their own path in a kinetic manner not possible with teleportation.

6.1 Comparison to other locomotion techniques

This work has the unique position of focusing almost entirely on seated use. This makes comparisons to techniques such as redirected walking [11] and walking in place [14] perhaps not meaningful, when analyzing immersion. These techniques bring users bodily situation closer to what is trying to be achieved in the virtual world, by the nature of the user being in a standing position as opposed to sitting down. Then again, techniques trying to map navigation in VR to walking in real space quickly will find their limits when elevated terrain comes into play.

The ability to jump has been shown in this work to be a major enabler of enjoyment not replicable by teleportation or any other motion-based or room scale-based locomotion technique. Perhaps multiplying the horizontal axis of the user's movement, similarly to seven league boots [33], could be used for enabling higher jumps, in lieu of the ability to physically clamber over obstacles. This would still lack the precision given by third person controls, since, unlike when moving along vertically, users cannot control the speed and height of their jumps mid-movement.

Continuous movement in first person using a controller can be a solution that offers similar abilities to third person controls, featuring higher immersion but also higher feelings of sickness [70]. Simulator sickness mitigation techniques can lead to levels almost on par with teleportation [85], but whether they are on par with the techniques suggested here or not, should be evaluated in future work.

Static camera and dynamic camera can be considered improvements on both 3PP-R [70] and Outstanding [64], at least for seated use. Outstanding does not allow for camera rotation and requires manual button presses for the camera to catch up. Both these points have been addressed in the control schemes created for this work. Furthermore, preliminary testing showed that the camera transition used in Outstanding caused considerable motion sickness in test subjects, something almost entirely eliminated in both static camera and dynamic camera. 3PP-R meanwhile did not have the ability to view the scene in first person if needed, did not enable seated use, as there was no way for the user to rotate the scene without rotating their head 360 degrees, and gave no ability to view a scene in its entirety.

7 Conclusion

This work set out to find virtual reality control schemes that allow users to freely explore any given scene, from a seated position. Two locomotion techniques were developed, both using a third person perspective for traversal, and the ability to switch to first person when needed. The hypothesis was made that these controls schemes would improve on teleportation, a commonly used VR locomotion technique, in the areas of user acceptability, trial performance and immersion.

The first control scheme developed for this work is called static camera. It uses, as the name implies, stationary camera locations, which need to be placed in the scene by a level designer. Volumes, which also need to be manually positioned, are connected to these cameras. When a user moves their analog stick controlled avatar inside one of these volumes, the user's perspective of the scene switches to that view. A quick zoom-in animation is played for switching between the third and first person perspective, and the view is automatically adjusted, so that users don't lose track of their avatars location.

The second control scheme created in this work was dynamic camera. It can be considered a hybrid between Outstanding [64] and 3PP-R [70]. During movement, most of the scene is faded out, except for a small radius around the avatar, and an Independent Visual Background is shown beneath. The switch to first person also fades out the scene, and matches the users view with the avatar's with one smooth rotating animation.

Three trials were developed, focusing on interior and exterior navigation, dodging obstacles, pathfinding and finding objectives in the scene. Test subjects completed all trials with every control scheme.

SSQ and PPQ showed no advantage for any control scheme. Both third person locomotion techniques caused little to no motion sickness, comparable to teleportation. Qualitative analysis showed that users in general found teleportation more immersive, but preferred dynamic camera for navigation overall. Static camera was chosen as most favorite by most users, while teleportation had the most votes for least favorites. Dynamic camera received equal amounts for most and least favorites, implying that this is the least polarizing control scheme, and a potentially safe choice for most scenarios.

The main advantage shown by the third person control schemes over teleportation is the maneuverability of the avatar. Especially, the ability to jump was felt as a great advantage over teleportation.

Both control schemes have potential for improvement. Static camera demands bespoke level design to work with minimal confusion. The requirements for such design still need to be researched. Users reported irritation when transitioning between camera positions. This could be improved using fade outs and fade ins, clear signs for where a transition would be triggered, and bespoke animations for entering and leaving areas with new camera locations.

Dynamic camera main disadvantage over the other control schemes was a lack of immersion. This could be improved by theming the experience around this control schemes. For example a holographic effect could imply what the user sees comes from a hologram. The Independent Visual Background could also be designed to better fit the theme of the virtual reality experience. Another area that could be improved in future work is how the faded out scene is shown during movement. Selectively making some objects always visible was shown to not have any negative impact on the users, thus showing the faded out scene in holographic wireframe manner might help users to orient themselves with similar results.

Both control schemes need to be tested with different scenarios where they can properly show their advantage, where horizontal and quick lateral movement is required. Scenarios where having an overview of a scene is advantageous, should be further tested.

This work only compared static camera and dynamic camera to teleportation, but other control schemes could offer themselves for interesting comparisons. Controller based continuous movement techniques in combination with motion sickness reducing techniques would be appropriate, as they too allow quick lateral and horizontal movement. These techniques usually achieve this by somehow reducing the user's view of the scene during movement therefore, a trial which requires quick reaction to suddenly appearing visually stimuli would be of interest.

Bibliography

[1] J. Bown, E. White, and A. Boopalan, "Looking for the Ultimate Display: A Brief History of Virtual Reality," *Boundaries of Self and Reality Online: Implications of Digitally Constructed Realities*, pp. 239–259, Jan. 2017, doi: 10.1016/B978-0-12-804157-4.00012-8.

[2] I. Sutherland, "A head-mounted three dimensional display," vol. 33, no. pt 1, pp. 757–764, 1968, doi: 10.1145/1476589.1476686.

[3] S. Ammanuel, I. Brown, J. Uribe, and B. Rehani, "Creating 3D models from Radiologic Images for Virtual Reality Medical Education Modules," *J Med Syst*, vol. 43, no. 6, pp. 1–3, Jun. 2019, doi: 10.1007/S10916-019-1308-3/FIGURES/1.

[4] P. Millais, S. L. Jones, and R. Kelly, "Exploring data in virtual reality: Comparisons with 2d data visualizations," *Conference on Human Factors in Computing Systems - Proceedings*, vol. 2018-April, Apr. 2018, doi: 10.1145/3170427.3188537.

[5] E. Chang, H. T. Kim, and B. Yoo, "Virtual Reality Sickness: A Review of Causes and Measurements," *Int J Hum Comput Interact*, pp. 1658–1682, 2020, doi: 10.1080/10447318.2020.1778351.

[6] A. Schäfer, G. Reis, and D. Stricker, "Controlling Teleportation-Based Locomotion in Virtual Reality with Hand Gestures: A Comparative Evaluation of Two-Handed and One-Handed Techniques," *Electronics 2021, Vol. 10, Page 715*, vol. 10, no. 6, p. 715, Mar. 2021, doi: 10.3390/ELECTRONICS10060715.

[7] E. Bozgeyikli, A. Raij, S. Katkoori, and R. Dubey, "Point & Teleport locomotion technique for virtual reality," in *CHI PLAY 2016 - Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play*, Association for Computing Machinery, Inc, Oct. 2016, pp. 205–216. doi: 10.1145/2967934.2968105.

[8] F. Buttussi and L. Chittaro, "Locomotion in Place in Virtual Reality: A Comparative Evaluation of Joystick, Teleport, and Leaning," *IEEE Trans Vis Comput Graph*, vol. 27, no. 1, pp. 125–136, Jan. 2021, doi: 10.1109/TVCG.2019.2928304.

[9] D. Wolf, "Augmenting Teleportation in Virtual Reality With Discrete Rotation Angles," 2021, Accessed: Feb. 08, 2023. [Online]. Available: https://www.epicgames.com/roborecall/en-US/home

[10] K. Moghadam, C. Banigan, and E. D. Ragan, "Scene Transitions and Teleportation in Virtual Reality and the Implications for Spatial Awareness and Sickness," *IEEE Trans Vis*

Comput Graph, vol. 26, no. 6, pp. 2273–2287, Jun. 2020, doi: 10.1109/TVCG.2018.2884468.

[11] S. Razzaque, Z. Kohn, and M. C. Whitton, “Redirected Walking,” *Eurographics*, pp. 2–7, 2001.

[12] E. A. Suma, S. Clark, D. Krum, S. Finkelstein, M. Bolas, and Z. Warte, “Leveraging change blindness for redirection in virtual environments,” *Proceedings - IEEE Virtual Reality*, no. April 2014, pp. 159–166, 2011, doi: 10.1109/VR.2011.5759455.

[13] M. Kanani, Y. Al-Jabir, S. Al-Ghanim, and O. Halabi, “Enhanced redirected walking algorithm,” in *2017 6th International Conference on Information and Communication Technology and Accessbility, ICTA 2017*, 2017. doi: 10.1109/ICTA.2017.8336063.

[14] J. Lee, S. C. Ahn, and J. I. Hwang, “A Walking-in-Place Method for Virtual Reality Using Position and Orientation Tracking,” *Sensors 2018, Vol. 18, Page 2832*, vol. 18, no. 9, p. 2832, Aug. 2018, doi: 10.3390/S18092832.

[15] M. McCullough *et al.*, “Myo arm-swinging to explore a VE,” *Proceedings - SAP 2015: ACM SIGGRAPH Symposium on Applied Perception*, pp. 107–113, Sep. 2015, doi: 10.1145/2804408.2804416.

[16] G. Lame, “Systematic literature reviews: An introduction,” in *Proceedings of the International Conference on Engineering Design, ICED*, Cambridge University Press, 2019, pp. 1633–1642. doi: 10.1017/dsi.2019.169.

[17] C. Boletsis and J. E. Cedergre, “VR Locomotion in the New Era of Virtual Reality : An Empirical Comparison of Prevalent Techniques,” 2019.

[18] C. Boletsis and D. Chasanidou, “A Typology of Virtual Reality Locomotion Techniques,” *Multimodal Technologies and Interaction 2022, Vol. 6, Page 72*, vol. 6, no. 9, p. 72, Aug. 2022, doi: 10.3390/MTI6090072.

[19] H. Cherni, N. Métayer, and N. Souliman, “Literature review of locomotion techniques in virtual reality,” *International Journal of Virtual Reality*, vol. 20, no. 1, pp. 1–20, Mar. 2020, doi: 10.20870/ijvr.2020.20.1.3183.

[20] N. Chr. Nilsson, “Walking Without Moving An exploration of factors influencing the perceived naturalness of Walking-in-Place techniques for locomotion in virtual environments,” 2015, doi: 10.5278/vbn.phd.engsci.00157.

[21] E. Kruijff *et al.*, “On your feet! Enhancing vection in leaning-based interfaces through multisensory stimuli,” *SUI 2016 - Proceedings of the 2016 Symposium on Spatial User Interaction*, pp. 149–158, Oct. 2016, doi: 10.1145/2983310.2985759.

[22] C. Khundam and F. Nöel, “A Study of Physical Fitness and Enjoyment on Virtual Running for Exergames,” *International Journal of Computer Games Technology*, 2021, doi: 10.1155/2021/6668280.

[23] B. Williams, S. Bailey, G. Narasimham, M. Li, and B. Bodenheimer, "Evaluation of walking in place on a Wii balance board to explore a virtual environment," *ACM Trans Appl Percept*, vol. 8, no. 3, Aug. 2011, doi: 10.1145/2010325.2010329.

[24] E. Langbehn, P. Lubos, and F. Steinicke, "Redirected Spaces: Going beyond Borders," *25th IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2018 - Proceedings*, pp. 767–768, 2018, doi: 10.1109/VR.2018.8446167.

[25] F. Steinicke, G. Bruder, J. Jerald, H. Frenz, and M. Lappe, "Estimation of detection thresholds for redirected walking techniques," *IEEE Trans Vis Comput Graph*, vol. 16, no. 1, pp. 17–27, 2010, doi: 10.1109/TVCG.2009.62.

[26] H. Chen, S. Chen, and E. S. Rosenberg, "Redirected Walking in Irregularly Shaped Physical Environments with Dynamic Obstacles," in *25th IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2018 - Proceedings*, 2018. doi: 10.1109/VR.2018.8446563.

[27] N. C. Nilsson *et al.*, "15 Years of Research on Redirected Walking in Immersive Virtual Environments," *IEEE Comput Graph Appl*, vol. 38, no. 2, pp. 44–56, 2018, doi: 10.1109/MCG.2018.111125628.

[28] N. C. Nilsson *et al.*, "15 Years of Research on Redirected Walking in Immersive Virtual Environments," *IEEE Comput Graph Appl*, vol. 38, no. 2, pp. 44–56, Mar. 2018, doi: 10.1109/MCG.2018.111125628.

[29] P. Schmitz, J. Hildebrandt, A. C. Valdez, L. Kobbelt, and M. Ziefle, "You spin my head right round: Threshold of limited immersion for rotation gains in redirected walking," *IEEE Trans Vis Comput Graph*, vol. 24, no. 4, pp. 1623–1632, Apr. 2018, doi: 10.1109/TVCG.2018.2793671.

[30] Y. Hoshikawa, K. Fujita, K. Takashima, M. Fjeld, and Y. Kitamura, "RedirectedDoors: Redirection while Opening Doors in Virtual Reality," *Proceedings - 2022 IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2022*, pp. 464–473, 2022, doi: 10.1109/VR51125.2022.00066.

[31] K. Ogawa, K. Fujita, K. Takashima, and Y. Kitamura, "PseudoJumpOn: Jumping onto Steps in Virtual Reality," *Proceedings - 2022 IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2022*, pp. 635–643, 2022, doi: 10.1109/VR51125.2022.00084.

[32] P. Abtahi, M. Gonzalez-Franco, E. Ofek, and A. Steed, "I'm a giant: Walking in large virtual environments at high speed gains," in *Conference on Human Factors in Computing Systems - Proceedings*, Association for Computing Machinery, May 2019. doi: 10.1145/3290605.3300752.

[33] V. Interrante, B. Ries, and L. Anderson, "Seven league boots: A new metaphor for augmented locomotion through moderately large scale immersive virtual environments," *IEEE Symposium on 3D User Interfaces 2007 - Proceedings, 3DUI 2007*, pp. 167–170, 2007, doi: 10.1109/3DUI.2007.340791.

[34] E. Langbehn, F. Steinicke, M. Lappe, G. F. Welch, and G. Bruder, “In the Blink of an Eye-Leveraging Blink-Induced Suppression for Imperceptible Position and Orientation Redirection in Virtual Reality,” *ACM Trans Graph*, vol. 37, no. 4, p. 11, 2018, doi: 10.1145/3197517.

[35] S. Liu, G. Lee, Y. Li, T. Piumsomboon, and B. Ens, “Force-based foot gesture navigation in virtual reality,” *Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST*, Dec. 2021, doi: 10.1145/3489849.3489945.

[36] D. Abdlkarim *et al.*, “A Methodological Framework to Assess the Accuracy of Virtual Reality Hand-Tracking Systems: A case study with the Oculus Quest 2,” *bioRxiv*, p. 2022.02.18.481001, Feb. 2022, doi: 10.1101/2022.02.18.481001.

[37] G. Buckingham, “Hand Tracking for Immersive Virtual Reality: Opportunities and Challenges,” *Front Virtual Real*, vol. 2, p. 140, Oct. 2021, doi: 10.3389/FRVIR.2021.728461/BIBTEX.

[38] V. Angelov, E. Petkov, G. Shipkovenski, and T. Kalushkov, “Modern Virtual Reality Headsets,” *HORA 2020 - 2nd International Congress on Human-Computer Interaction, Optimization and Robotic Applications, Proceedings*, Jun. 2020, doi: 10.1109/HORA49412.2020.9152604.

[39] C. Anthes, R. J. García-Hernández, M. Wiedemann, and D. Kranzlmüller, “State of the art of virtual reality technology,” *IEEE Aerospace Conference Proceedings*, vol. 2016-June, Jun. 2016, doi: 10.1109/AERO.2016.7500674.

[40] A. K. T. Ng, L. K. Y. Chan, and H. Y. K. Lau, “A low-cost lighthouse-based virtual reality head tracking system,” *2017 International Conference on 3D Immersion, IC3D 2017 - Proceedings*, vol. 2018-January, pp. 1–5, Jul. 2017, doi: 10.1109/IC3D.2017.8251910.

[41] V. Angelov, E. Petkov, G. Shipkovenski, and T. Kalushkov, “Modern Virtual Reality Headsets,” *HORA 2020 - 2nd International Congress on Human-Computer Interaction, Optimization and Robotic Applications, Proceedings*, Jun. 2020, doi: 10.1109/HORA49412.2020.9152604.

[42] D. A. Bowman, R. P. McMahan, and E. D. Ragan, “Questioning naturalism in 3D user interfaces,” *Commun ACM*, vol. 55, no. 9, pp. 78–88, Sep. 2012, doi: 10.1145/2330667.2330687.

[43] M. al Zayer, I. B. Adhanom, P. MacNeilage, and E. Folmer, “The effect of field-of-view restriction on sex bias in VR sickness and spatial navigation performance,” *Conference on Human Factors in Computing Systems - Proceedings*, May 2019, doi: 10.1145/3290605.3300584.

[44] I. B. Adhanom, N. Navarro Griffin, P. MacNeilage, and E. Folmer, “The Effect of a Foveated Field-of-view Restrictor on VR Sickness,” pp. 645–652, Jun. 2020, doi: 10.1109/VR46266.2020.00087.

[45] R. Shi, H. N. Liang, Y. Wu, D. Yu, and W. Xu, “Virtual Reality Sickness Mitigation Methods,” *Proceedings of the ACM on Computer Graphics and Interactive Techniques*, vol. 4, no. 1, p. 15, Apr. 2021, doi: 10.1145/3451255.

[46] H. Buhler, S. Misztal, and J. Schild, “Reducing VR Sickness Through Peripheral Visual Effects,” *25th IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2018 - Proceedings*, pp. 517–519, Aug. 2018, doi: 10.1109/VR.2018.8446346.

[47] A. S. Fernandes and S. K. Feiner, “Combating VR sickness through subtle dynamic field-of-view modification,” *2016 IEEE Symposium on 3D User Interfaces, 3DUI 2016 - Proceedings*, pp. 201–210, Apr. 2016, doi: 10.1109/3DUI.2016.7460053.

[48] N. Norouzi, G. Bruder, and G. Welch, “Assessing vignetting as a means to reduce VR sickness during amplified head rotations,” *Proceedings - SAP 2018: ACM Symposium on Applied Perception*, vol. 18, Aug. 2018, doi: 10.1145/3225153.3225162.

[49] F. Wu, G. S. Bailey, T. Stoffregen, and E. Suma Rosenberg, “Don’t Block the Ground: Reducing Discomfort in Virtual Reality with an Asymmetric Field-of-View Restrictor,” *Proceedings - SUI 2021: ACM Spatial User Interaction 2021*, p. 10, Nov. 2021, doi: 10.1145/3485279.3485284.

[50] K. Carnegie and T. Rhee, “Reducing Visual Discomfort with HMDs Using Dynamic Depth of Field,” *IEEE Comput Graph Appl*, vol. 35, no. 5, pp. 34–41, Sep. 2015, doi: 10.1109/MCG.2015.98.

[51] L. O’Hare, T. Zhang, H. T. Nefs, and P. B. Hibbard, “Visual Discomfort and Depth-of-Field,” *http://dx.doi.org/10.1068/i0566*, vol. 4, no. 3, pp. 156–169, Jan. 2013, doi: 10.1068/I0566.

[52] S. Hillaire, A. Lécuyer, R. Cozot, and G. Casiez, “Depth-of-field blur effects for first-person navigation in virtual environments,” *IEEE Comput Graph Appl*, vol. 28, no. 6, pp. 47–55, 2008, doi: 10.1109/MCG.2008.113.

[53] C. Wienrich, C. K. Weidner, C. Schatto, D. Obremski, and J. H. Israel, “A virtual nose as a rest-frame-the impact on simulator sickness and game experience,” *2018 10th International Conference on Virtual Worlds and Games for Serious Applications, VS-Games 2018 - Proceedings*, Oct. 2018, doi: 10.1109/VS-GAMES.2018.8493408.

[54] D. Clarke, G. McGregor, B. Rubin, J. Stanford, and T. C. N. Graham, “Arcaid: Addressing situation awareness and simulator sickness in a virtual reality Pac-Man game,” *CHI PLAY 2016 - Proceedings of the Annual Symposium on Computer-Human Interaction in Play Companion*, pp. 39–45, Oct. 2016, doi: 10.1145/2968120.2968124.

[55] S. P. Sargunam and E. D. Ragan, “Evaluating joystick control for view rotation in virtual reality with continuous turning, discrete turning, and field-of-view reduction,” *ACM International Conference Proceeding Series*, pp. 74–79, Apr. 2018, doi: 10.1145/3191801.3191815.

[56] Y. H. Peng *et al.*, “WalkingVibe: Reducing Virtual Reality Sickness and Improving Realism while Walking in VR using Unobtrusive Head-mounted Vibrotactile Feedback,” *Conference on Human Factors in Computing Systems - Proceedings*, vol. 20, Apr. 2020, doi: 10.1145/3313831.3376847.

[57] T. Maeda, H. Ando, and M. Sugimoto, “Virtual acceleration with galvanic vestibular stimulation in a virtual reality environment,” *IEEE Proceedings. VR 2005. Virtual Reality, 2005.*, pp. 289–290, 2005, doi: 10.1109/VR.2005.1492799.

[58] M. Sra, A. Jain, and P. Maes, “Adding proprioceptive feedback to virtual reality experiences using galvanic vestibular stimulation,” *Conference on Human Factors in Computing Systems - Proceedings*, May 2019, doi: 10.1145/3290605.3300905.

[59] A. Matviienko *et al.*, “Reducing Virtual Reality Sickness for Cyclists in VR Bicycle Simulators,” *Conference on Human Factors in Computing Systems - Proceedings*, p. 14, Apr. 2022, doi: 10.1145/3491102.3501959.

[60] G. Arrighi, Z. S. See, and D. Jones, “Victoria Theatre virtual reality: A digital heritage case study and user experience design,” *Digital Applications in Archaeology and Cultural Heritage*, vol. 21, p. e00176, Jun. 2021, doi: 10.1016/J.DAACH.2021.E00176.

[61] T. Dybå, B. A. Kitchenham, and M. Jørgensen, “Evidence-Based Software Engineering for Practitioners,” 2005. doi: 10.1109/MS.2005.6.

[62] “Google Scholar.” https://scholar.google.com/ (accessed May 10, 2023).

[63] “ACM Digital Library.” https://dl.acm.org/ (accessed May 10, 2023).

[64] S. Cmentowski, J. Krüger, and A. Krekhov, “Outstanding: A perspective-switching technique for covering large distances in VR games,” in *Conference on Human Factors in Computing Systems - Proceedings*, Association for Computing Machinery, May 2019. doi: 10.1145/3290607.3312783.

[65] N. N. Griffin and E. Folmer, “Out-of-body locomotion: Vectionless navigation with a continuous avatar representation,” in *Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST*, Association for Computing Machinery, Nov. 2019. doi: 10.1145/3359996.3364243.

[66] H. Galvan Debarba, S. Bovet, R. Salomon, O. Blanke, B. Herbelin, and R. Boulic, “Characterizing first and third person viewpoints and their alternation for embodied interaction in virtual reality,” 2017, doi: 10.1371/journal.pone.0190109.

[67] L. Berger and K. Wolf, “WIM: Fast locomotion in virtual reality with spatial orientation gain & Without motion sickness,” in *ACM International Conference Proceeding Series*, Association for Computing Machinery, Nov. 2018, pp. 19–24. doi: 10.1145/3282894.3282932.

[68] R. Pausch, T. Burnette, D. Brockway, and M. E. Weiblen, “Navigation and Locomotionin Virtual Worlds via Flight into Hand-held Miniatures,” *SIGGRAPH ’95: Proceedings of*

the 22nd annual conference on Computer graphics and interactive techniques, pp. 399–400, Sep. 1995.

[69] M. Kim, J. Lee, C. Kim, and J. Kim, "TPVR: User Interaction of Third Person Virtual Reality for New Presence and Experience," 2018, doi: 10.3390/sym10040109.

[70] I. Evin, T. Pesola, M. D. Kaos, T. M. Takala, and P. Hämäläinen, "3PP-R: Enabling Natural Movement in 3rd Person Virtual Reality," in *CHI PLAY 2020 - Proceedings of the Annual Symposium on Computer-Human Interaction in Play*, Association for Computing Machinery, Inc, Nov. 2020, pp. 438–449. doi: 10.1145/3410404.3414239.

[71] H. Iriye and P. L. St Jacques, "Memories for third-person experiences in immersive virtual reality," *Scientific Reports* |, vol. 11, p. 4667, 2021, doi: 10.1038/s41598-021-84047-6.

[72] N. N. Griffin and E. Folmer, "Out-of-body locomotion: Vectionless navigation with a continuous avatar representation," *Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST*, Nov. 2019, doi: 10.1145/3359996.3364243.

[73] "The labors of Theseus: how we designed a 3rd person VR experience." https://web.archive.org/web/20221102160649/https://www.gamedeveloper.com/design/the-labors-of-theseus-how-we-designed-a-3rd-person-vr-experience (accessed Nov. 02, 2022).

[74] "(15) Outstanding: A Multi-Perspective Travel Approach for Virtual Reality Games - YouTube." https://www.youtube.com/watch?v=boj4WrZUXBg (accessed Jan. 07, 2023).

[75] H. Been, L. Duh, D. E. Parker, and T. A. Furness, "An 'Independent Visual Background' Reduced Balance Disturbance Evoked by Visual Scene Motion: Implication for Alleviating Simulator Sickness," 2001.

[76] P. Brown, P. Spronck, and W. Powell, "The simulator sickness questionnaire, and the erroneous zero baseline assumption," *Front Virtual Real*, vol. 3, Sep. 2022, doi: 10.3389/frvir.2022.945800.

[77] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, "Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness," *Int J Aviat Psychol*, vol. 3, no. 3, pp. 203–220, 1993, doi: 10.1207/s15327108ijap0303_3.

[78] B. G. Witmer and M. J. Singer, "Measuring Presence in Virtual Environments: A Presence Questionnaire," *Presence*, vol. 7, no. 3, p. 225, 1998.

[79] B. G. Witmer, C. J. Jerome, and M. J. Singer, "The factor structure of the presence questionnaire," 2005.

[80] I. S. MacKenzie, *Human-computer interaction*. Burlington: Elsevier Science, 2012.

[81] "Oculus Safety Center | Oculus." http://web.archive.org/web/20230227153247/https://www.oculus.com/safety-center/ (accessed Feb. 27, 2023).

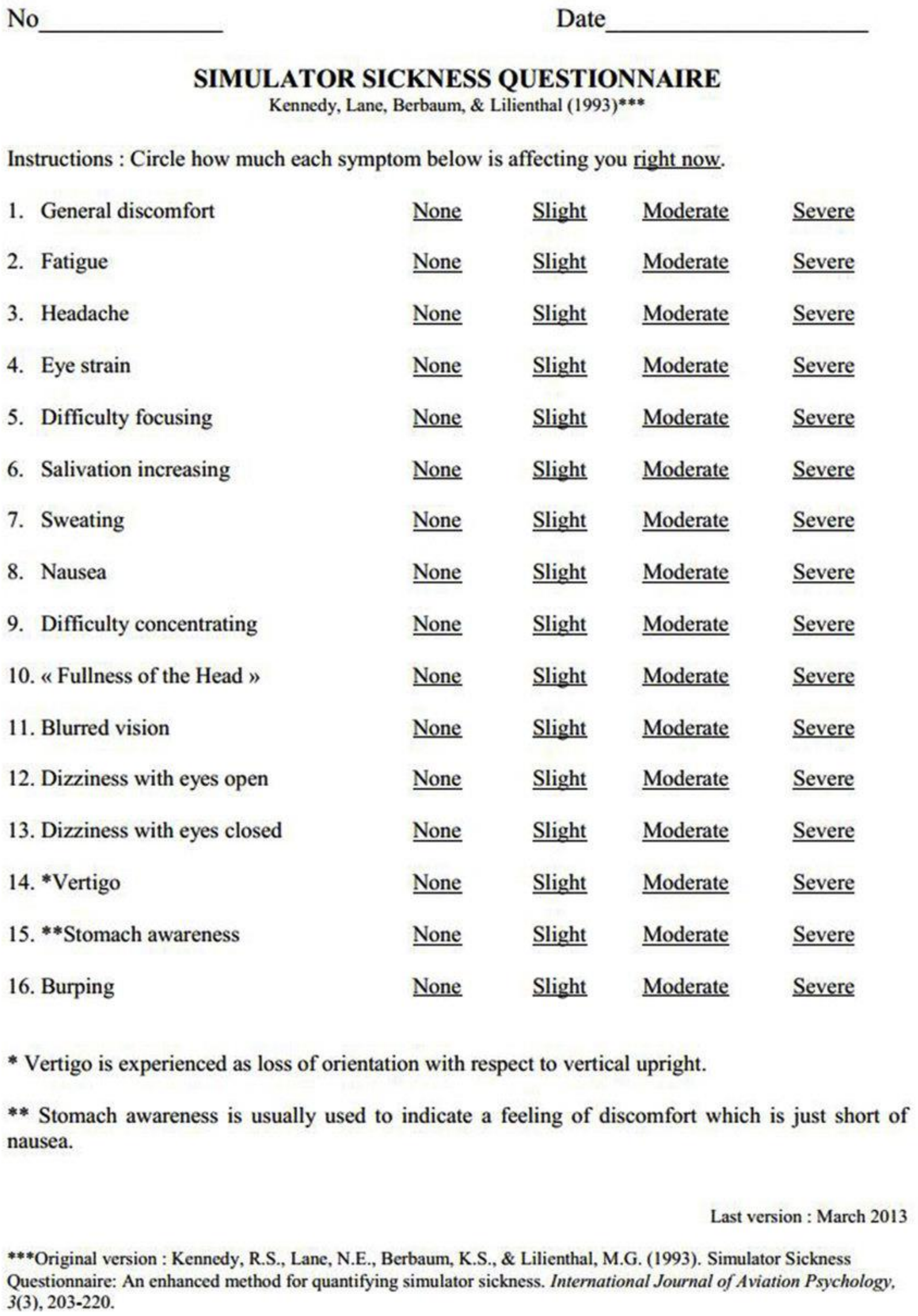
[82] "Steam Hardware & Software Survey." https://web.archive.org/web/20221102113614/https://store.steampowered.com/hwsurvey/Steam-Hardware-Software-Survey-Welcome-to-Steam (accessed Nov. 02, 2022).

[83] "ShadowPlay: Record, Share Game Videos & Screenshots | NVIDIA." https://web.archive.org/web/20230523152144/https://www.nvidia.com/en-us/geforce/geforce-experience/shadowplay/ (accessed Jun. 03, 2023).

[84] "jamovi - open statistical software for the desktop and cloud." https://www.jamovi.org/ (accessed Jun. 02, 2023).

[85] D. Monteiro, H. Chen, H. N. Liang, H. Tu, and H. Dub, "Evaluating Performance and Gameplay of Virtual Reality Sickness Techniques in a First-Person Shooter Game," *IEEE Conference on Computatonal Intelligence and Games, CIG*, vol. 2021-August, 2021, doi: 10.1109/COG52621.2021.9619145.

Appendix



No______________ Date____________________

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

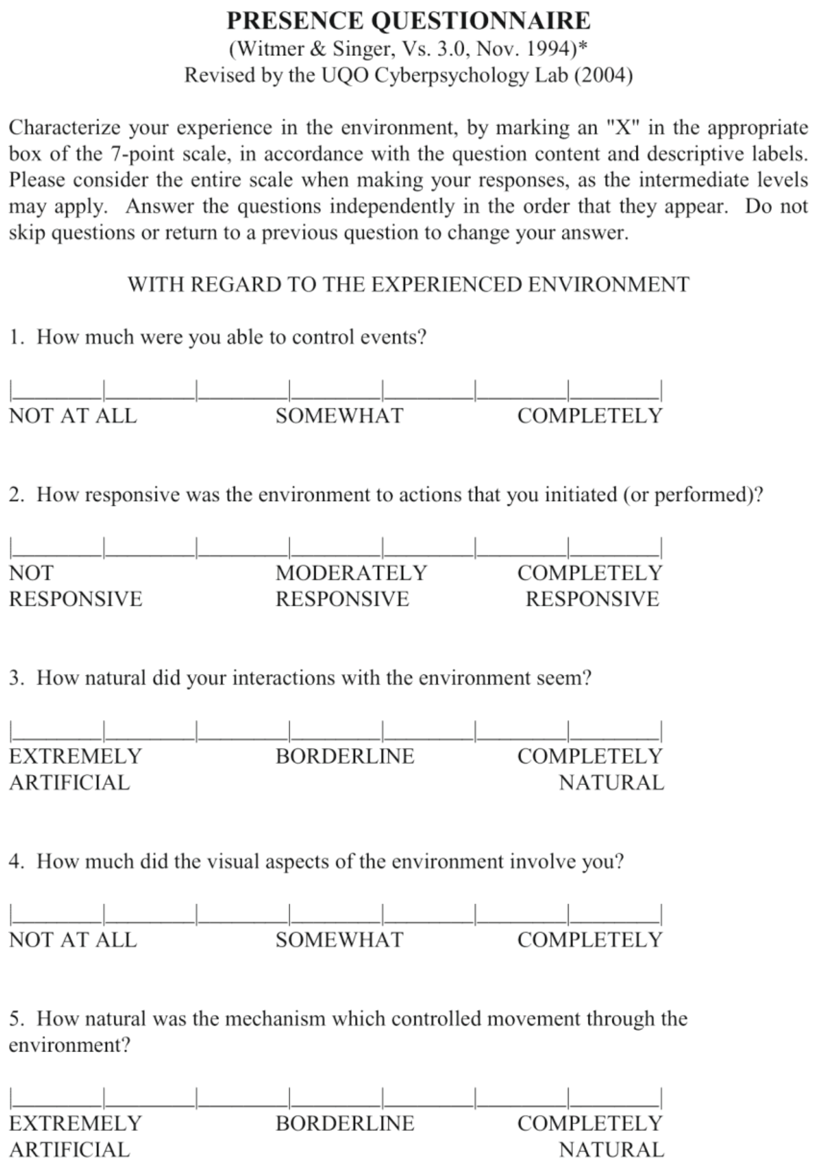
* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*(3), 203-220.

Figure 50: Simulator Sickness Questionnaire



PRESENCE QUESTIONNAIRE
(Witmer & Singer, Vs. 3.0, Nov. 1994)*
Revised by the UQO Cyberpsychology Lab (2004)

Characterize your experience in the environment, by marking an "X" in the appropriate box of the 7-point scale, in accordance with the question content and descriptive labels. Please consider the entire scale when making your responses, as the intermediate levels may apply. Answer the questions independently in the order that they appear. Do not skip questions or return to a previous question to change your answer.

WITH REGARD TO THE EXPERIENCED ENVIRONMENT

1. How much were you able to control events?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

2. How responsive was the environment to actions that you initiated (or performed)?

|________|________|________|________|________|________|________|
NOT RESPONSIVE MODERATELY RESPONSIVE COMPLETELY RESPONSIVE

3. How natural did your interactions with the environment seem?

|________|________|________|________|________|________|________|
EXTREMELY ARTIFICIAL BORDERLINE COMPLETELY NATURAL

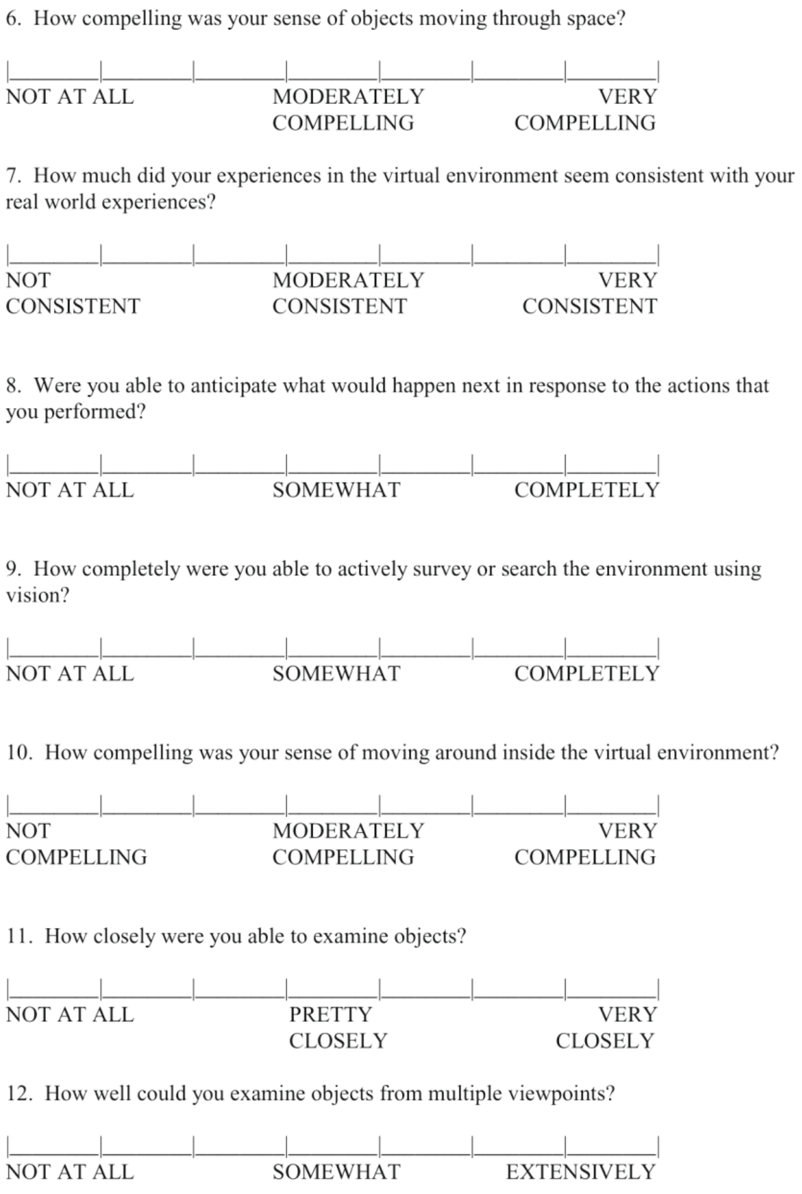
4. How much did the visual aspects of the environment involve you?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

5. How natural was the mechanism which controlled movement through the environment?

|________|________|________|________|________|________|________|
EXTREMELY ARTIFICIAL BORDERLINE COMPLETELY NATURAL

Figure 51: Presence Questionnaire page 1



6. How compelling was your sense of objects moving through space?

|________|________|________|________|________|________|________|

NOT AT ALL	MODERATELY COMPELLING	VERY COMPELLING

7. How much did your experiences in the virtual environment seem consistent with your real world experiences?

|________|________|________|________|________|________|________|

NOT CONSISTENT	MODERATELY CONSISTENT	VERY CONSISTENT

8. Were you able to anticipate what would happen next in response to the actions that you performed?

|________|________|________|________|________|________|________|

NOT AT ALL	SOMEWHAT	COMPLETELY

9. How completely were you able to actively survey or search the environment using vision?

|________|________|________|________|________|________|________|

NOT AT ALL	SOMEWHAT	COMPLETELY

10. How compelling was your sense of moving around inside the virtual environment?

|________|________|________|________|________|________|________|

NOT COMPELLING	MODERATELY COMPELLING	VERY COMPELLING

11. How closely were you able to examine objects?

|________|________|________|________|________|________|________|

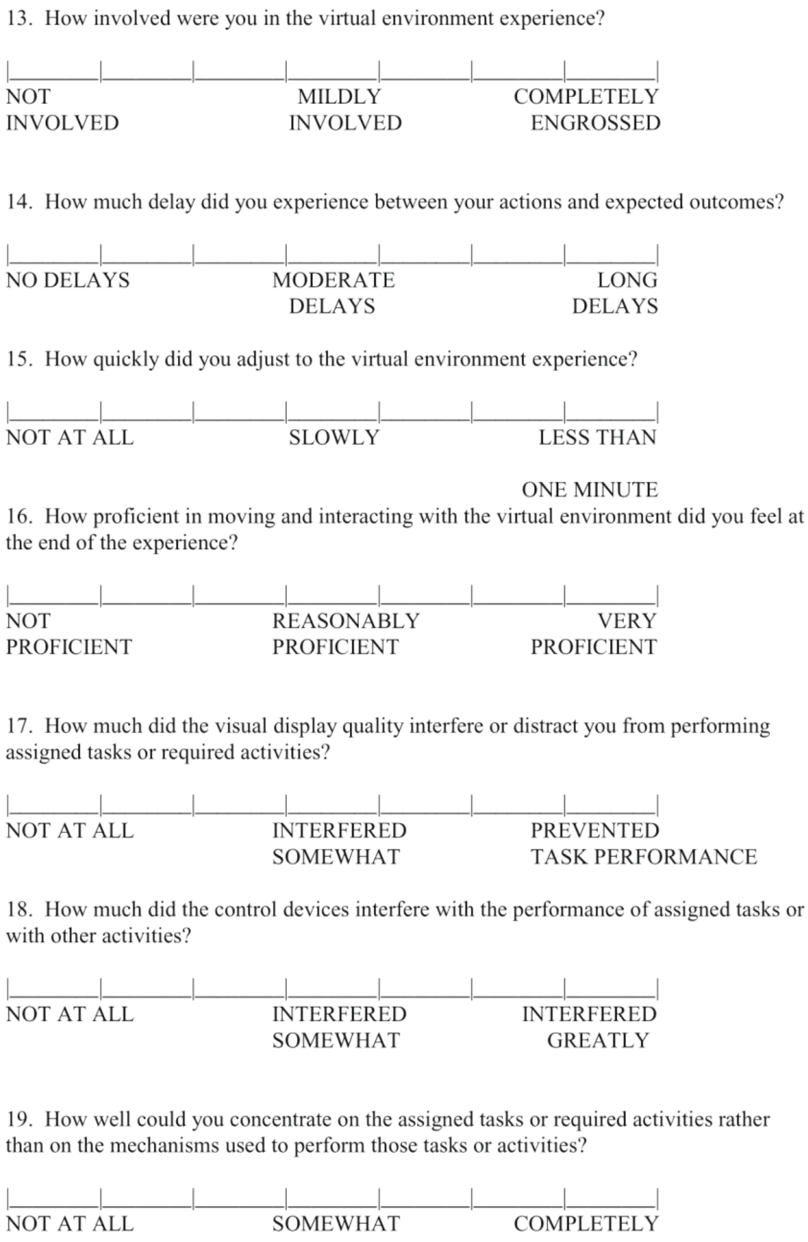
NOT AT ALL	PRETTY CLOSELY	VERY CLOSELY

12. How well could you examine objects from multiple viewpoints?

|________|________|________|________|________|________|________|

NOT AT ALL	SOMEWHAT	EXTENSIVELY

Figure 52: Presence Questionnaire page 2



13. How involved were you in the virtual environment experience?

|________|________|________|________|________|________|________|

NOT INVOLVED — MILDLY INVOLVED — COMPLETELY ENGROSSED

14. How much delay did you experience between your actions and expected outcomes?

|________|________|________|________|________|________|________|

NO DELAYS — MODERATE DELAYS — LONG DELAYS

15. How quickly did you adjust to the virtual environment experience?

|________|________|________|________|________|________|________|

NOT AT ALL — SLOWLY — LESS THAN ONE MINUTE

16. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

|________|________|________|________|________|________|________|

NOT PROFICIENT — REASONABLY PROFICIENT — VERY PROFICIENT

17. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

|________|________|________|________|________|________|________|

NOT AT ALL — INTERFERED SOMEWHAT — PREVENTED TASK PERFORMANCE

18. How much did the control devices interfere with the performance of assigned tasks or with other activities?

|________|________|________|________|________|________|________|

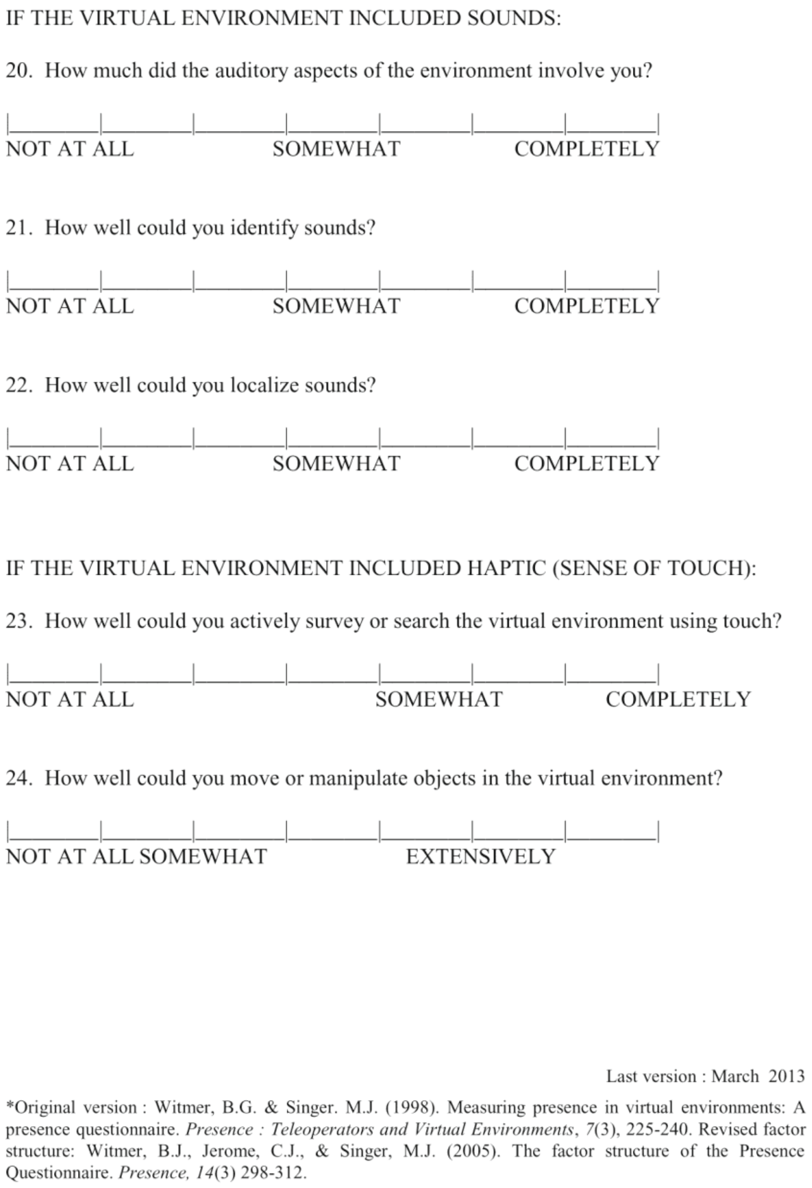
NOT AT ALL — INTERFERED SOMEWHAT — INTERFERED GREATLY

19. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

|________|________|________|________|________|________|________|

NOT AT ALL — SOMEWHAT — COMPLETELY

Figure 53: Presence Questionnaire page 3



IF THE VIRTUAL ENVIRONMENT INCLUDED SOUNDS:

20. How much did the auditory aspects of the environment involve you?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

21. How well could you identify sounds?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

22. How well could you localize sounds?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

IF THE VIRTUAL ENVIRONMENT INCLUDED HAPTIC (SENSE OF TOUCH):

23. How well could you actively survey or search the virtual environment using touch?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

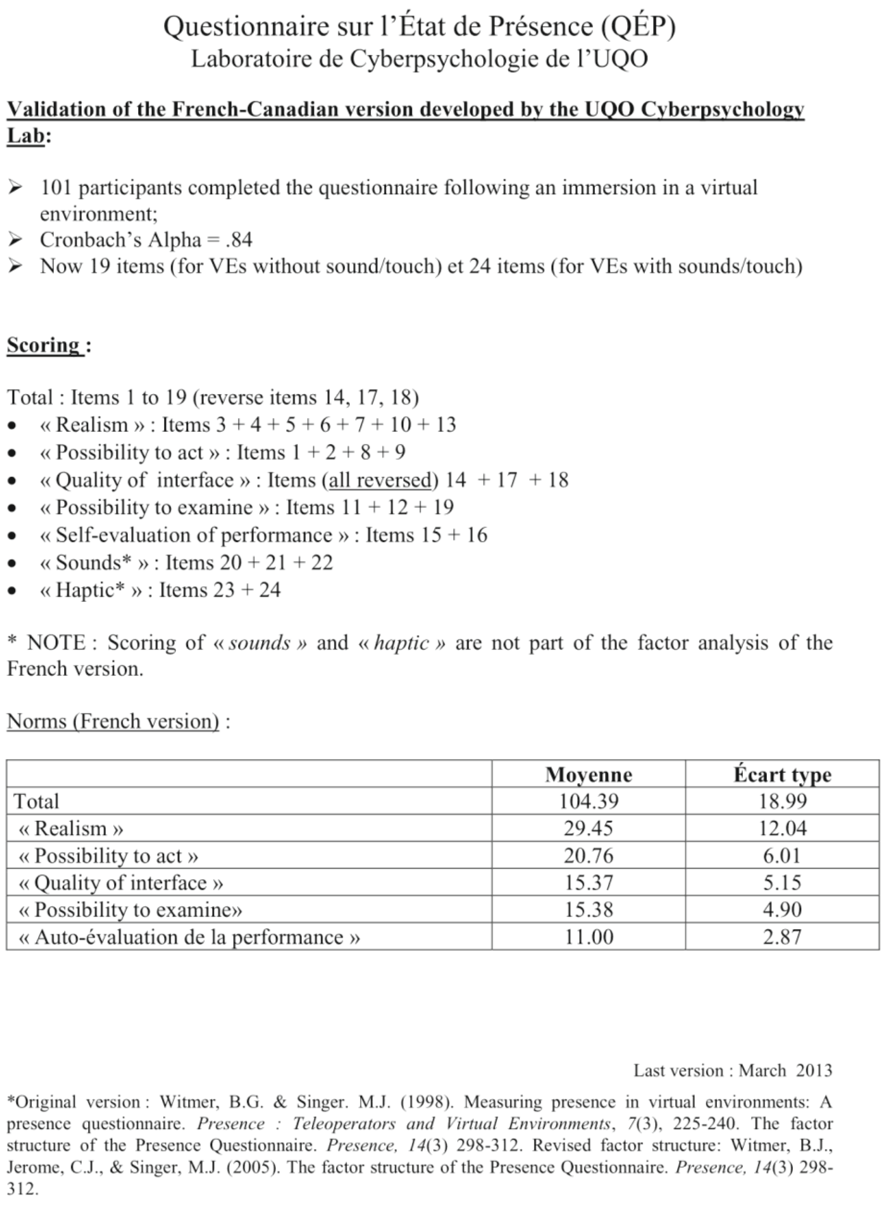
24. How well could you move or manipulate objects in the virtual environment?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT EXTENSIVELY

Last version : March 2013

*Original version : Witmer, B.G. & Singer. M.J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence : Teleoperators and Virtual Environments*, *7*(3), 225-240. Revised factor structure: Witmer, B.J., Jerome, C.J., & Singer, M.J. (2005). The factor structure of the Presence Questionnaire. *Presence, 14*(3) 298-312.

Figure 54: Presence Questionnaire page 4



Questionnaire sur l'État de Présence (QÉP)
Laboratoire de Cyberpsychologie de l'UQO

Validation of the French-Canadian version developed by the UQO Cyberpsychology Lab:

- ➢ 101 participants completed the questionnaire following an immersion in a virtual environment;
- ➢ Cronbach's Alpha = .84
- ➢ Now 19 items (for VEs without sound/touch) et 24 items (for VEs with sounds/touch)

Scoring :

Total : Items 1 to 19 (reverse items 14, 17, 18)

- « Realism » : Items 3 + 4 + 5 + 6 + 7 + 10 + 13
- « Possibility to act » : Items 1 + 2 + 8 + 9
- « Quality of interface » : Items (all reversed) 14 + 17 + 18
- « Possibility to examine » : Items 11 + 12 + 19
- « Self-evaluation of performance » : Items 15 + 16
- « Sounds* » : Items 20 + 21 + 22
- « Haptic* » : Items 23 + 24

* NOTE : Scoring of « *sounds* » and « *haptic* » are not part of the factor analysis of the French version.

Norms (French version) :

	Moyenne	**Écart type**
Total	104.39	18.99
« Realism »	29.45	12.04
« Possibility to act »	20.76	6.01
« Quality of interface »	15.37	5.15
« Possibility to examine»	15.38	4.90
« Auto-évaluation de la performance »	11.00	2.87

Last version : March 2013

*Original version : Witmer, B.G. & Singer. M.J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence : Teleoperators and Virtual Environments*, *7*(3), 225-240. The factor structure of the Presence Questionnaire. *Presence, 14*(3) 298-312. Revised factor structure: Witmer, B.J., Jerome, C.J., & Singer, M.J. (2005). The factor structure of the Presence Questionnaire. *Presence, 14*(3) 298-312.

Figure 55: Presence Questionnaire page 5