Evaluating the User Experience and Usability of Virtual Reality Locomotion Techniques

An Empirical Comparison

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Abstract

Virtual reality technology has recently had a revival with new VR-hardware being introduced to the consumer market. This can be considered a turning point in the field as it has now become more accessible and affordable to the public. Since this revival, VR-technology has been subject to multiple HCI studies, where also VR locomotion techniques have been examined. However, a majority of these studies emphasize constructive research problems with a focus on understanding the technical aspects of the interaction. New and novel VR locomotion techniques are constructed without any empirical evaluation of the human aspects to support this work. Without the knowledge of already existing issues with the interaction, there is a research gap in the current field of VR locomotion studies.

To fill this research gap, we examined and compared three of the currently prevalent VR locomotion techniques; joystick, teleportation and "walk in place" with a focus on the user experience and usability. We examined these techniques through an empirical study followed by a Game Experience Questionnaire, questionnaire for the System Usability Scale and semi-structured interviews. This provided useful data to be analyzed and compared to determine which UX aspects were considered important, and how the usability was perceived for each technique.

Based on the results, a few issues related to the interaction was identified. Taking these issues into consideration, we propose some design implications to address the current issues. This can be a contribution to improve the problem-solving capacity in the research field of VR to drive the field forward and support new and better constructive work in the future.
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Chapter 1

Introduction

1.1 Motivation

Virtual reality (VR) can be defined as "a simulation in which computer graphics is used to create a realistic-looking world" (Burdea and Coiffet, 2003, p. 2), where the virtual environments are often presented through a head-mounted display (HMD). The technology began as something highly experimental, but has since evolved and gotten traction in various fields thanks to the technological developments in recent years. Additionally, VR-systems are more easily adopted by both consumer and industry due to lower costs (Hilfert and König, 2016). Even though the technology has developed and matured during the last decade, there are still challenges to the use of VR-technology. One of the major challenges is related to the travel techniques in the virtual environments, also named "VR locomotion". As locomotion is one of the most basic and essential interactions performed in virtual environments, this is also an aspect which is challenging to implement in a way which is universally enjoyed by the users (Bowman, 1999, p. 88).

VR had a revival and made an impact on the consumer market due to the release of the affordable and now well established VR-systems Oculus Rift in 2013 and HTC Vive in 2016 (Olszewski et al., 2016; Hilfert and König, 2016). A review of recent HCI studies of VR locomotion since this revival shows that there has been a highly constructive approach where new and
novel techniques are constructed with a focus on examining the technical aspects of the interaction (Boletsis et al., 2017, p. 3-4; Nabiyouni et al., 2015; Kitson et al., 2017; Schmidt et al., 2015; Kruijff et al., 2016).

What we see, however, is lack of empirical examination of the already existing and prevalent VR locomotion techniques with a focus on the interaction issues related to the human aspects such as the user experience (UX) (Boletsis, 2017, p. 10-11). As of now, there is a disconnect between the recent constructive work and any empirical evaluation to support this, presenting a research gap in the recent HCI studies of VR locomotion (Boletsis et al., 2017, p. 4; Oulasvirta and Hornbæk, 2016, p. 4956-4967; Laudan, 1978).

Furthermore, future studies of VR locomotion should include more comparative studies in the field (Boletsis, 2017, p. 11). By conducting comparative empirical studies utilizing the currently common VR locomotion techniques, it will be possible to examine and compare both the UX aspects and usability between the techniques at the same time.

If studies were to address this research gap through comparative empirical studies, it could in time contribute to a better knowledge of how to design new and better constructive solutions which address the current interaction issues in the VR locomotion field (Boletsis et al., 2017, p. 4). This could contribute to strengthen and move the field forward, ultimately providing a better problem-solving capacity for VR studies (Oulasvirta and Hornbæk, 2016; Laudan, 1978). The discussion related to the problem-solving capacity in VR research is based on our joint publication "HCI Research in Virtual Reality: A Discussion of Problem-solving" which also identifies the research gap related to this field (Boletsis et al., 2017).
1.2  Research context

The study was conducted in cooperation with SINTEF\textsuperscript{1} and support from the Center for Service Innovation (CSI)\textsuperscript{2}. This study is a part of a CSI-topic called ”Design for service” aiming to address innovation challenges of service design for added customer value.

1.3  Research questions

Through this study of locomotion in VR, the objective was to examine, compare and discuss the UX and usability of the widely used VR locomotion techniques through an empirical study including both qualitative and quantitative data. The prominent VR locomotion techniques were selected based on a typology and literature review of 36 recent studies within the field (Boletsis, 2017). The selection of techniques includes both artificial and physical interaction types to document the UX and usability of both interactions, as well as supporting open VR interaction spaces. Based on the research gap presented in section 1.1, the following research questions are proposed for this work:

- **RQ1:** What is the current state of the art in the VR locomotion field, and which techniques are the currently most prevalent?

- **RQ2:** How is the UX of currently prevalent VR locomotion techniques experienced by users in open VR interaction spaces, and which UX aspects are considered important?

- **RQ3:** How is the perceived usability of currently prevalent VR locomotion techniques in open VR interaction spaces?

- **RQ4:** What are the differences regarding usability and UX of the currently prevalent VR locomotion techniques in open VR interaction spaces?

\textsuperscript{1}https://www.sintef.no

\textsuperscript{2}https://www.nhh.no/en/research-centres/csi/about/
1.4 Contributions

By answering the research questions, this master thesis will contribute to the following:

1. Identifying the currently prevalent VR locomotion techniques which should be examined based on the current state of the art in the field.

2. A qualitative analysis and discussion about important aspects related the UX and usability of the prevalent VR locomotion techniques.

3. A comparison and discussion about the UX and usability of the prevalent VR locomotion techniques.

4. Proposed design implications for how to address current issues related to the interaction of the prevalent VR locomotion techniques.

5. A methodology for a comparative empirical evaluation of VR locomotion techniques.

Contribution 1   By getting an overview of the current state of the art in the VR locomotion field it should be able to identify the currently most common and prevalent VR locomotion techniques. The result of this finding will not only be important to this empirical study but should also be taken into consideration for future studies in the field.

Contribution 2   The qualitative analysis will shed light on the human aspects and usability of the current prevalent VR locomotion techniques which previously had little examination. This will identify which aspects of the interaction the users find important when utilized in open VR interaction spaces, as well as aspects which are considered problematic with the current interaction which should be addressed.

Contribution 3   A comparison of the examined techniques will be able to highlight the differences between the techniques in terms of UX and usability. This will contribute to getting a better understanding of which
techniques potentially provides the overall most satisfying experience when used in an open VR environment. As there is a lack of comparative empirical work evaluating the UX and usability in the field, this will be a contribution to this knowledge and a baseline for further examination.

**Contribution 4** Based on previous literature on VR locomotion and the analysis and discussion of the collected data, the proposed design implications are suggestions on how to address the currently identified interaction issues of the examined techniques. These suggestions could be taken into consideration for future studies and constructive work in the VR locomotion field.

**Contribution 5** The applied methodology to examine UX and usability for VR locomotion techniques could inspire future related studies in the field as this approach can provide a comprehensive data-set to examine and discuss the important aspects of UX and usability and the related interaction issues.

### 1.5 Chapter overview

**Chapter 2: Background** This chapter gives a brief history of the VR technology and how this field has evolved through the 90’s. An overview of the field of VR locomotion research in the past will be presented, as well as how the VR revival made a change to the field. The research gap among the current studies will be discussed, including why this is important to cover. Based on this, we will present our current work for the thesis.

**Chapter 3: Tools and techniques** The hardware and VR-system which we will utilize gets presented in this chapter, as well as an overview and description of the examined VR locomotion techniques. This chapter will also cover the virtual environment in which will be used in the study by the participants.
CHAPTER 1. INTRODUCTION

Chapter 4: Methodology  This chapter covers the methodology applied in this study, including each method used to gather and analyze the data. The procedure for the whole empirical study will be presented and how the study will be conducted in practice with the selected participants.

Chapter 5: Results  The results of the quantitative and qualitative data will be presented in this chapter. This includes the statistical analysis to reveal any statistically significant differences as well as the coded themes from the interview data.

Chapter 6: Discussion  This chapter will interpret and discuss the analyzed data to find remarks related to the UX and usability for each VR locomotion technique. The results from each techniques will also be compared in terms of UX and usability. Based on the remarks, we will propose design implications to address the current issues identified with the examined techniques. Limitations of the study will also be discussed at the end of the chapter.

Chapter 7: Conclusion  A conclusion will be made to sum up the thesis work including the contributions, as well as suggested future work to examine aspects outside the scope of this thesis.
Chapter 2

Background

This chapter will cover a brief history of how the virtual reality technology emerged, how it has evolved and why locomotion is an important and yet challenging topic within the field. By looking into the past, the revival and the current state of the field, we will be able to identify the most prevalent VR locomotion techniques. Additionally, we will discuss a literature review of recent studies of locomotion and elaborate upon how a comparative empirical evaluation related to UX and usability can lead to a higher problem-solving capacity in the field of VR.

2.1 History of Virtual Reality

VR-technology has been around for decades, ever since Ivan Sutherland (1965) HMD named "The Ultimate Display" in the 1960’s (Sutherland, 1965). Building upon Sutherland’s project, Jim Clark from the University of Utah rebuilt the virtual reality technology further. His contribution allowed for visualization of 3D virtual environments in an HMD, as well as interaction in the virtual environment with a 3D wand input device (National Academy of Sciences, 1999, p. 231). The visual aspect of 3D graphics during the earlier days of VR-studies was, however, not quite like the "reality". The graphics were low-fidelity or jerky, and the environments could not respond quickly to the movements performed by the user (Briggs, 1996, p. 2). Dur-
CHAPTER 2. BACKGROUND

In the 90’s, VR technology advanced, and had an increased adoption and lower cost which made VR applicable beyond simple simulation and entertainment (Brooks, 1999, p. 20). This would also allow to have a more "naturalistic" approach to human-computer interaction, thus resulting in several new HCI studies related to the field of VR-technology (Slater et al., 1995). Studies identified categories such as selection, manipulation and viewpoint motion control as desired user actions (Bowman and Hodges, 1999, p. 38). The viewpoint motion control (also named travel or locomotion) implies the movement from one location to another in virtual environments, and is one of the most common interaction tasks in VR. Through the 90’s and early 2000, multiple locomotion-techniques got studied. Both so-called "artificial" VR locomotion with some type of physical controller (Bowman et al., 1997, p. 45), and "physical" VR locomotion with the use of optical trackers for physical movement (Ward et al., 1992) were subject for HCI studies.

2.2 VR locomotion in the past

To describe various locomotion techniques, it is common to use "metaphors" to illustrate the techniques as an interaction that resembles common real-life actions or situations. Among the earliest examples of metaphors for travel in a virtual environment was by Ware and Osborne (1990) who proposed and compared three metaphors; eyeball in hand, scene in hand (figure 2.1) and flying vehicle control to enable six degree control in a virtual environment (Ware and Osborne, 1990). Building upon Ware and Osborne metaphors, Stoakley et al. (1995) used the idea of scene in hand to create the World in Miniature (WIM) metaphor which allowed the user to see the whole virtual environment in miniature as illustrated in figure 2.2 (Stoakley et al., 1995). Through this metaphor, Stoakley et al. suggested the possibility for the user to "fly" through the environment, or let the user navigate the scene by "picking" their self up to change location. Early categorization of interaction types in VR was conducted by Mine et al. (1995) where hand directed and gaze-directed motion were proposed (Mine et al., 1995, p. 3). Hand directed motion could determine the direction of motion though pointing with your
finger, while gaze-directed motion used the direction of the head to determine the direction of movement. These locomotion techniques were among the earliest examples of artificial travel in VR.

In opposite to artificial interaction in the virtual environment with an input device, being able to track motion and have a freedom of movement in real time would introduce another way of VR locomotion. Additionally, by actually walking in physical space, the feeling of presence in the virtual environment got enhanced compared to using a physical input device (Slater et al., 1995, p. 11). With the use of an HMD and LED-lights in the roof, a system would be able to track a user in physical space and transfer the movement to the virtual environment (Ward et al., 1992). Some of the limitations were the weight of the HMD, limited rotation, and sensitivity of other light sources, but one could consider this as the early predecessor to today’s "room scale" technology. Slater et al. (1995) suggested an alternative metaphor for a more "naturalistic" interaction for locomotion with the Virtual Treadmill (Slater et al., 1995). This metaphor would also allow the movement of the user in the physical space to be transferred into the virtual environment but could solve some of the issues from Ward et al. (1992)'s system regarding the tracking technology and limited physical space. The Virtual Treadmill implies that the user could walk in place (WIP) to move around the virtual environment by lifting their legs, similar to real life walking. However,
this metaphor would not be suitable when the virtual environment covered a large area, as this technique could be both slow and tiresome compared to, for instance, the WIM-metaphor.

Figure 2.3: Ward et al. tracking of a HMD in physical space (Ward et al., 1992)

For many of the earlier studies of VR locomotion, Bowman et al. (1997) made a taxonomy for virtual travel techniques illustrated in figure 2.4 (Bowman et al., 1997). This conceptualization was early on considered a reference point for classification of VR locomotion when constructing the techniques.

As various applications can be very different from each other, Bowman et al. (1997) also propose a list of quality factors to support effectiveness for locomotion (see table 2.1). This list is intended as a starting point for comparative studies of various techniques.
2.2. VR LOCOMOTION IN THE PAST

Figure 2.4: Bowman et al. (1997)’s taxonomy of travel techniques in VR (Bowman et al., 1997)

<table>
<thead>
<tr>
<th>Quality factors</th>
<th>Description</th>
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<tbody>
<tr>
<td>Speed</td>
<td>Appropriate velocity</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Proximity to the desired target</td>
</tr>
<tr>
<td>Spatial Awareness</td>
<td>The user’s implicit knowledge of his position and orientation within the environment during and after travel</td>
</tr>
<tr>
<td>Ease of Learning</td>
<td>The ability of a novice user to use the technique</td>
</tr>
<tr>
<td>Information Gathering</td>
<td>The user’s ability to actively obtain information from the environment during travel</td>
</tr>
<tr>
<td>Presence</td>
<td>The user’s sense of immersion or “being within” the environment</td>
</tr>
</tbody>
</table>

Table 2.1: Bowman et al. (1997) quality factors for VR locomotion (Bowman et al., 1997, p. 59)
Even though Bowman et al. (1997) work was useful, they state that the work "only scratch the surface" of locomotion in virtual environments (Bowman et al., 1997, p. 64). For future work, Bowman et al. want a more developed and comprehensive taxonomy for further discussion and testing.

2.2.1 Summary of the past

Multiple studies of locomotion in virtual environments emerged after Ware and Osborne (1990) metaphors (Ware and Osborne, 1990). To study and understand the technological possibilities of VR and locomotion at this time, there was conducted a lot of constructive work during that decade. Many different locomotion techniques were subject to study. Based on these studies, we suggest that locomotion can be divided into two overall categories;

- "Artificial" locomotion - With the use of controllers and tools for travel in VR
- "Physical" locomotion - Physical movement in real space transfers to VR

Previous studies show that techniques of both categories can provide an overall good experience and usability, but there were still issues regarding the interaction and no definite way of locomotion in virtual environments (Ward et al., 1992; Slater et al., 1995; Stoakley et al., 1995). As some techniques were more useful than others in different contexts, as well as the user experience can vary between users, it would be difficult to conclude with only one technique which works flawlessly in an application for all the users. There are multiple factors which can affect the user experience and performance, which proves that locomotion is a challenging topic of VR (Bowman et al., 1998, p. 12-15).

By the late 90’s, Bowman et al. (1998) provided a more conceptual approach to the field by proposing a taxonomy, framework, and classification for VR, including locomotion (Bowman et al., 1998). However, some of
Bowman et al.’s work could be considered outdated by today’s standards as computer hardware had a rapid development which has allowed for higher-fidelity content and more accessible and standardized VR solutions. Due to the advancements in both hardware and software related to VR, this taxonomy does not longer cover the whole extent of the current technologies.

2.3 VR revival

Beginning in 2013 the Oculus Rift and HTC Vive made an impact on the VR-market by offering high-end and affordable VR-systems (Olszewski et al., 2016; Hilfert and König, 2016). In combination with more powerful hardware and a strong development community for VR, the technology had a rapid change in this period compared to the pre-2013 systems. This has resulted in a variety of locomotion techniques which aims towards the newest VR-technologies in games and applications (see overview at Lunerfox (2017)). Following this change, there has again been an interest in the HCI research community related to VR, and a few studies on locomotion has been conducted in the recent years.

Improving on the Virtual Treadmill by Slater et al. (1995), Nilsson et al. propose several of natural WIP techniques which includes feet gestures like tapping and wiping, as well as arm swinging (Nilsson et al., 2016). In addition to these techniques, Nilsson et al. further conducted research on “steering-techniques”. A more natural solution to the gaze-directed motion proposed by Mine et al. (1995) was the torso-directed technique, where the direction of the torso would specify the direction of movement. This can be combined with a omnidirectional WIP technique such as the Virtusphere (Nabiyouni et al., 2015) or Leaning-Amplified-Speed Walk-In-Place (LAS-WIP) (Langbehn et al., 2015). These techniques allow travel in the virtual environment by tuning into any direction and walking in place. This could allow for virtual environments to surpass the boundaries of the physical interaction space. In addition, Langbehn et al. (2015) implemented the possibility to change the walking speed by leaning the torso. Various ways of leaning-based VR locomotion techniques got further examined and compared by Kitson et al.
The pointing-techniques like Hand Directed locomotion proposed by Mine et al. (1995) eventually opened for the possibility for teleportation through virtual environments. By teleportation, the user can point to any desired destination in the virtual environment and instantly move to that position (Bozgeyikli et al., 2016, p. 207). A comparative study conducted by Bozgeyikli et al. (2016) suggested that point and teleport was significantly more effective in environments without obstacles. Teleportation can be considered as a technique which is more result-oriented rather than process-oriented and, and has advantages in terms of less motion sickness, better speed and higher accuracy (Bozgeyikli et al., 2016, p. 211-212).

Ways of teleporting beyond pointing have been examined by Ruder et al.
(2017), where clicking a button, jumping forward in real space and gesturing was compared (Ruder et al., 2017). The use of a button was mostly preferred and is a common implementation of the teleportation technique. The different ways of physical input methods for locomotion lags behind, where the default input device is often controllers for game consoles which are not designed for VR (Liang et al., 2016, p. 455). A study conducted by Liang et al. (2016) looks into three types of controllers (Xbox, HTC Vive controllers, and a tablet interface), and suggest an alternative design for input control named the VRMController which utilize a mobile phone with an on-screen touch interface to control direction and speed. The result of a comparison between these controllers showed that the VRMController was overall comfortable, easy, and pleasant to use followed by a regular gamepad (Liang et al., 2016, p. 459).
2.4 Problem solving in VR

The rapid technological development has allowed the VR user-community to develop multiple VR locomotion techniques featured in games and applications which both further builds upon previous techniques, but also all new techniques (see Lunerfox (2017) for list of current techniques). However, few of these VR locomotion techniques have been examined with empirical research problems to understand the human aspects which can allow for a higher problem-solving capacity in HCI (Oulasvirta and Hornbæk, 2016). Oulasvirta and Hornbæk (2016) defines three types of research problems in HCI listed in table 2.2.

<table>
<thead>
<tr>
<th>Type of research problem</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Empirical problems</td>
<td>“[...] aimed at creating or elaborating descriptions of real-world phenomena related to human use of computing.”</td>
</tr>
<tr>
<td>Conceptual problems</td>
<td>“[...] aimed at explaining previously unconnected phenomena occurring in interaction.”</td>
</tr>
<tr>
<td>Constructive problems</td>
<td>“[...] aimed at producing understanding about the construction of an interactive artefact for some purpose in human use of computing.”</td>
</tr>
</tbody>
</table>

Table 2.2: Types of HCI research problems (Oulasvirta and Hornbæk, 2016, p. 4956-4967)
What is implied in problem-solving capacity, Oulasvirta and Hornbæk refers to Laudan (1978) work who describes scientific progress through two fundamental concepts: the research problem and the solution. As for the solution, this includes "the outcome, finding and results of research" (Oulasvirta and Hornbæk, 2016, p. 4). The problem-solving capacity can be considered as how research offers effectively, efficiently, and valid solutions to important and recurring problems in HCI.

Many recent studies on locomotion in VR mainly address constructive research problems as in developing new and novel VR locomotion techniques and describing the technical aspects directly related to the interaction (Boletsis et al., 2017, p. 3-4). What we see missing is a more user-centric approach to the current issues related to the human aspects such as the UX for already prevalent VR locomotion techniques (Boletsis, 2017, p. 10-11). Without any empirical evaluation to support the constructive work, there is a research gap in the recent HCI studies of VR locomotion which should be addressed (Boletsis et al., 2017, p. 4; Oulasvirta and Hornbæk, 2016, p. 4956-4965; Laudan, 1978).

The lack of comparative empirical work should also be addressed to be able to compare the differences in UX and usability between various VR locomotion techniques (Boletsis, 2017, p. 11). Taking all of this into consideration when conducting future studies of VR, the result of the studies can in time contribute to a better knowledge of how to design new and better constructive solutions which address the current interaction issues in the VR locomotion field. Through this work, it is more likely to reach a higher level of HCI problem-solving capacity, thus driving the field forward (Oulasvirta and Hornbæk, 2016, p. 4962-4965).

### 2.5 Typology for VR locomotion

When taking the recent technological development in the VR-field into consideration, a literature review of recent studies on locomotion in VR between 2014-2017 was conducted to create an overview of locomotion techniques as a research field (Boletsis, 2017). This literature review builds upon our earlier
joint publication "HCI Research in Virtual Reality: A Discussion of Problem-solving", which identifies the research gap related to this field (Boletsis et al., 2017). Through a systematic search in the Scopus academic search engine\(^1\) with a focus on VR locomotion supported by empirical studies, 92 articles in total were found. After excluding the papers which were not found to be relevant to the literature review, 36 articles in total were included. These articles were validated through peer-review and with an expert.

Based on the result of the literature review, a typology for VR locomotion techniques was proposed (Boletsis, 2017, p. 12). The typology includes categorization of VR interaction types such as physical and artificial interaction, VR motion types as continuous and non-continuous, VR interaction spaces such as open or limited environments (referring to the boundaries of the virtual environment), and four VR locomotion types divided into motion-based, roomscale-based, controller-based and teleportation-based.

\[\text{Figure 2.9: Typology for VR locomotion (Boletsis, 2017, p. 12)}\]

This typology can function as a common ground when studying the field of VR. Such typology can be used by "[...] researchers of HCI and VR and the public who uses these systems to communicate the interaction aspects and functionality that were previously difficult to describe and classify, thus enhancing the field’s social impact" (Boletsis, 2017, p. 12).

The review of 36 articles had in total 73 instances of various VR lomo-
2.6. OUR STUDY ON VR LOCOMOTION

tion techniques, whereas 47 of the reviewed techniques can be considered as physical interaction and 26 artificial interaction. The most utilized locomotion technique was WIP which is categorized as a motion-based locomotion type as it’s supported by physical movement. Following WIP, techniques enabled by a controller or joystick was the second most utilized VR locomotion technique, and is categorized as controller-based locomotion. Both of these techniques are representative in the natural (WIP) and artificial (joystick) VR locomotion interaction types. As both techniques have a smooth and uninterrupted movement when in use, both WIP and joystick are considered a continuous motion type.

The teleportation technique is among the dominant locomotion techniques in VR which are utilized in many VR games and applications (Boletsis, 2017, p. 10). In the recent studies, teleportation has only been examined in 3 articles, proving that this technique has been overseen by many researchers. Teleportation is considered as an artificial interaction type as no physical movement is required. Due to the nature of teleportation-based VR locomotion techniques, it provides a non-continuous movement due to the instant motion. Given that teleportation is a well adopted VR locomotion technique in current VR games and applications, this should be a subject of examination.

2.6 Our study on VR locomotion

Based on the literature review conducted on VR locomotion in section 2.5, we wish to fill the research gap discussed in section 2.4 related to the missing empirical evaluation of UX and usability in the field by utilizing the currently most prevalent VR locomotion techniques. The reviewed articles showed that WIP and joystick techniques are widely examined. Furthermore, teleportation seemed to be ignored by researchers despite this being a common technique in current VR-software (Boletsis, 2017, p. 10). This addresses RQ1, in which WIP, joystick and teleportation was selected for examination in this study.
Looking at the highlighted version of the VR locomotion typology in figure 2.10, these techniques cover the majority of the categories. The techniques to be examined covers both the artificial and physical interaction types, are represented in both continuous and non-continuous motion types categories, as well as facilitating for traversing open VR interaction spaces which we utilized in our study. An open VR interaction space implies that the virtual environment potentially can be bigger than the real environment. An empirical and comparative evaluation was conducted with the main objective to compare the UX and usability of these prevalent VR locomotion techniques. Additionally, these techniques can be utilized without any additional peripherals besides the recent standalone VR-systems in the market.

The empirical study included both quantitative and quantitative data to examine and compare the UX and usability related to the VR locomotion techniques. To examine this, we utilized validated questionnaires related to game experiences and usability, as well as interviews to get an in-depth understanding of the user experience. Through statistical analysis and coding of the data, we were able to find remarks related to the UX and usability of each locomotion technique. The result of this study can contribute to the field of VR locomotion by providing comparative empirical work which shed light on the current interaction issues. This knowledge can support future constructive work, and increase the problem-solving capacity in the field (Oulasvirta and Hornbæk, 2016, p. 4962-4965).
2.6. OUR STUDY ON VR LOCOMOTION

Figure 2.11: An overview of important work within the field of VR locomotion.
Chapter 3

Tools and techniques

To be able to examine the VR locomotion techniques discussed in section 2.6, we utilized current well established VR-technology. This chapter will cover the hardware used in this study, the use and implementation of the examined VR locomotion techniques and the virtual environment utilized in this study.

3.1 HTC Vive

With the current technologies in mind, we decided for this study to use the HTC Vive. This VR-system provided an all-in-one solution without the need for any additional peripherals to utilize the techniques we examined, and is supported by a wide range of software (HTC Corporation, 2018). By utilizing all-in-one solutions which are well developed and established, the results of the study could be more easily applicable to a wider range of adopted technology.

The HTC Vive is well established in the VR consumer market, and allows for high fidelity graphics with 2160*1200 resolution displays, 90Hz refresh rate to prevent any lag, 110° wide field of view, full 360° roomscale body tracking with the included Lighthouse infrared sensors, and arm interaction with the included Vive Controllers. In addition, this system supports the Vive Tracker which can track physical objects into the virtual environment.
and movement of specific body parts like the users feet.

![Image of HTC Vive and Vive Controllers](image1)

**Figure 3.1:** The HTC Vive and Vive Controllers used in the study.

![Image of Vive Tracker attached to the foot](image2)

**Figure 3.2:** The Vive Tracker attached to the foot

### 3.1.1 Desktop computer

To make sure the experience with the HTC Vive was fluently, we made sure to utilize hardware powerful enough to get the best experience. The desktop
computer had a MSI GTX1080 GPU, Intel i7-6700K CPU, 16GB of DDR4 2400Mhz RAM and a MSI Z270 Gaming Pro motherboard.

3.2 Techniques to be examined

The joystick and WIP techniques were conducted in a VR-software named Freedom Locomotion developed by Huge Robot (Huge Robot, 2018). The teleportation technique was conducted in Modbox developed by Alien Trap (Alien Trap, 2018). Both applications ran with the HTC Vive system using the same virtual environment for all techniques. Both applications are available on the Steam gaming platform on PC (Valve Corporation, 2018).

Joystick  The user utilizes a physical controller or gamepad with a joystick as input device to execute the movement.

With the HTC Vive system, we used the included Vive Controllers as an input device. This controller has a touch-pad which has the same joystick-functionality as a traditional gamepad. The positioning of the thumb on the touch-pad can regulate the speed of movement. The in-game settings for speed were set to resemble the same speed as when walking or running in real life to facilitate for a natural experience. The direction of movement is determined by the direction of the Vive Controllers and is shown by an arrow in the HMD interface. To change the direction of movement, the user has to turn their body into the desired direction physically.
Teleportation  This technique allows the user to move through the virtual environment by pointing at the desired location to instantaneously move to this location.

In the current implementation, the teleportation uses the Vive Controller as an input device for pointing to the desired location. On the controllers, there are two buttons located in the grip of the controller which have to be pushed to activate the technique. When pushed, a ray followed by a marker on the ground in the virtual environment will appear as a visual cue which indicated the location of movement (see figure 3.5). The possible range of this location is limited so the user can’t teleport across the virtual environment in one action. The instant movement is executed by releasing the buttons on the controller. The standing direction of the user determines the direction of teleportation.
3.2. TECHNIQUES TO BE EXAMINED

Figure 3.4: The layout of the HTC Vive controller with track-pad on top and button for teleportation visible at the grip.

Figure 3.5: A marker shows where the user will be teleported when the button is released.
CHAPTER 3. TOOLS AND TECHNIQUES

**WIP**  This technique requires the user to physically step in place in the physical room to execute the movement in the virtual environment.

This implementation of WIP utilizes the Vive HMD and the Vive Controllers to track the movement. By walking in place, the software will determine the pace of the steps and the movement of the arms to adjust the virtual movement speed in accordance with this. If the user decides to run in place, the movement speed increases accordingly. The in-game settings of the speed were set to resemble the same speed as when walking or running in real life to facilitate a natural experience. The direction of movement is determined by the standing direction of the user in the physical room. Due to the integration of the WIP technique in Freedom Locomotion where only the movement of the HMD and controllers are tracked, the Vive Tracker was used as a dummy for a "Wizard of Oz" approach to motivate the user to move their feet (Rogers et al., 2015, p. 391).

![Example of WIP in action.](image)

Figure 3.6: Example of WIP in action.
3.3 The virtual environment

The virtual environment used for the experiment was an urban city environment named *Simple Town* made by Synty Studios (2016). This city is varied with multiple assets and interesting locations for the user to navigate and locate while utilizing the different locomotion techniques. The graphical style is simplistic and cartoon-inspired, so the users easily could navigate and focus on the task at hand. Simple Town is an asset-pack with a collection of 3D models and a pre-made city which is implemented in both Freedom Locomotion and Modbox.

Figure 3.7: An overview of Synty Studios ”Simple Town” (Synty Studios, 2016)
Chapter 4

Methodology

As we examined, compared and evaluated the UX and usability of the VR locomotion techniques discussed in section 2.6, our hypothesis was formulated as follows:

**Hypothesis:** The examined VR locomotion techniques show statistically significant differences in aspects related to UX and usability for open VR interaction spaces.

The methodology included both qualitative and quantitative data. An empirical examination of the three VR locomotion techniques was conducted as three scenarios. The study had a within-group design where each participant completed four tasks within three scenarios in total (Lazar et al., 2010, p. 46). Each scenario was immediately followed by a questionnaire, and a semi-structured interview was conducted at the end of the procedure. The results from the questionnaire was analyzed through statistical analysis methods, and the interviews was analyzed through open and axial coding.
CHAPTER 4. METHODOLOGY

4.1 Participants

For the empirical study, the participants were selected through convenience sampling based on ease of access and their availability (Rogers et al., 2015, p. 228). This consisted of students from the University of Oslo, but also participants in the Oslo-area in general in various age-groups. The inclusion criteria were people to be able to utilize VR-technology, regardless of age or previous experience with the technology. We made sure to have enough participants to get a valid and feasible result by eliminating the noise in the quantitative data caused by the individual variations of each participant during the study (Lazar et al., 2010, p. 57). When recruiting, the participants got as little information as possible about the execution of the experiment beforehand to avoid any possible bias. After the participants had completed the study, they received a universal gift card as an appreciation of attending the study.

4.2 Procedure

The total duration of the study was set to be up to 1 hour and 50 minutes per participant including a short break. The study had three main components; the scenarios, the questionnaires, and the interview distributed in the time-slots shown in figure 4.1. The first part of the study was an introduction which included the consent form, practical information and filling out the demographics (see appendix B and E). Following, the participant got informed about how they were supposed to execute each scenario. As for the information given to the participants, we followed a script with detailed instructions to make sure the wording was consistent for every participant (see appendix C). This is critical to avoid any systematic errors caused by procedure bias (Lazar et al., 2010, p. 60). Variation in how the instruction is provided could cause differences in interpretation or performance which could lead to low reliability of the results.
4.2. PROCEDURE

Figure 4.1: An overview of the procedure of this study.
CHAPTER 4. METHODOLOGY

4.2.1 Scenarios

The empirical study consisted of one scenario for each locomotion technique in VR, resulting in three scenarios in total. Each scenario contained four tasks for the participant to complete sequentially in the virtual environment Simple Town. For each task, the participant was asked to locate a point of interest in the virtual environment, also named checkpoints. If the participant found all the checkpoints or spent 15 minutes in the virtual environment in total during a session, we would stop them and continue the procedure. Using tasks like checkpoints or point of interests has been a common practice in multiple empirical studies on locomotion in VR as this is useful to evaluate the techniques (Nabiyouni et al., 2015; Kitson et al., 2017; Ruder et al., 2017; Bozgeyikli et al., 2016). Such tasks put the user within a user context when utilizing VR locomotion, and keeps the participant focused on the virtual environment.

The various checkpoints were selected based on unique locations and monuments such as pictured in figure 4.3 and 4.4. We also made sure that each checkpoint for each scenario had approximately the same distance in between, so the difficulty level was the same for each task. These were picked by using an overview-screenshot of Simple Town and measuring the distance in between each checkpoint (see figure 4.2). The checkpoints were set in a specific order to make sure the distance between each checkpoint was approximately equal. As the same virtual environment was used for each scenario, there was a chance of learning effect. To avoid this issue, we chose to randomize the order in which each participant conducted the scenarios to get "a clean comparison between the experiment conditions" (Lazar et al., 2010, p. 28). When multiple participants conducted each scenario in a random order, the noise caused by the learning effect would be eliminated.

The locomotion technique utilized was demonstrated before each scenario. After the demonstration, the participant would be able to try out the locomotion technique themselves for up to five minutes, or until they told us that they were ready to continue. The tasks were presented after the demonstration and trial in a set order for them to locate.
Figure 4.2: Overview of Simple Town with the planned routes indicated as lines and checkpoints as circles.

The participant was told to perform the tasks in the given order and find as many checkpoints as they could manage within 15 minutes. When they reached a checkpoint, we would let them know by telling them to continue to the next checkpoint. If the participant had any questions during the study, they were allowed to ask while they were in the virtual environment. However, we did not provide any information regarding where the checkpoints were located.
CHAPTER 4. METHODOLOGY

Figure 4.3: Example of checkpoint 1 and 2.

Figure 4.4: Example of checkpoint 3 and 4.
4.3.2 Pilot

To make sure the main study could be executed as planned, it was important to conduct a preliminary pilot prior to the main study. During the pilot study, we made sure to identify any possible bias and fix potential mistakes which could be overlooked during the preparation (Lazar et al., 2010, p. 60). The pilot was executed exactly like the main study, following the procedure. We also examined the VR locomotion settings to make sure these were feasible.

4.3 Collected data

Following each scenario with the VR locomotion techniques, a questionnaire was answered by the participants to gather quantitative data about the UX and usability (see appendix F for questionnaire). The questionnaire was based on the Game Experience Questionnaire (GEQ) and the System Usability Scale (SUS) (IJsselsteijn et al., 2008; Brooke et al., 1996). The questionnaire also allowed the participants to fill out a free form so they could elaborate on their answers. These qualitative answers were discussed further during the following interview.

4.3.1 Game Experience Questionnaire (GEQ)

The GEQ has previously been used to examine the UX of various applications including games, virtual reality and augmented reality software due to its wide range of experiential factors providing good reliability (Nabioyuni and Bowman, 2015; Lee et al., 2012; Poels et al., 2007). The GEQ intends to give researchers a tool to get reliable and valid measures of "participants subjective experiences associated with digital gameplay" (Poels et al., 2007, p. 4).

The GEQ consists of three modules: The core questionnaire (GEQ) which is related to the in-game experience, the post-game questionnaire (PGQ) which relates to the experience after the gaming session and the following after effects, and finally the social presence module (SPGQ) which is about the participants experience and involvement with other co-player(s). In our
study, we only evaluated the participants by combining the GEQ-module with the PGQ-module. The SPGQ module was not relevant to our study as there were no co-players involved.

To calculate the score for each component in the GEQ, one must find the mean value of each item taken from the questionnaire. Each participant answered each item in the questionnaire with a Likert-scale from 0 to 4. The mean value for each component can be interpreted as "not at all" for 0, "slightly" for 1, "moderately" for 2, "fairly" for 3 and "extremely" for 4. The selection of the components we examined is mainly from the GEQ in-game module in addition to two components from the post-game module. Each component and the associated items are listed in appendix D.

Two non-parametric statistical methods were applied to the data to be able to determine any significant differences related to the UX in the GEQ components. The first method was the Friedman test which showed if there were any overall statistically significant differences between the three examined VR locomotion techniques. As a post hoc analysis, Wilcoxon signed rank test was applied for a pair-wise comparison to identify where the specific differences were located. If there were statistically significant differences, these were examined further through the data from the interviews. These methods were applied to the data with the use of Statistical Package for Social Sciences (SPSS). The significance level was set to $p < 0.05$ meaning that the result only had a 5% possibility of happening by chance (Lazar et al., 2010, p. 32).

4.3.2 System Usability Scale (SUS)

SUS is a questionnaire commonly used to quickly get a quantitative measurement of the usability of computer systems during an evaluation session (Brooke, 2013). SUS is freely available and is considered to be the industry standard for usability testing.

Each item in the SUS-questionnaire is presented as a Likert-scale ranging from 0 to 4. To calculate the actual SUS score, there must be conducted two calculations which result in a final score between 0 and 100. As we applied
4.3. COLLECTED DATA

the SUS calculations for each participant, a mean SUS score per technique will be presented. Hence that this score is not a percentage, but a percentile meaning how many percent of other systems are below the measured system (Brooke, 2013, p. 36). For instance; a SUS-score of 80 means that the evaluated system has a score higher than 80% of other systems. As the average is a score of 68, a system with the score of 70 would be at or around the 50th percentile (Sauro, 2011, p. 36). The SUS-score can be converted into a grade scale ranging from F being the worst imaginable to A being the best imaginable as illustrated in figure 4.5.

![Figure 4.5: The SUS-score system Brooke (2013)](image)

4.3.3 Interviews

After all three scenarios had been completed, a semi-structured interview with the participant was useful for additional qualitative data to get a more in-depth understanding of the underlying thoughts during the empirical study. The interview mainly consisted of open-ended questions which resulted in a conversation about the experience and usability of each VR locomotion technique. Our approach to the study had similarities to Kitson et al. (2017) who conducted both a questionnaire and an interview to support the empirical study related to specific aspects of usability and UX in VR for a richer understanding (Kitson et al., 2017, p. 4). The interview was semi-structured to be able to discuss and explore the thoughts of the participant, a few questions
were used as a guideline through the interview (see appendix A for interview guideline).

Both the free form in the questionnaires and the in-depth semi-structured interviews provided qualitative data. This resulted in a set of sentences based on the free form and notes from the interviews representing the experience from each participant. Analysis of this data was conducted through open coding to create labels related to the various themes, followed by axial coding to reveal relations and create higher thematic categories of the UX from these labels (Crang and Cook, 2007, p. 132-149). Following this, a visual representation of the qualitative data was made by putting the frequency of each category into a chart. This way, it was possible to see where it was a consensus about the UX and usability for each locomotion technique.

4.3.4 Scenario completion time

During each scenario, we collected some measures from the participants for additional quantitative data. These measures were records of the participants time spent on the trial and the total time spent with each locomotion technique. Based on these measures we calculated the mean completion time of the trial and the total completion time for each scenario. This result was only used to examine if there could be any correlation between the usability, the UX and the mean time spent on each VR locomotion technique.

4.4 Research ethics

During the whole study, we followed the law according to the Norwegian Personal Data Act, chapter 2, §8 which covers the possession of personal data, how to store it, and the need for the participants to have freely given consent of participation through a consent form (Personopplysningsloven, 2015). During the study, we did not collect or store any sensitive personal data from the participants as this was not necessary for our study.

To make sure the interest of both the study and the participant were protected, an informed consent form (see appendix B) was reviewed and
signed by the participants before the experiment began to confirm consensus (Rogers et al., 2015, p. 228). The form consisted of a summary of the study including the whole process, information about the data that would be collected, as well as the participants’ rights as being a part of the study. This includes the possibility to quit the experiment whenever the participant wish to do so, and the right to decline the use of any provided data from the current session at any given time. Additionally, the form made the participants aware of possible negative effects of using VR, like nausea and motion sickness.
Chapter 5

Results

The result from the pilot was proven useful to plan the main study ahead. The results from the main study provided a comprehensive data-set to be analyzed through statistical analysis and coding. This chapter will cover all the results from the empirical study including the analysis.

5.1 Pilot study results

The result of the pilot study gave positive results and feedback. The pilot participant said that the procedure worked well and the virtual environment in combination with the locomotion techniques had nice variation during the scenarios. There was no sign of fatigue during the process including the five minute break. The VR locomotion settings for the joystick and WIP proved be suitable for the tasks, but calibration of the participant height prior to the execution of the WIP-scenario was important. The trial of the WIP-technique showed that a bad calibration of the height could affect the continuous speed of the technique. Other factors noted was the questionnaire which mostly worked well. Some of the words during the questionnaire such as "cumbersome" was asked to be defined, so it was important to have a consistent definition of such words to avoid misinterpretation.

Overall, the pilot study performed satisfactory. It did make us aware of some important factors such as calibration of the software and definition of
CHAPTER 5. RESULTS

some words during the questionnaire, but the results showed no need for any significant changes to the procedure or to the VR locomotion settings.

5.2 Main study results

As the pilot study showed good results, we kept the settings and procedure as planned. The participants were gathered on the go during the duration of the empirical study which was four weeks.

5.2.1 Demographics

In total, 24 participants contributed to the study. The mean age of the participants was 25.26 (SD: 5.08), where 63% were male, and 38% female. As for previous experience with VR-technology, 40% had tried it only once before, 36% had tried it a few times, and 20% hadn’t any experience at all. Only 4% (1 participant) used VR on a regular basis.

<table>
<thead>
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<th>Value</th>
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</tr>
<tr>
<td></td>
<td>Only once: 9</td>
</tr>
<tr>
<td></td>
<td>A few times: 9</td>
</tr>
<tr>
<td></td>
<td>Using VR all the time: 1</td>
</tr>
</tbody>
</table>

Table 5.1: Overview of demographics.
5.2. MAIN STUDY RESULTS

5.2.2 Scenario Completion Time

Looking at the mean values trial and scenario completion time, WIP had the highest mean value at 81.3 seconds trial (SD: 59.5) and 641 seconds total completion time (SD: 200.4). Following is joystick with a mean value of 59.6 seconds for the trial (SD: 50.2), and 330.6 seconds for the total completion time (SD: 108.7). Teleportation had the lowest mean values at 54.6 seconds trial (SD: 39.7) and 296.1 seconds total completion time (SD: 128.2).

Figure 5.1: Participants’ previous experience with VR.

Figure 5.2: The mean trial and total completion time of each scenario in seconds.
CHAPTER 5. RESULTS

5.2.3 Game Experience Questionnaire

The mean values of each GEQ component are presented in figure 5.3, and the statistical analysis is presented below. The result of the Friedman test is presented first, followed by the post hoc Wilcoxon signed rank test. A total overview of the Wilcoxon tests is presented in table 5.2.

**Competence**  The Friedman test indicated a difference in the Competence component, $X^2(2) = 14.073, p = 0.022$. A post hoc analysis using Wilcoxon signed-rank tests indicated significant differences when comparing the Competence of WIP & teleport ($Z = -3.033, p = 0.002$) in favor of teleport with a mean rank score of 11.88, and WIP & joystick ($Z = -2.478, p = 0.013$) in favor of WIP with a mean rank score of 13.17.

**Sensory and Imaginative Immersion**  The Friedman test indicated no differences in the Sensory and Imaginative Immersion component between the three techniques, $X^2(2) = 4.216, p = 0.121$.

**Flow**  There was found no statistically significant differences in the Flow component between the three techniques. However, the WIP & joy-
stick pair came close to the significance level ($Z = -1.858, p = 0.063$) in favor of joystick with a mean rank score of 12.83.

**Tension** The Friedman test indicated no differences in the Tension component between the three techniques, $X^2(2) = 3.138, p = 0.208$.

**Challenge** The Friedman test indicated a difference for the Challenge component, $X^2(2) = 30.860, p < 0.001$. The post hoc analysis indicated significant differences between WIP & teleport ($Z = -4.041, p < 0.001$) in favor of teleport with a mean rank score of 3.00, and WIP & joystick ($Z = -4.220, p < 0.001$) in favor of joystick with a mean rank score of 0.00. Note that a lower mean rank score means less challenge in this component.

**Negative Affects** The Friedman test indicated a difference in the Negative Affects component, $X^2(2) = 12.184, p = 0.002$. The post hoc analysis indicated significant differences in a pair-wise comparison between WIP & joystick ($Z = -3.642, p < 0.001$) in favor of joystick with a mean rank score of 4.00. A lower mean rank score is considered better.

**Positive Affects** The Friedman test indicated no differences in the Positive Affects component between the three techniques, $X^2(2) = 0.816, p = 0.665$.

**Tiredness** The Friedman test indicated a difference in the Tiredness component, $X^2(2) = 21.802, p < 0.001$. The post hoc analysis indicated significant differences in pair-wise comparison between WIP & teleport ($Z = -2.967, p = 0.003$) in favor of teleport with a mean rank score of 8.20, and WIP & joystick ($Z = -4.055, p = 0.000$) in favor of joystick with a mean rank score of 0.00. A lower mean rank score is considered better.

**Return to Reality** The Friedman test indicated a statistically significant difference in the Returning to Reality component, $X^2(2) = 23.455, p < 0.001$. The post hoc anal-
CHAPTER 5. RESULTS

Analysis indicated significant differences in pair-wise comparison between WIP & teleport ($Z = -3.832, p < 0.001$) in favor of WIP with a mean rank score of 10.00, WIP & joystick ($Z = -2.869, p = 0.004$) in favor of WIP with a mean rank score of 11.34 and finally teleport & joystick ($Z = -2.961, p = 0.003$) in favor of joystick with a mean rank score of 9.62.

<table>
<thead>
<tr>
<th>Component</th>
<th>Technique</th>
<th>Mean Rank</th>
<th>Z</th>
<th>Sig. (2-tailed)</th>
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<tr>
<td>Competence</td>
<td>WIP &lt;Teleport</td>
<td>7.25 &lt;11.88</td>
<td>-3.033</td>
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<td>9.73 &gt;8.90</td>
<td>-1.834</td>
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</tr>
<tr>
<td></td>
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<td>8.18 &lt;9.20</td>
<td>-1.183</td>
<td>0.237</td>
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<tr>
<td></td>
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<td>-0.291</td>
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<td>Immersion</td>
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<tr>
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<td>7.83 &lt;8.25</td>
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<td></td>
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<td>-1.594</td>
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<td></td>
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<td>Tension</td>
<td>WIP &lt;Teleport</td>
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<td>0.000</td>
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<tr>
<td></td>
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<td>-4.220</td>
<td>0.000</td>
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<td></td>
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<td>9.19 &gt;7.81</td>
<td>-0.290</td>
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<td>-0.047</td>
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<td>WIP &gt;Teleport</td>
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<td>-3.832</td>
<td>0.000</td>
</tr>
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<td>Reality</td>
<td>Joystick &gt;Teleport</td>
<td>9.62 &gt;3.67</td>
<td>-2.961</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Table 5.2: Summary of the Wilcoxon signed rank tests.
5.2. MAIN STUDY RESULTS

5.2.4 System Usability Scale

After calculating the mean SUS score, the joystick technique had the highest score at 84.48 (SD: 8.62), followed by Teleportation at 82.92 (SD: 9.10). Both these techniques falls into grade B in the SUS Grade Scale which is considered "excellent" and within "acceptable" range. The WIP technique had the lowest SUS score at 67.60, (SD: 17.26) falling into grade D as "ok". This is just within the marginal acceptance range according to the SUS score system.

<table>
<thead>
<tr>
<th>Locomotion technique</th>
<th>SUS Score</th>
<th>SUS Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joystick</td>
<td>84.48</td>
<td>B - Excellent</td>
</tr>
<tr>
<td>Teleportation</td>
<td>82.92</td>
<td>B - Excellent</td>
</tr>
<tr>
<td>WIP</td>
<td>67.60</td>
<td>D - OK</td>
</tr>
</tbody>
</table>

Table 5.3: The mean SUS Score for each technique.

5.2.5 Interview data

The qualitative data was first analyzed through open coding, followed by axial coding to find the higher thematic categories related to the UX and usability. During this process, five main categories emerged related to; how fast it was in use, the comfort, if the implementation was good, the degree of immersion and how easy it was to use. Each of the categories is divided into positive and negative aspects for each technique. The categories are defined as followed:

**It was fast/slow in use**  This category covers whether the participants found the technique to be fast and effective in terms of speed. Comments like "The speed was ok, but I wish it were faster." could be put into this category.

**It was comfortable/tiresome to use**  How the participant experienced the technique. This includes any emotional effects, as well as negative effects like motion sickness, tiredness or disorientation. Comments like "It
made me a bit motion sick, it felt artificial [...]” could be put into this category.

**The implementation was good/bad** This category has a more technical focus related to the technical implementation and usability of the technique. Comments like "WIP was nice because I had much control over the speed, and it was very sensitive to movement.” could be put into this category.

**It provided high/low immersion** At what degree the participant felt a presence in the virtual environment due to the technique utilized. This is mainly emphasized on how the technique itself allows for immersion and not general immersion in VR. Comments like "It was the least immersive experience because I felt like an observer [...]” could be put into this category.

**It was easy/difficult to use** This category is about how the participant experienced the use of the technique. This includes the ease of use and how to approach to execute the movement. Comments like "Joystick was easy, intuitive and familiar because I’ve been playing with gamepads before.” could be put into this category.

To be able to visualize the result of this analysis, each category with their subcategories are put into a chart for each locomotion technique and the frequency of each category in figure 5.4.
Figure 5.4: Frequencies of categories coded from the qualitative data.

Looking at chart 5.4 beginning from the left, teleportation had the most positive feedback when it comes to the speed of the technique. The data suggest that this technique was very effective in use as the movement was instant. Both WIP and joystick had a more negative impact on this category as it was said that these techniques could be slow in use.

As for the comfort during use, the joystick technique was said to provide the overall best comfort followed by WIP. However, we also see that WIP had the most issues when it comes to this category. The data indicated that WIP could make the participant dizzy as well as it was the most tiresome technique due to the physical movement. Joystick still had the lowest frequency of discomfort and tiredness.

As for the most intuitive technique, WIP was said to have the most exciting implementation which resembled a natural movement. Additionally, the possibility to control the speed by changing the pace of the physical movement was appreciated. Meanwhile, the data suggests that teleportation had the most negative implementation due to the blinking between each transition. This was said to be very tiresome for the eyes after a while.

For immersion, WIP had the highest frequency as the movement was natural and resembled real life motion. The negative feedback on WIP is
slightly higher than teleportation, due to the fact that the participants often tended to physically move away from their standing spot in the room. This made the participants be more aware of objects and the wall in the physical room, in fear of colliding. This had an impact on the overall immersive experience. Teleportation had the lowest frequency of positive feedback and high on the negative feedback. It was said that the instant transition of the technique affected the immersion negatively.

The joystick technique was considered the easiest technique to use. The implementation was said to be simple and intuitive, and it had similarities to traditional gamepads. Teleportation was also considered as an easy to use technique due to the low effort of pointing and clicking. WIP was considered to have a steeper learning curve compared to the other techniques.

5.2.6 Summary of results

Looking into the overall result of the statistical analysis of the GEQ, the result from the SUS and the data coded from the interviews, it shows multiple differences between each examined VR locomotion technique. As the examined VR locomotion techniques show statistically significant differences in aspects related to UX and usability for open VR interaction spaces, the hypothesis set in Chapter 4 can be confirmed.
Chapter 6

Discussion

The data collected through the GEQ, SUS, and interviews provided a useful data-set related UX and usability for all the examined VR locomotion techniques. We will discuss the data per technique (addressing RQ2 and RQ3) followed by a comparative examination of all the techniques (addressing RQ4). The quotes from the participants are referenced as ”P” followed by their participant number.

6.1 Teleportation

Teleportation was considered easy to use with a simple implementation which provided an effective and rapid movement through the virtual environment. However, overall the technique got mixed feedback due to the effect of the rapid movement.

Looking at the high value of the Negative Affects component, this could indicate that teleportation did not provide an overall satisfactory experience (RQ2). The non-continuous motion of the technique resulted in a short blinking of the screen between each transition from location to location. This effect was considered tiresome over time which also seems to have affected the Tiredness component where the values are somewhat high. This non-continuous motion is considered an artificial VR locomotion type (see figure
2.9 for typology), which does not involve any natural or physical interaction to traverse the virtual environment. This could affect the immersion during use due to the unnatural interaction which is reflected in a low value of the Return to Reality component. It could suggest that the participants got removed from the immersion during the process because of the nature of the technique. This can arguably highlight some of the weaknesses related to artificial non-continuous VR locomotion where little physical or natural interaction is emphasized to execute the movement. Overall, the participants found the technique to be easy to learn and intuitive to use in the open VR environment, as indicated by a high value in the Competence component. The point and click nature of the technique also reflects on to the Challenge component which shows that the technique itself did not provide any additional challenge when traversing the virtual environment. This would in practice allow the user to rapidly move through the virtual environment due to the instant motion and low effort.

Despite the seemingly negative overall experience, teleportation shows positive results regarding usability (RQ3). The fact that the user can point to a location and instantly move there by a push of a button is a simple implementation of movement which requires little effort to execute. The implementation also has a visual cue which indicated where the user will move to, something that adds to the precision of the controller. The result of this shows good usability with a SUS score of 82.92. This gives teleportation a grade B, meaning the usability of this technique is acceptable within the SUS.

The good usability can also be reflected in the completion times. The mean completion time of the trial was the lowest at 54.6 seconds. The total mean time was also low at 296.1 seconds which could indicate that the technique allows for an effective movement through the virtual environment to solve the tasks quickly.

During the interviews, a few important remarks were made by the participants. As mentioned earlier regarding the blinking in between each transition, many participants expressed their dissatisfaction about this. As the technique would allow the participant to move by pointing and clicking
through the environment rapidly, this transition was said to get tiresome over time (as shown by the Tiredness GEQ component). Whether this is an issue for non-continuous VR locomotion techniques in general needs closer examination, but one participant suggested a more "smooth" transition to address this issue.

- "It had too much blinking while moving which was tiresome.” [P11]

- "When moving, it was also too flashy, so it would be nice to have a smoother movement.” [P18]

In addition, there was a set limitation to the range of the selected location of movement. This limitation was pointed out by a few participants and was considered to be too short. A desire of an extended range for the teleportation was expressed more than once to be able to teleport even further. This could have a correlation with the tiresome transition due to a short range. In sum, the overall expression regarding these issues is that the participants want to maintain the effective movement but reduce the need for frequent transitions in between each movement. If the range was longer, it could lead to fewer transitions and still maintain an effective movement which could result in a better experience.

- "Teleporting had way too short range, and the blinking was very tiresome for my eyes.” [P22]

- Teleportation has much potential, but a better range would be nice because now it was too much clicking. [P23]

Among the more discussed topics during the interviews was the degree of immersion this technique provided. As this technique is categorized as an artificial VR locomotion type with non-continuous movement, the interaction
CHAPTER 6. DISCUSSION

does not require any physical movement from the user. It was stated that pointing and clicking with an instant transition was an unnatural and static way of movement. It is arguably not necessarily the immersion itself which is essential to be able to solve tasks in VR, but it does affect parts of the overall experience (as stated regarding the Return to Reality GEQ component for teleportation). Some of the participants suggested that teleportation would be more fitting if the virtual environment were designed for this type of VR locomotion technique, with less emphasis on providing an immersive experience. This could suggest that it’s contradictory to strive for an overall high immersive experience if teleportation is utilized as the primary VR locomotion technique.

- "Teleportation was like navigating Google Maps. It was the least immersive experience because I felt like an observer [...]” [P2]

- "[...] suitable for puzzles where you don’t have to be that immersed.” [P7]

- "I think teleportation is useful for specific type of tasks, and especially in software which is designed around teleportation as locomotion technique.” [P10]

- "[...] it all felt like a slideshow.” [P22]

The participants were positive towards the ease of use and low effort with the technique, as indicated by the GEQ as well. The simple implementation seemed to be beneficial to solve the tasks effectively, and the participants appreciated to be able to move rapidly. Despite the negative effects the rapid movement resulted in, the rapid movement was also an aspect which was considered important to the overall experience during use. Furthermore, the ability to point exactly where you want to move was precise and added to the feeling of control. This precision was considered positive by the participants.
and could provide to the high values in the Competence GEQ component in addition to the ease of use.

- "Teleport was my favorite. It was easy and simple to navigate around." [P9]

- "Teleporting was the best because it was easy to use, basic and intuitive." [P16]

- "Teleportation was the easiest technique where I felt I had the best control over the movement." [P18]

6.1.1 Remarks from teleportation

The teleportation technique provided some aspects related to UX which were considered important to the participants (addressing RQ2 for teleportation) and overall good usability (addressing RQ3 for teleportation). The following remarks were made for this technique:

1. Easy to learn and use due to simple and precise controls.

2. Effective movement through the virtual environment to solve the tasks.

3. Rapid movement caused a tiresome transition between each execution of the teleportation due to the non-continuous motion type.

4. Limited range of the teleportation caused many sequential transitions.

5. Provided overall low immersion due to the artificial interaction and non-continuous motion type.

6.2 Joystick

The joystick-technique was according to the results easy to use and was familiar to traditional gamepads. The main issues were related to the speed of
movement and the continuous motion.

As this technique builds upon the interaction of traditional gamepads with joysticks, it was considered simple and familiar in use resulting in an overall good experience (RQ2). This is indicated by high values in both the Competence and Positive Affects components of the GEQ, indicating an overall satisfactory experience. The simplicity of the implementation also reflects on to the Tiredness component which has a low value next to the Negative Affects. In sum, this could suggest that an implementation based on already established interactions and traditional controller-schemes could be beneficial. The fact that the joystick techniques are widely examined and compared to other VR locomotion techniques can indicate that this type of technique is considered a benchmark of locomotion in virtual environments (see section 2.5 for literature review). This also gets reflected by a high mean SUS score of 84.48 with a grade B, making the usability of this technique acceptable (RQ3). The results of the GEQ and SUS could indicate that the joystick technique has important qualities appreciated by the users which should be further examined through the interview data.

The mean scenario completion time for joystick show rather fast results. The mean completion time of the trial was 59.6 seconds, while the total mean completion time was 330.6. However, despite the low mean scenario completion times, the speed of the technique was considered an issue during use.

In the interview data, many participants claimed that the speed of this technique was too slow in general. Even if they chose to move faster by adjusting the movement speed, it eventually got unnecessarily time-consuming to explore and get from checkpoint to checkpoint which provides a less enjoyable experience. By increasing the general speed of the technique itself or add better controls to regulate the speed, this issue could most likely be addressed.

- "Joystick was a bit slow and linear and wasn’t much fun.” [P6]
6.2. JOYSTICK

- "Joystick was ok, but I wish it were a little faster. I didn’t feel much difference in speed when clicking the trackpad.” [P13]

- "It’s nice for exploring, and I would use this technique again if I had to. However, I wanted it to go faster.” [P20]

The joystick-technique is categorized as an artificial and continuous VR locomotion technique where an uninterrupted movement is executed by an input device (see figure 2.5 for typology). However, there seems to be a disagreement between the participants whether the continuous motion of the joystick-technique provides a positive or negative experience. Some participants found the continuous motion to be nice because it was comfortable in use and even added to the immersion. Others got affected negatively by experiencing dizziness or slightly motion sickness. By having a continuous motion in the virtual environment while physically standing still could result in a disconnect between the physical body and the perceived motion resulting in the said negative effects. Whether this correlates to a combination of artificial interaction and continuous motion should also be further examined. This issue is not clear by looking at the Negative Affects component of the GEQ exclusively but was noticeable during the interviews.

- "Was little effort, comfortable movement almost like flying, [...] and didn’t feel dizzy.” [P1]

- "It was nice to be able to stand still while still being able to move in VR.” [P15]

- "It made me a bit motion sick, it felt artificial. [P10]

- "[..] by looking around while moving, I got dizzy.” [P12]
The technique was said to be overall intuitive, easy to use and low effort with the added benefit of the familiarity to traditional gamepads. For some participants, this familiarity provided a natural way to interact with virtual environments in general, including non-VR environments. This familiarity, however, is very dependent on the previous experience the participant has with traditional gamepads. The familiarity and ease of use seem to be important factors in which results in an enjoyable experience overall as indicated by the GEQ. One could argue that this familiarity in combination with the continuous motion could provide a better immersion as well because the user can focus more on the virtual environment and the task at hand rather than a complex implementation and how to utilize this.

- For me, it felt natural and familiar because I’ve been playing with gamepads before. It was easy to learn, and the best way to explore the environment. [P14]

- "/.../ easy, intuitive and familiar because I’ve been playing with gamepads before. It also provided a good immersion." [P21]

### 6.2.1 Remarks from joystick

The participants were overall satisfied with the joystick technique. It provided some well-appreciated aspects to the UX (addressing RQ2 for joystick), and showed positive results in terms of usability (addressing RQ3 for joystick). The following remarks were made for this technique:

1. Intuitive and easy to use controls.

2. Benefit of building upon traditional game controllers.

3. A continuous motion type added to the immersion and provided a comfortable experience for some.

4. Participants found the technique general set speed to be too slow. Limitations in terms of speed control.
5. The continuous motion made some participants dizzy and slightly motion sick.

6.3 WIP

The participants found WIP to provide the best immersion overall due to the natural interaction of physical movement, but it was also the most tiresome and challenging technique during use.

As the WIP technique requires the need for physical motion by tapping in place to execute the movement, this seems to provide a high degree of cognitive load which affected the overall experience (RQ2). By looking at the high value of the Challenge component and slightly low value of the Competence component, the participants found this technique to be a bit difficult to utilize and master correctly. This also indicates an effect on both the Negative Affects and Tiredness components, suggesting an overall negative experience due to the high effort required to traverse the virtual environment. However, WIP can be considered a technique which includes natural elements to the movement with the physical interaction and continuous movement categorization (see figure 2.5 for typology). This seemed to provide a higher immersion during use as the value in the Return to Reality component is high. Nevertheless, the sum of the negative aspects did affect not only the overall experience but also the usability of the technique (RQ3). This results in a low mean SUS score at 67.60, giving it a grade D in the scale. This is considered within the lower margin of an acceptable usability score in the SUS. As these results could indicate important issues with the technique, this should be examined closer in the interview data.

The immersion during use of WIP was said by the participants to be high due to the physical movement. As this can be considered a natural interaction which can resemble both walking and running in real life, this provided good immersion in combination with the continuous movement. It was also found intuitive to be able to decide the speed by regulating the pace of the physical movement. Some participants stated that the physical aspect
of the technique was a nice change from traditional game-experiences where the user is usually stationary. Furthermore, physical movement in combination with continuous motion did result in less motion sickness among some of the participants. These remarks could suggest that a natural interaction is beneficial to provide good immersion in the virtual environment and leading to an enjoyable experience. Whether higher immersion and less motion sickness is a direct effect of physical interaction combined with continuous motion should be examined further.

- "WIP was interesting with the best immersion. It was the most realistic technique with natural movement, so it provided the least motion sickness." [P10]

- "[…] it was fun and felt realistic due to the physical movement. It had the best experience and immersion, and it was nice to be able to regulate the speed by running.” [P13]

A noticeable remark from the interviews is that a high immersion itself could introduce new issues which affected the immersion negatively. When being completely immersed in the virtual environment while being physically active by tapping the feet, the participants tend to move away from their spot in the physical room. As the participants were not aware of this themselves due to being immersed in the virtual environment, they had to make sure to not crash into any physical objects in the room or the physical wall. Among the participants, this seemed to raise a fear of colliding making them more aware and considerate of the physical room. This shifted the focus away from the virtual environment, thus resulting in loss of immersion. The degree of movement in the physical room varied between each participant, but by reducing the need for physical movement this could potentially address this issue.

"[...] because it was difficult to stay in place in the physical room, I was always thinking about not hitting obstacles which removed
6.3. WIP

"me from the immersion. It was disorienting related to the real world." [P3].

"Too much movement made me worry about moving and hitting obstacles." [P4]

As indicated by the GEQ, the WIP technique was an overall tiresome experience with profoundly negative effects. This gets confirmed during the interviews where the need for the physical movement was considered high effort with little reward regarding movement. The walking speed was said to be too slow in general, so the participants increased the pace of physical movement to compensate and be able to move faster. When solving the tasks in the open VR environment over time, this physical movement got tiresome. Some participants suggested that a setting where the virtual environment is made for walkabouts or design reviews, a natural movement speed would be more fitting to add to the overall experience. The desire for faster speeds, in this case, can indicate that the goal was considered more important than the process of getting there, thus making the nature of the WIP technique itself an issue. This could be addressed by an increase of the speed in general or reduce the effort needed for movement. In addition, the combination of stationary physical movement and continuous motion in the virtual environment also affected the balance and made some participants dizzy and disoriented during use. This added to the overall bad experience and negative effect with this technique. Being physically active while trying to stand stationary combined with a continuous motion in the virtual environment, could arguably lead to the effect of physically moving around the room as well.

- "I felt it was slow, and it made me dizzy and unbalanced. It was also too much movement, as I don’t like to be physically active while playing games." [P7]
"If I’m in a virtual world, why should the movement speed be like reality?" [P12]

"Why should I give so much effort when the reward of movement is so small?" [P14]

"[...] needed very much effort to move. It was too slow when walking, and felt like an exercise when running. I think it’s suitable in settings where you’re in a walkabout because it felt like ”visiting” the virtual world.” [P17]

### 6.3.1 Remarks from WIP

The WIP technique was overall considered a technique with aspects which made a highly negative impact on the UX (addressing RQ2 for WIP). This also seemed to have a negative effect on the overall usability (addressing RQ3 for WIP). The following remarks were made for this technique:

1. Provided a highly immersive experience due to the natural interaction of movement.
2. A different type of interaction with virtual environments.
3. Needed high effort in use, leading to a tiresome experience over time.
4. A unique but slightly challenging technique to master.
5. Due to the high immersion and physical movement, there was a seemingly fear of colliding with physical objects or the wall in the physical room.

### 6.4 Comparison of the techniques

All the three VR locomotion techniques examined in this study have both clear strengths and limitations in terms of UX and usability. The techniques
cover both the artificial and physical interaction types of VR locomotion and
demonstrate different important aspects related to these.

Regarding usability, the joystick and teleportation techniques showed
good results. Due to the simple implementation and ease of use, these tech-
niques were proven useful to solve the task at hand. Both techniques have a
high SUS score of 84.48 (joystick) and 82.92 (teleportation) suggesting that
these were the overall preferred techniques in terms of usability in our study.
The WIP technique had several negative aspects related to its use, includ-
ing a more challenging interaction compared to the other techniques. This
got revealed during the interviews and resulted in the lowest SUS score of
67.60. Besides, WIP had the highest mean scenario completion time of 641.1
seconds (SD: 200.4) which could be a direct result of the low usability and
negative effects.

As discussed, WIP got mixed feedback from the participants. Due to
the need for physical interaction, it was considered a profoundly tiresome
technique with many considerations needed to execute the movement which
made it challenging. The result is an experience of giving too much ef-
fort for little reward in terms of movement. Also, some participants expe-
rienced dizziness and disorientation in relation to the physical room which
was uncomfortable. When comparing the Negative Affects GEQ component
between the three techniques, the result indicates a significant difference,
\( X^2(2) = 12.184, p = 0.002 \). The Wilcoxon signed rank test revealed a sig-
nificant difference when comparing WIP (mean rank score = 12.17) to an
artificial VR locomotion like the joystick technique (mean rank score = 4.00),
\( Z = -3.642, p < 0.001 \), which provided an overall good experience and scored
high in the SUS.

The main difference between these techniques is obviously the stationary
nature of the joystick technique requiring low effort, but also the simplicity
and ease of use. Also, the joystick technique builds upon already established
and traditional input methods which should be emphasized as beneficial.
The use of this technique share similarities with the teleportation technique
where simple interaction such as point and click is needed to execute the
movement. When comparing the three techniques, it was revealed that the
artificial VR locomotion techniques were considered easier to use and more intuitive than the physical technique, despite the more natural interaction of the latter. This reflects on to the Challenge component where it is indicated a significant difference between the techniques, $X^2(2) = 30.860, p < 0.001$. The post hoc Wilcoxon test found significant differences when comparing both joystick (mean rank score = 0.00) with WIP (mean rank score = 12.00), ($Z = -4.220, p < 0.001$), and teleportation (mean rank score = 3.00) with WIP (mean rank score = 12.86), ($Z = -4.041, p < 0.001$) both in favor of the artificial techniques. This suggests a significant lower challenge in use of the artificial techniques and raises a question about whether a natural interaction of VR locomotion provides a good experience when the main goal in the virtual environment is to solve a specific task.

In addition to the simple implementation of teleportation, it also provided precise controls for movement. This made the participants feel in control which would allow them to solve the task at a pace they found fitting. Being able to have this control was also appreciated for the WIP, where the pace of physical movement would decide the speed of movement in the virtual environment. There was found to be a difference between the techniques in the corresponding Competence component, $X^2(2) = 14.073, p = 0.022$. The Wilcoxon test showed a significant difference in favor of WIP (mean rank score = 13.17) compared to joystick (mean rank score = 10.03), $Z = -2.478, p = 0.013$, and WIP (mean rank score = 7.25) in favor of teleportation (mean rank score = 11.88), $Z = -3.033, p = 0.002$. The results suggest that the point and click nature of teleportation was considered a better way to control movement than the physical nature of WIP. This could indicate that an artificial interaction would be preferred, but the possibility to regulate the speed in a natural manner as in WIP was more appreciated compared to the joystick technique. As discussed, a majority of the participants found the joystick technique to be too slow with limited possibilities to regulate the speed. This could have affected the feeling of competence for this technique.

The teleportation and joystick techniques can be considered result-oriented techniques where only a push of a button or having a thumb on the track-pad...
is required to execute the movement. On the other hand, WIP is a process-oriented technique where there is a more complex process to execute the movement. In this case where there was a task at hand and a clear goal to the context, a result-oriented technique like teleportation seems to be more preferred. As the process of executing the movement is more complex for the WIP technique, the process itself turns out to be an issue that affects the experience. Solving tasks utilizing the WIP technique could be tiresome over time which is confirmed by significant differences in the Tiredness component of the GEQ, $X^2(2) = 21.802, p < 0.001$. The Wilcoxon test show significant differences in favor of both teleportation (mean rank score = 8.20) compared to WIP (mean rank score = 13.06), $Z = -2.967, p = 0.003$, and joystick (mean rank score = 0.00) compared to WIP (mean rank score = 11.00), $Z = -4.055, p = 0.000$.

Teleportation was found to be fast and effective in use for solving the given tasks in this study. However, this technique was also said to provide the least immersive experience due to the non-continuous motion type with instant transitions. On the other hand, WIP provided a fairly high immersion overall due to the natural interaction and continuous motion type. There was found a significant difference in the Return to Reality component ($X^2(2) = 23.455, p < 0.001$), where the Wilcoxon test showed a significant difference between teleportation (mean rank score = 0.00) and WIP (mean rank score = 10.00), $Z = -3.832, p < 0.001$, in favor of the latter. This could suggest a trade-off between having a fast and effective artificial technique in favor of high immersion through a physical technique with a natural interaction or vice versa. This trade-off should be considered when developing applications, and decide whether immersion should be the main emphasis of the application and the virtual environment. As suggested by some of the participants, a physical VR locomotion technique such as WIP would be more fitting in a review context where immersion is emphasized. While teleportation may be more suitable for solving tasks without the need for high immersion, it’s also pointed out that the virtual environment should be designed with the VR locomotion type in mind.
6.4.1 Remarks from the comparison

In the comparison between the three VR locomotion techniques, we see some clear differences regarding both UX and usability (addressing RQ4). The following remarks were made for the comparison of the techniques:

- **Teleportation** was considered the most effective technique for solving the tasks, was low effort in general, had precise and intuitive controls and was easy to use. However, it provided the least immersive experience overall. The usability was perceived as good in total.

- **WIP** provided the best immersive experience compared to the other techniques due to the physical interaction. On the other hand, it was also the most tiresome and challenging technique to master requiring high effort to execute. This resulted in an overall negative experience and lowest usability between the techniques.

- **Joystick** provided overall the most positive experience compared to the other techniques. It was low effort in use as well as easy to learn due to the familiarity with traditional gamepads. Even if the participants found the technique to be slow in general, it gave the highest result in terms of usability.

Based on the interviews and data collected, an overview of the discussed remarks is illustrated in figure 6.1. The figure includes the important aspects revealed through the interview, and suggested virtual environment types for each technique. The suggested environments are based on what the participants suggested during the interviews and a synergy between the interview data and results from the GEQ and SUS.
6.5 Addressing the issues

As for each VR locomotion technique examined, a few remarks were made related to the current issues of these techniques which affected the overall experience. Following, possible design implications will be proposed which could address these issues based on the conducted interviews and relevant literature for VR locomotion.

**Teleportation remark #3:** Rapid movement caused a tiresome transition between each execution of the teleportation due to the non-continuous motion type.

**Teleportation remark #5:** Provided overall low immersion due to the artificial interaction and non-continuous motion type.

**How to address:** Some of the participants suggested a more "smooth" movement for each transition. By providing a selection of transition effects, like an sliding effect or fading transition, this issues could be addressed with
options which the user finds less tiresome. Bozgeyikli et al. (2016) did evaluate both a sliding effect and a sliding transition through their implementation of the point and teleport technique (Bozgeyikli et al., 2016, p. 208). This did, however, indicate loss of immersion when having an fading transition and increased motion sickness when having a sliding effect. If we were to compare these transition effects, a continuous sliding effect would arguably make the technique more immersive as our data indicate that a continuous motion type like the joystick and WIP techniques did provide better immersion than the non-continuous motion of teleportation. However, a sliding effect could affect the effectiveness which was an aspect revealed to be important by our participants. A fading transition could, in this case, be more suitable even if it would affect the immersion. This highlights our earlier argument that a teleportation VR locomotion technique does not necessarily facilitate for an overall highly immersive experience in general, thus should be utilized when immersion is less emphasized and less important for the overall experience.

Teleportation remark #4: Limited range of the teleportation caused many sequentially transitions.

How to address: As stated by some of the participants, this could be addressed by adding the possibility to freely regulate the range as desired. Another option could be to implement a type of WIM-metaphor (see section 2.2) similar to Stoakley et al. (1995) where the user can teleport to a selected location by getting an overview of the whole virtual environment (Stoakley et al., 1995). This could arguably cause a higher degree of disorientation, which teleportation has indicated in earlier studies (Bowman, 1999, p. 32 Bozgeyikli et al., 2016, 214). Nevertheless, some participants suggested that the context and virtual environment should be designed for teleportation as being the primary VR locomotion technique, thus allowing for longer teleportation range.

Joystick remark #4: Participants found the technique general set speed to be too slow. Limitations in terms of speed control.
6.5. ADDRESSING THE ISSUES

**How to address:** A synthesis of what the participants said during the interviews indicated the need for better controls on the regulation of movement speed during use. If a higher speed would be needed, the participant could more easily be able to adjust this accordingly. The possibility of speed regulation is stated in Bowman et al. (1997) taxonomy and list of quality factors (see figure 2.4 and table 2.1), which suggests that this is still an important aspect to take into consideration to facilitate for a good experience (Bowman et al., 1997, p. 59).

**Joystick remark #5:** The continuous motion made some participants dizzy and slightly motion sick.

**How to address:** When utilizing a continuous movement type in a virtual environment while being stationary in the physical environment, this can result in a disconnect between the perceived motion and physical motion of the body. This negative effect in VR and has previously been prominent when examining joystick-based techniques (Fernandes and Feiner, 2016; Langbehn et al., 2018). As suggested by Fernandes and Feiner (2016), an option for a dynamic field of view can address this issue by reducing the overall motion in the HMD. Their study also indicate that a subtle change in the field of view did not affect the feeling of presence negatively (Fernandes and Feiner, 2016, p. 208). As not all the participants felt discomfort while using the joystick technique, this functionality should be optional with the possibility of regulating the dynamic field of view as desired.

**WIP remark #3:** Needed high effort in use, leading to a tiresome experience over time.

**WIP remark #4:** A unique but slightly challenging technique to master.

**WIP remark #5:** Due to the high immersion and physical movement, there was a seemingly fear of colliding with physical objects or the wall in the physical room.

**How to address:** Taking the comments from the interviews into consideration, the need for lower effort to execute the movement should be beneficial
to address this issue. As stated by some of the participants, the reward should be higher than the effort when utilizing a VR locomotion technique with a physical interaction type such as WIP. With the need for too much effort, it will get tiresome over time leading to a bad overall experience. An example on how to address this could be to adopt functionality like the *Seven League Boots* which makes one physical step in the real world translate to seven steps in the virtual environment (Interrante et al., 2007, p. 168). Another option to reduce the apparent challenging use of the technique according to the data, could be to remove the need for tapping the feet and only requiring subtle movement of the head or arms. Nilsson et al. (2016) propose *arm swinging* as a gestural input for WIP locomotion which could be beneficial in this case (Nilsson et al., 2016, p. 43). This would require less physical movements, but it should be investigated how this could affect the overall immersion which was said by the participants to be the most appreciated aspect of this VR locomotion technique. This design implication could also address the seemingly fear the participants had of colliding with physical objects or the physical wall while being immersed in the virtual environment. This seemingly effect is interesting and should be examined further related to physical VR locomotion interaction types like WIP.

The proposed design implications to address the identified issues regarding UX and usability are based on the use-context utilized during our empirical study. The discussion of which VR locomotion technique that provides a good experience can vary depending on different use contexts. As discussed, teleportation can be considered a result-oriented technique which is effective in use and is suitable for solving tasks with a given goal. However, this comes with a trade-off in terms of immersion where the data indicated that WIP provided the best immersive experience. Some participants suggested that the WIP technique would be more fitting in use-contexts where immersion is emphasized such as virtual walkabouts because it felt like "visiting" the virtual world. As for the joystick technique, the participants were satisfied with the overall experience, so it should be examined further if this is the case in other VR use-contexts as well.
6.6 Lessons learned

In addition to the suggested design implications to address the current issues, we also learned that the applied methodology used to examine the UX and usability for VR locomotion was useful. We suggest a similar approach when conducting future studies related to UX and usability for VR. This methodology is partly inspired by Kitson et al. (2017) work on leaning-based locomotion in VR (Kitson et al., 2017). In our experience, this allows for a rich understanding through a comprehensive data set including both quantitative and qualitative data from the GEQ, SUS and semi-structured interviews. Table 6.1 summarize the applied methodology. These were the most important lessons learned during the study:

- The empirical study included tasks which utilized the currently prevalent VR locomotion techniques in use-cases which are feasible in cases outside a lab setting. The tasks involving checkpoints in an open VR interaction space was proven useful for the participants to be kept motivated while utilizing the locomotion techniques. This approach has previously been used in VR studies (Nabiyouni et al., 2015; Kitson et al., 2017; Ruder et al., 2017; Bozgeyikli et al., 2016). Additionally, we kept a record of time measures to see if this could have any correlation with the perceived UX or usability.

- Through the GEQ and SUS, we were able to get an overview of the UX and usability related to each VR locomotion technique. The analysis of the GEQ was conducted through SPSS with the Friedman and Wilcoxon signed rank significant tests for non-parametric data.

- To further explore the human aspects and make the participants elaborate upon their experience, a semi-structured interviews was conducted mainly as a conversation about the overall experience when utilizing the techniques. This approach gave an in-depth understanding of the underlying thoughts of the participants. The interviews were analyzed through open and axial coding to reveal themes related to the UX and usability.
• The use of currently established VR-systems such as the HTC Vive provided an all-in-one solution to utilize and examine the currently most prevalent VR locomotion techniques. As there was no need for any additional peripherals to be able to utilize the techniques, the proposed design implications and future related constructive work should be able to apply to the mainstream consumer VR-systems. Furthermore, the HTC Vive have support for a wide range of software and development tools which opens for many possibilities.
### 6.6. LESSONS LEARNED

<table>
<thead>
<tr>
<th>Conducted work</th>
<th></th>
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<tbody>
<tr>
<td>Empirical study</td>
<td>Involving tasks with checkpoint to experience the VR locomotion techniques.</td>
</tr>
<tr>
<td>Comparative study</td>
<td>To compare the UX and usability between the VR locomotion techniques.</td>
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### Data collected

<table>
<thead>
<tr>
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<th>The subjective experience of the UX.</th>
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<tr>
<td>System Usability Scale (SUS)</td>
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<tr>
<td>Scenario completion time measurement</td>
<td>Time spent on trial and total time spent on each scenario.</td>
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<tr>
<td>Semi-structured interviews</td>
<td>A semi-structured interview to get an in-depth understanding of the UX and usability.</td>
</tr>
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### Analysis

<table>
<thead>
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<th>Friedman test</th>
<th>Non-parametric statistical significant test to reveal any significant differences in the overall data set.</th>
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<tbody>
<tr>
<td>Wilcoxon signed rank test</td>
<td>Non-parametric statistical significant test to reveal any significant differences in a pair-wise comparison.</td>
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</table>

### Coding

<table>
<thead>
<tr>
<th>Open coding</th>
<th>Create labels related to the various themes.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial coding</td>
<td>Reveal relations and create higher thematic categories of the UX and usability.</td>
</tr>
</tbody>
</table>

Table 6.1: Overview of the applied methodology.
6.7 Limitations

Among the limitations related to this study was the convenience sampling of the participants. The majority of the sample was gathered from the University of Oslo due to the availability during the time of the study. This makes it difficult to generalize the results to other groups or populations and should be addressed in future studies.

Secondly, proprietary software was used to implement the examined VR locomotion techniques. As for the WIP technique, we used the HTC Vive tracker for a Wizard of Oz approach. As mentioned in section 3.2, the software would register the HMD and Vive Controllers to determine the speed of motion in the virtual environment. In practice, this would allow the participant only to move their head and shake their hands to execute the movement. To avoid this, the Vive Tracker was mounted to the participant’s foot to motivate them to walk in place through the scenario.

As for the tasks within each scenario, these were picked based on unique landmarks in the virtual environment with approximately the same distance in between each checkpoint (as described in section 4.2). The difficulty level of the tasks for each scenario was supposed to be uniform. However, there is no proof that this is the case.
Chapter 7

Conclusion

In this study, the objective was to fill a research gap in the field of VR locomotion research. After the technological development the latest years and the VR revival in 2013, few studies of locomotion in VR examined issues related to the human aspects of already prevalent VR locomotion techniques. A literature review conducted on recent studies of VR locomotion revealed that a majority of the recent studies mainly focused on constructing new and novel techniques with emphasis on the technical aspects without any empirical evaluation of existing issues to support this. The lack of problem-solving capacity to drive the field forward was allegedly missing. To fill this gap, we looked at the current state of the art in the VR locomotion field and identified the three of the currently most prevalent VR locomotion techniques: joystick, teleportation and walk-in-place. Having these techniques selected, an empirical study was conducted to examine and compare the UX and usability. Through the use of validated questionnaires related to game experiences and usability in addition to analysis of both qualitative and quantitative data, a few remarks related to each of the VR locomotion techniques got revealed. These remarks included important UX and usability aspects where a few interaction issues got identified. To address these issues, we proposed some design implications based on the collected data and relevant literature in the field. Furthermore, the applied methodology was useful to get a comprehensive data-set to examine both UX and usability which should be taken into
CHAPTER 7. CONCLUSION

consideration for future related studies. What we learned from this empirical evaluation is a contribution to the knowledge of an evolving field which can improve the problem-solving capacity of VR studies. The proposed design implications should be considered to address the current interaction issues and could be a baseline when constructing new and better VR locomotion techniques.

7.1 Future work

Future work should consist of further examination and validation of the empirical result and proposed design implications. For continued development of locomotion techniques in VR, researchers and developers should consider the discussed issues when constructing new solutions, followed by additional empirical evaluation. Whether the suggested design implications address the current interaction issues should be studied and elaborated upon further in future studies. Among the more important aspects of VR locomotion which was outside the scope of this study, is whether the technique and interaction can cause motion sickness. This should be further examined with the VR locomotion typology in mind to discover if there is any correlation between VR interaction types, VR motion type, and negative effects such as motion sickness and disorientation (see figure 2.9 for typology).

As we used an open VR environment with multiple tasks at hand, future empirical studies should examine the prevalent VR locomotion techniques in different use-contexts as well. VR technology and locomotion can be utilized in a wide range of use-contexts, and the experience may be different according to this. For example, by implementing VR locomotion into a larger scale environment or a collaborative environment could introduce new challenges which should be taken into consideration and be addressed in future work. The various locomotion techniques would also have different implications according to what type of interaction is required, whether it is a social context, a design review context or an high-paced gaming context.

Additionally, the proposed design implications for the current issues should be evaluated with other VR-systems as well. As the field is in rapid develop-
7.1. FUTURE WORK

ment, it is important to keep up with the current technologies and commonly used VR locomotion techniques. This study should also be an example of why more empirical and comparative studies are needed within the field of VR and be a motivation for more researchers to do so.
Appendices

A

Interview guideline

- How do you feel?
- Have you used any of the locomotion techniques before? If so, which?
- Which locomotion technique did you like the most? Why?
- Which locomotion technique did you like the least? Why?
- What do you think about the immersion using the different locomotion techniques?
Appendices

B

Consent form

Forespørsel om deltakelse i forskningseksperiment

UX i VR

Hjelprom og for formål
masteroppgave gjennomført et empirisk studie i form av et eksperiment. Formålet med eksperimentet er å undersøke brukeropplevelsen (UX) ved bruk av virkelig virkelighet (VR).

Prosedyr
1. Du vil bli bedt om å ta på deg en VR-hodesett som skal brukes til å løse gitte oppgaver
2. Etter hver oppgave bet vi deg være på en sporrenundersøkelse
3. Når alle oppgavene og sporrenundersøkelsene er fulført, ønsker vi å gjøre en kort intervju

Hele prosessen vil ta opp til 2 timer per sесsjon fastsatt mellom deg og studieansvarlig(e).

Risikoner/Fordeler for deltakeren

Deltakelsen vil bidre til å bedre forståelsen av UX ved bruk av VR. Som takt for deltakelsen vil alle deltakere motta et gavekort.

Hva sliter med informasjonen om deg?

Frivillig deltakelse
Det er frivillig å delta i dette eksperimentet, og du kan når som helst trekke ditt samtykke uten å oppgi noen grunn. Du vil også ha muligheten til å trekke deg undervis. Dersom du trekker deg, vil alt data fra din deltakelse bli slettet.

Dersom du har spørsmål eller ønsker å trekke deg, ta kontakt med.

Samtykke til deltakelse i studiet

Jeg har mottatt informasjon om studiet, og er villig til å delta

---------------------------------------------------------------------------------------------------------------------------------- (Signert av deltaker, dato)
C

Description of study

Beskrivelse av oppgave

I dette forsknings eksperimentet skal du gjennom 3 oppgaver i VR. Hver oppgave vil bestå av flere interessepunkter i den virtuelle byen. Oppgaven er å finne så mange av disse interessepunktene som mulig i en bestemt rekkefølge ved å bevege deg rundt i denne virtuelle byen. Jeg vil stoppe deg når det ikke er flere interessepunkter å finne, eller hvis det har gått 15 minutter.

Før hver oppgave vil jeg instruere deg i hvordan man beveger seg rundt i den virtuelle byen. Du vil dermed få muligheten til å prøve å bevege deg trett rundt i denne byen inntil du føler deg komfortabel med bruken, eller opp til 5 minutter. Deretter vil jeg gi deg de konkrete interessepunktene du kan finne.

Du vil ha mulighet til å stille generelle spørsmål til meg underveis, og jeg vil gi deg en bekreftelse når du har funnet et interessepunkt.

Etter hver av de 3 oppgavene bør vi deg bevare en spørreundersøkelse. Når alle oppgavene og spørreundersøkelserne er fulgt vil vi gå gjennom et kort intervj. Det er satt av tid til en pause mellom oppgave 2 og 3. Spørsmål?

Vi ber deg lese nøye gjennom samtykkeskjemaet og signere hvis du ikke har noen innvendinger.

Hva går oppgavene ut på?

Jeg vil gi deg instrukser om oppgaven før hver oppgave.

Hva skjer hvis jeg ikke finner alle interessepunktene?

Det gjør ingen ting. Formålet er ikke å finne alle, og tidsbegrensningen er kun for å avgrense tiden vi bruker innenfor rammen vi har avtalt (maksimum 2 timer).

Hva skjer hvis jeg blir ferdig med en gang?

Hvis du blir ferdig, så gjør ikke det noe heller. Merk at formålet heller ikke er å være så rask som mulig. Ta den tiden du trenger i et tempo som føles naturlig for deg.

Hva hvis jeg finner et interessepunkt i feil rekkefølge?

Vi ønsker at du finner interessepunktene som i rekkefølgen i oppgaven. Hvis du finner et annet interessepunkt først bør jeg deg se etter det forrige punktet før du eventuelt kommer tilbake til denne.

Hva hvis jeg glemmer det jeg skal finne?

Du kan når som helst be meg minne deg på hva du skal se etter. Formålet er ikke å huske hva du skal finne utenat.

Hva hvis jeg går inn i vegg, krasjer med noe, eller mister balansen?

Jeg følger med under hele prosessen og vil passe på at du hverken går inn i veggen, krasjer med noe eller faller på gulvet.
## Appendices

### D

## GEQ Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Items</th>
<th>Description</th>
</tr>
</thead>
</table>
| Competence | 2 - I felt successful  
9 - I felt skillful | How the participant felt they mastered the technique |
| Sensory and Imaginative Immersion | 1 - I was interested in the task  
4 - I found it impressive | How the participant felt presence in the virtual environment |
| Flow | 5 - I forgot everything around me  
10 - I felt completely absorbed | How immersed the participant felt in the virtual environment. |
| Tension | 6 - I felt frustrated  
8 - I felt irritable | How the technique provoked pressure |
| Challenge | 12 - I felt challenged  
13 - I had to put a lot of effort into it | Whether the participant found to struggle with the technique |
| Tiredness (post-game) | 10 - I felt exhausted  
13 - I felt weary | How the participant found the technique to be tiresome |
| Positive affect | 11 - I felt content  
14 - I felt good | How the participant found the technique to be satisfying |
| Negative affect | 3 - I felt bored  
7 - I found it tiresome | How the participant found the technique to be unsatisfying |
| Returning to reality (post-game) | 3 - I found it hard to get back to reality  
9 - I felt disoriented  
17 - I had a sense that I had returned from a journey | To which degree the techniques immersed enough to make it difficult to separate from reality |
E

Demographics questionnaire

ID: *

Your answer

Age: *

Your answer

Sex *

- Female
- Male

Education *

- < Secondary
- Secondary
- Bachelor
- Master
- PhD

Have you used VR before? *

- No
- Only once
- A few times
- I'm using VR all the time
Appendices

If you have used VR before, what kind of device did you use? (more than one answers are possible) *

☐ Told you I haven't used VR before :)

☐ VR headset & Smartphone

☐ HTC Vive

☐ Oculus Rift

☐ Playstation VR

☐ Other: ________________________________

Do you own a VR device? (more than one answers are possible) *

☐ No

☐ VR headset + Smartphone

☐ Oculus Rift

☐ HTC Vive

☐ Playstation VR

☐ Other: ________________________________

If you have used VR before what kind or titles of VR apps have you used? (If you don't have VR experience leave this field blank)

Your answer

☐
UX Questionnaire

ID: *
Your answer

Please indicate how you felt while navigating in VR.

1. I was interested in the task *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

2. I felt successful *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

3. I felt bored *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely
4. I found it impressive *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

5. I forgot everything around me *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

6. I felt frustrated *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

7. I found it tiresome *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely
8. I felt irritable *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

9. I felt skilful *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

10. I felt completely absorbed *
    - Not at all
    - Slightly
    - Moderately
    - Fairly
    - Extremely

11. I felt content *
    - Not at all
    - Slightly
    - Moderately
    - Fairly
    - Extremely
Appendices

12. I felt challenged *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

13. I had to put a lot of effort into it *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

14. I felt good *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

Please indicate how you felt after you finished navigating in VR.

1. I found it hard to get back to reality *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely
2. I felt disoriented *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

3. I felt exhausted *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

4. I felt weary *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely

5. I had a sense that I had returned from a journey *
   - Not at all
   - Slightly
   - Moderately
   - Fairly
   - Extremely
Please check the box that reflects your immediate response to each statement.

1. I think that I would like to use this VR navigation technique frequently *
   - 1  2  3  4  5  (Strongly disagree)  (Strongly agree)

2. I found the VR navigation technique unnecessarily complex *
   - 1  2  3  4  5  (Strongly disagree)  (Strongly agree)

3. I thought the VR navigation technique was easy to use *
   - 1  2  3  4  5  (Strongly disagree)  (Strongly agree)

4. I think that I would need the support of a technical person to be able to use this VR navigation technique *
   - 1  2  3  4  5  (Strongly disagree)  (Strongly agree)

5. I found the various functions in this VR navigation technique were well integrated *
   - 1  2  3  4  5  (Strongly disagree)  (Strongly agree)

6. I thought there was too much inconsistency in this VR navigation technique *
   - 1  2  3  4  5  (Strongly disagree)  (Strongly agree)
7. I would imagine that most people would learn to use this VR navigation technique very quickly *

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Strongly disagree | Strongly agree

8. I found the VR navigation technique very cumbersome to use *

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Strongly disagree | Strongly agree

9. I felt very confident using the VR navigation technique *

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Strongly disagree | Strongly agree

10. I needed to learn a lot of things before I could get going with this VR navigation technique *

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Strongly disagree | Strongly agree

Please indicate what you LIKED about this VR navigation technique *

Your answer

Please indicate what you DIDN'T LIKE about this VR navigation technique *

Your answer
Bibliography


