



Smooth locomotion in VR

Comparing head orientation and controller orientation locomotion

Fu Keung Tu

This thesis is submitted to the Faculty of Computing at Blekinge Institute of Technology in partial fulfilment of the requirements for the degree of Bachelor of Science in Software Engineering. The thesis is equivalent to 10 weeks of full time studies.

The authors declare that they are the sole authors of this thesis and that they have not used any sources other than those listed in the bibliography and identified as references. They further declare that they have not submitted this thesis at any other institution to obtain a degree.

Contact Information:

Author(s):

Fu Keung Tu

E-mail: futu14@student.bth.se

University advisor:

Yan Hu

Department of Computer Science

Faculty of Computing
Blekinge Institute of Technology
SE-371 79 Karlskrona, Sweden

Internet : www.bth.se
Phone : +46 455 38 50
00
Fax : +46 455 38 50 57

ABSTRACT

Background. Virtual reality (VR) technology has evolved to a stage where affordable consumer devices are available. Still, there are limitations to technology which causes compromises to be made. One of the big problems in VR is locomotion, especially regarding immersion and comfort. There are two common ways for locomotion in VR, Teleportation and smooth continuous locomotion. Smooth locomotion is often considered superior for immersion but commonly causes simulation sickness.

Objectives. This paper is comparing two different methods of smooth locomotion, one based on head orientation and the other based on controller orientation. The objective is to determine which method is preferred regarding comfort, immersion and ease of use.

Methods. To identify the strength and weaknesses of each method, a VR experiment was designed which simulates tasks common in video games. A comparative study was made with fifteen subjects. The fifteen participants performed tasks involving exploring a VR environment and using the VR controller to shoot at targets. After using each of the methods the subjects then answered questionnaires about the usability and the simulations sickness caused by the method. Other data was collected on how well the task was performed such as number of targets hit.

Results. The users ranked controller orientation locomotion higher for perceived naturalness and likeability and was ranked lower for items relating to restrictiveness and difficulty. No significant difference was found regarding simulator sickness and performance.

Conclusion. Controller orientation locomotion ranked at least as good or better than head orientation locomotion in all categories. This shows that it is the preferred orientation method in this use case where the application is similar to a first person shooter game.

Keywords: Comparative study, Virtual reality, Locomotion, Navigation, Simulation sickness

ACKNOWLEDGEMENTS

I would like to thank my supervisor Dr. Yan Hu, for guidance during my thesis work.

Contents

ABSTRACT	III
ACKNOWLEDGEMENTS	IV
LIST OF FIGURES.....	6
LIST OF TABLES.....	7
1 INTRODUCTION	8
1.1 AIM AND OBJECTIVES	8
1.2 BACKGROUND	9
1.3 SIMULATOR SICKNESS	9
1.4 LOCOMOTION	9
1.5 ORIENTATION METHODS	9
1.6 OVERVIEW.....	10
2 RELATED WORK.....	11
3 METHOD.....	13
3.1 RESEARCH QUESTIONS.....	13
3.2 HARDWARE	13
3.3 TESTING ENVIRONMENT	13
3.4 PARTICIPANTS	13
3.5 THE EXPERIMENT.....	14
3.6 THE TASK	16
3.7 STUDY PROCEDURE	16
3.8 DATA COLLECTION	16
3.9 SIMULATOR SICKNESS QUESTIONNAIRE	16
3.10 GENERAL USABILITY QUESTIONNAIRE	17
4 RESULTS AND ANALYSIS	19
4.1 USABILITY QUESTIONNAIRE	19
4.2 SIMULATOR SICKNESS QUESTIONNAIRE	22
4.3 PERFORMANCE	24
5 DISCUSSION.....	25
6 CONCLUSION AND FUTURE WORK	26
7 REFERENCES	27

LIST OF FIGURES

Figure 1. The VR-environment from a first person view.	15
Figure 2. Section of the VR-course from a bird's eye view.	15
Figure 3. Box plot for usability questionnaire.....	19
Figure 4. Controller orientation usability questionnaire.....	21
Figure 5. Bar chart of total score for SSQ.....	23
Figure 6. Means of balloons destroyed.	24

LIST OF TABLES

Table 1. Distribution of items in symptom categories.	17
Table 2. Central tendency for head orientation.	20
Table 3. Central tendency for controller orientation.	21
Table 4. Significant difference in usability questionnaire.	22
Table 5. Mean total score for SSQ.	22

1 INTRODUCTION

Virtual reality (VR) is a computer-generated virtual environment which simulates real-world interactions using devices which track the user's movements. These hardware devices usually consist of a head mounted display and a pair of motion controllers which track the users' hands. The idea is not new, but through advances in technology, VR has had a renaissance in recent years [8].

VR game design is a relatively new concept and there are still many unknowns to what works in VR and what does not. One thing that VR does better than regular games played on a monitor is immersion, the feeling of presence, the feeling of physically being inside the environment. This immersion can quickly be broken if the player movements feel unnatural, or the response is not as expected. Movement in game needs to be as natural as possible and needs to match the user's physical movements not only for the experience to be immersive, but in the worst scenario it can even make the user feel sick. These feelings of discomfort are also known as simulation sickness [1].

The big problem with movement in VR is locomotion since there is no easy way to map physical bodily movement in a restricted area to in-game changes. Most games use the joystick on one of the motion controllers for a smooth movement input, which is usually the cause of this disconnection. To mitigate this, most VR applications use a click-to-teleport system that places the player at the position the user desires at the click of a button. Since this happens instantly, no discomfort is felt by the user.

For players that can handle smooth movement, usually performed by moving a joystick or a touchpad, there has been primarily two ways that you can navigate. The first method is head orientation locomotion [3], where the player will always walk towards the direction he/she is looking. This is simple and intuitive. The second method is controller-based orientation in the sense that the player will walk in the direction that the controller is pointing. This may be a more natural way to navigate since the look direction and walking direction is decoupled. This paper will investigate which of these two navigation methods feels the most natural when it comes to ease of use and comfort.

1.1 Aim and objectives

The aim is to compare head orientation locomotion to controller orientation locomotion and find out which is the preferred navigation method regarding comfort, immersion and ease of use.

The objectives are:

- a. Develop a VR application with both head orientation locomotion and controller orientation locomotion.
- b. Conduct an experiment where the subjects perform tasks in the application, using one orientation method after the other.
- c. Gather data from participants using questionnaires about comfort and simulation sickness.
- d. Analyze the gathered data.

1.2 Background

In recent years the interest in VR has grown immensely. It was not that long ago that VR equipment were so prohibitively expensive that only the likes of government institutes or big companies had access to it. For many years high quality VR has been a tool for research and in different vehicle simulators in the private or military sector.

A few attempts were made to break into the consumer sector, but it was painfully apparent that the technology just was not anywhere close to where it needed to be to make a good yet affordable consumer product. It was not until 2013, with the release of their development kit that Oculus VR proved that technology had finally caught up and that high-quality consumer VR were now a possibility [11].

Today there is a plethora of high-grade consumer VR devices, but the longstanding problems that have plagued VR still exist. Two of the big issues are simulator sickness and locomotion.

1.3 Simulator sickness

Simulator sickness is related to motion sickness that many people have experienced when riding in a vehicle. The symptoms are certainly very similar which are typically, but not limited to nausea, vertigo, dizziness and sweating. Simulator sickness is caused by a disconnect between the information that a person's visual system is receiving and what the vestibular system is experiencing [9].

In a VR simulation the user might be moving in the virtual world, but its physical body is standing still. This discrepancy in what the person is seeing and what the body is feeling is what could potentially cause simulator sickness. This is in fact the inverse to motion sickness. In studies, simulator sickness is usually assessed by using questionnaires, with the simulator sickness questionnaire being considered the de facto standard.

1.4 Locomotion

The most natural way to move in VR is obviously by moving your physical body and have the virtual avatar mirror the movements in the virtual world [12]. This is accomplished by having sensors on the VR equipment which are tracked in 3D space. It would mean that to get the most accurate tracking you need as many sensors as possible on as many parts of the body as possible. Obviously for economic and practical reasons only a few body parts are usually tracked. It is the most common setup for consumer VR kits to be shipped with a tracked headset and hand controllers.

There is also the issue with limited tracking range and having physical boundaries such as walls in the physical space. For these reasons artificial ways for locomotion are used for long range traversals where you control locomotion by pressing a button on the hand controller. It is usually solved by using mechanics such as teleportation or using smooth locomotion as is traditionally used in video games. Using smooth locomotion often causes simulator sickness.

1.5 Orientation methods

This is the subject being focused on in this study. This is related to smooth locomotion where there are two common ways to decide in which direction to move. This is an issue because since the user's legs normally are not tracked, another artificial way must be invented to decide the walking direction. The two methods are head orientation and controller orientation. Head orientation means the forward locomotion is always the direction the user is looking. Controller orientation means forwards movement is wherever the controller is pointing towards.

There are pros and cons for each method. Head based direction is arguably easier to use and is more intuitive since you simply must look in the direction you want to move. There is a trade of function for

complexity since you cannot move and look in separate directions. With controller-based orientation it is possible to simultaneously move and look in separate directions. This is more similar to how movement is conducted in real life as the legs move separately from the head. This adds complexity since it might not be intuitive to have your walking direction controlled by the direction of your hand. This method is arguably more desirable for games since awareness in one's surroundings play a big part in many genres.

Simpler VR-experiences, where there is not much user interaction tend to use head orientation locomotion while more action-oriented games mostly use controller orientation. Some games let the player change the setting to one or the other in the options menu.

1.6 Overview

Related work in the field of VR locomotion is presented in chapter 2. This describes different approaches taken to solve the problem. In Chapter 3 the methodology is described. This includes description of the experiment and evaluation methods used. In chapter 4 the results will be presented and analyzed with graphs and tables. A discussion about the findings and possible causes and interpretations is presented in chapter 5. A summarization and conclusion is presented in chapter 6. In that chapter the topic of what can be worked on in the future is also discussed. A list of references to articles and sources used in this paper is found in the last chapter.

2 RELATED WORK

With the release of consumer grade VR devices in recent years we can see there has been an uplift in VR related research. VR technology still has a very big room for improvement because VR is just a hard problem to solve. With limited technology a lot of compromises must be made. Not surprisingly one of the most researched problems in VR is locomotion. In a study in 2016 by Cardoso, J. [3] three types of input methods were tested for locomotion in VR. The first method was using a device called Leap motion which uses sensor technology to read hand gestures. It was mounted on the VR head mounted device (HMD) and the user could turn and walk by making different gestures with their hands in the field of view of the sensor.

The second method was using a traditional gamepad and using the analog stick for locomotion. Forward locomotion followed the orientation of the headset, which is the equivalent to head orientation locomotion described in this paper. The third method was called “gaze-directed locomotion”. In this type of locomotion, the user could go to location by looking at it and press a button. The user would then automatically move there, like a combination of teleportation and smooth locomotion.

The different locomotion methods were assessed in the areas of performance, comfort and simulation sickness. Cardoso concluded that gamepad locomotion was both the most performant and most comfortable to use. The gesture-based controls scored the lowest in both performance and comfort. In the simulator sickness test, no statistical significance was found in the results. It should be noted that none of the aforementioned input methods were designed with VR in mind, but the gamepad controls are related to the research in this paper since both test smooth locomotion.

The other way to do locomotion is by using teleportation mechanics. In a paper from 2016 [6] Medeiros D. et al. investigated three different teleportation techniques. The first technique utilizes instant teleportation to a chosen spot. This is the most common implementation in commercial VR software. The second technique was called “linear motion”. The difference to the first method was that the user was moved to the destination with a constant velocity for two seconds. In the third method, which the authors called “animated teleport box”, a box was animated around the user, blocking the users view at the start and finish of the teleportation. This method was designed with the intention of minimizing the user’s disorientation during teleportation.

The research goals for this study was to find the best of the three techniques regarding comfort and simulation sickness. Their results show that using the linear motion method caused the most discomfort, but it was still the method the users was most satisfied with. No noticeable difference was found in the results between instant teleportation and animated teleportation box. The time consumed to complete different tasks with each method was also measured but no significant difference between them was observed. This paper is indication that while teleportation is usually the most comfortable way for locomotion, many users still prefer methods that are similar to smooth locomotion.

In another study from 2017 investigating VR locomotion [7], Tregillus S, Al Zayer M and Folmer E, designed a system which used the inertial sensors in the VR headset to control walking direction. To walk in a certain direction, the user simply tilted its head in that direction. The researchers argued that this control scheme could be superior for increased immersion or for reducing simulation sickness. They also argued that tilt-based controls would be more suitable for mobile VR which normally do not come with hand controllers.

The team compared the tilt-based controllers with two other methods. The walking in place (WIP) scheme combined tilt-based controls with a system that could control walking speed. By having the sensors in the headset pick up on lateral movement, the user could increase the walking speed by walking in place. This method was created from a theory to further increase the immersion. The last method was the tried and true joystick controls. To test their theories the team designed an application with navigation tasks. They tested for performance, immersion and simulator sickness and found that the tilt method was significantly faster at completing the task than the other two. WIP-tilt and tilt controls offered the most immersion while no difference was found in simulator sickness between input systems.

These are some of the examples of research on VR input and locomotion and research is still ongoing. There is usually a balancing act between performance, ease of use, immersion and comfort. So far there is no one size fits all solution. This paper is focusing on smooth locomotion and more specifically the orientation aspect of it.

3 METHOD

Given that both head orientation and controller orientation locomotion are still commonly used, and the problems with smooth locomotion, this paper will focus on finding the differences in the user experience between the two orientation methods. This means the information gathered will mostly consist of qualitative data.

3.1 Research questions

The research questions are:

- Which orientation method feels more natural and immersive between head orientation locomotion and controller orientation locomotion?
- Between head orientation locomotion and controller orientation locomotion, which the easiest to use?
- Between head orientation locomotion and controller orientation locomotion, which technique causes less simulation sickness?

In order to answer the research questions, an experiment was used as research method. The factor in this case is the orientation method. A virtual reality application was created where test subjects would perform tasks using both methods. Since the goal was to gather qualitative data, it was decided that using questionnaires would be the best way. After completing the tasks, the participants were asked to take a simulator sickness questionnaire and a general usability questionnaire.

3.2 Hardware

The VR-application was running on a PC with an Intel core i7 CPU, a Nvidia GTI 980 GPU, 16 gigabytes of system memory and using Windows 10 64-bit as operating system. The VR-equipment used was the HTC Vive. The HTC Vive headset and controllers are fully tracked in 3D-space by two base stations, so their positions and orientations are known at all times.

3.3 Testing environment

The experiments were conducted in a quiet and private environment at the BTH VR lab. Participants in the study had approximately an area of three by three meters of tracked space for the VR experiment. The participants had to do the experiment standing up and were free to move and turn their bodies within the tracked area. The questionnaires were answered electronically on one of the lab computers.

3.4 Participants

The total number of participants in the experiment was fifteen people. All participants were volunteering and were students at BTH. Out of the fifteen participants, eleven were male and four were female. Twelve of them were international students and three were local students. When asked, three of the fifteen people answered they had previous experience with some form of VR. All the participants were chosen at random and had no connection to the researcher.

Before starting the experiment, the participants had to read an information letter describing the experiment and give their written consent. In the letter there is a statement that the participant can abort the experiment at any time if any discomfort or uneasiness was experienced. All fifteen people finished the experiment with no dropouts.

3.5 The experiment

For this to be an effective study it was decided that the experiment had to be practical and mimicked something with real life applications. At the same time, it should also leverage the usage of orientation by encouraging the user to look around. For this reason, an VR-application was developed with mechanics similar to a first-person shooter game.

One of the VR-controllers was used as a gun which shot a laser when the trigger was pulled. The controllers are fully modeled and represented in VR and the user will have to aim simply by using the direction of the controller as there is no crosshair. This was not a problem in the experiment as there is unlimited ammunition and there is no time limit. The beam of the laser is also clearly visible so the aim could be adjusted as needed.

Locomotion was accomplished by clicking on the touchpad on the face of the second controller. In the case of controller-based orientation it was the orientation of this second controller that determined the forward direction. To minimize simulator sickness the walking speed was kept low and the participants were told that time would not be a factor in the experiment. For this reason, common game mechanics such as jumping and sprinting were not implemented.

The virtual environment was created with a predetermined linear path. The course was approximately 170 times 50 square meters in size and was closed off with walls. The sides of the path were similarly closed off by using solid walls high enough to block the user from seeing what is behind them. This was a deliberate design choice to force the user to use more head movement to search for targets. Other than that, the participant was free to explore the environment at his/her own pace. Figure 1 shows an overview of the start section of the course.

At application start 12 red balloons, approximately 40 times 40 cm in size, was spawned at different locations on the course. Figure 2 shows an example of a balloon. There are a total of 23 spawn points and where the balloons will spawn was randomized for each execution. These spawning points were strategically chosen at locations that are not too easy to spot. These locations were usually nooks and crannies and forced the user to visually scan each area.

The participants each play through the course twice, once for each orientation method. Half of them started with Head-based orientation and the other half started with controller-based orientation. This is to minimize the impact of memorization of the course layout, as this might have an impact on the results. The locations of the balloons will be different between both playthroughs because of randomization.

The application was developed in the game development engine Unity version 19.3 and all original code was programmed in C# language. Additional graphical assets such as 3D models was downloaded from the Unity asset store. The design of the environment had a low-polygon aesthetic and even though using these additional assets have little meaning for the experiment, I wanted the environment to look somewhat pleasant and increase the immersion.

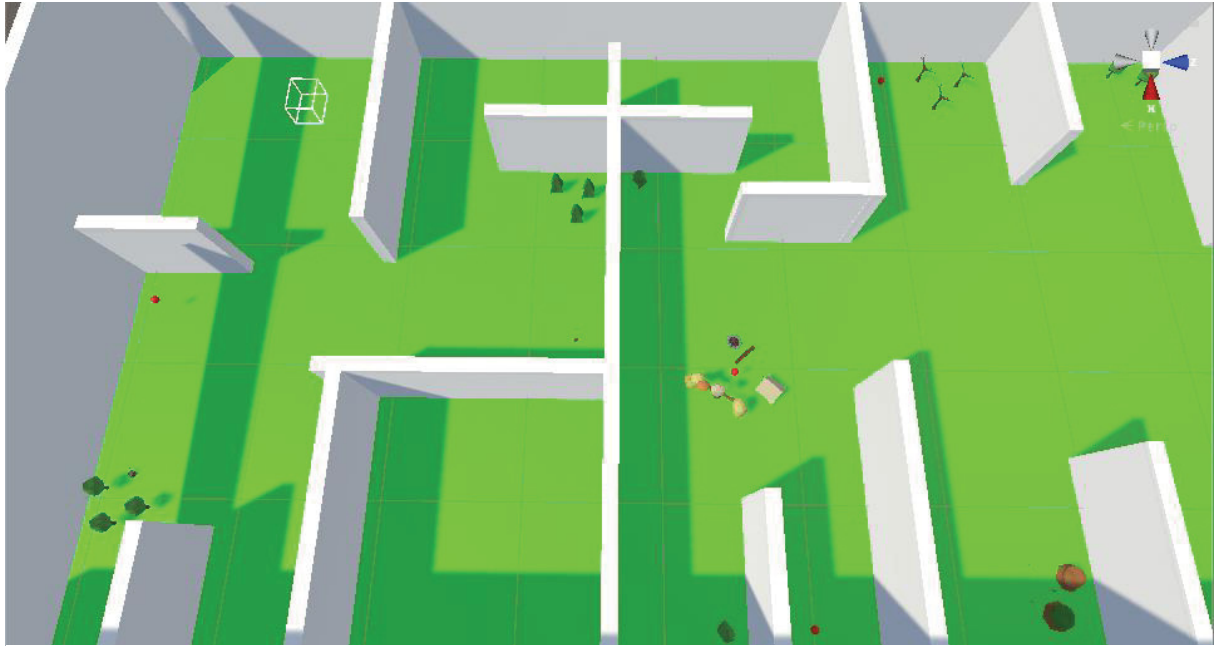


Figure 2. Section of the VR-course from a bird's eye view.



Figure 1. The VR-environment from a first person view.

3.6 The task

The user had to navigate through the course using one of the orientation methods and at the same time destroy any balloons they encounter on the path by shooting at them with the laser. The objective is to reach the end of the course marked by a stone gate. Each playthrough typically lasts about 8 minutes. After reaching the gate the number of balloons destroyed are collected.

3.7 Study procedure

Before the actual experiment each participant had to read an information letter which briefly described the process of the experiment and give their consent by signing it. I would then describe the process and the task in more detail (4 minutes). The participant was then asked about any previous experience with VR. Depending on the experience, the workings of the equipment was described in more or less detail. After the participant confirmed he/she had understood and had no further questions the participant was helped to put on the gear (2-3 minutes).

Then began the first run of the VR-application using one the orientation methods, where the participant had to complete the task described in section 3.6 (7-9 minutes). After completing the task, the participant was asked to fill out the simulator sickness questionnaire and then the usability questionnaire. This also gave the participant a break before the second part of the experiment started, in case of any simulator sickness (5 minutes). When the participant was ready, the second run of the VR-application began, using the other orientation method (7-9 minutes). Again, after completing the task the same questionnaires are answered (5 minutes). Typical length for one session is about 30-35 minutes.

3.8 Data collection

When the participant had completed a course by reaching the stone gate, the application was closed, and the number of balloons destroyed was logged. This data could be used as a performance measurement and it was later analyzed, to see if there were any differences between the two methods. The data was saved on a local text file on the hard drive. The data from the questionnaires were saved on a private cloud-drive.

3.9 Simulator sickness questionnaire

The experiment was designed to follow guidelines for minimizing simulation sickness, such as having low locomotion speed. Because of this, and combined with the short duration of the tests, the participants were not expected to get seriously simulation sick. The most commonly used questionnaire for evaluating simulator sickness is the simulator sickness questionnaire (SSQ) [9]. It was itself based on earlier work that attempted to quantify the symptoms of simulator sickness that was developed for military use, such as flight simulators. The SSQ has now been considered the standard to use for over 20 years.

Generally, the symptoms can be placed in the three categories of nausea, oculomotor (concerning vision) and disorientation. The questionnaire lists 16 items of symptoms of simulator sickness and asks the participant to rate them on a four-point scale, from none to severe.

In table 1 below, the distribution of the items is shown. Some items can belong to more than one category.

Symptoms	Nausea	Oculomotor	Disorientation
General discomfort	x	x	
Fatigue		x	
Headache		x	
Eye strain		x	
Difficulty focusing		x	x
Increased salivation	x		
Sweating	x		
Nausea	x		x
Difficulty concentrating	x	x	
Fullness of head			x
Blurred vision		x	x
Dizzy (eyes open)			x
Dizzy (eyes closed)			x
Vertigo			x
Stomach discomfort	x		
Burping	x		

Table 1. Distribution of items in symptom categories.

The participants were asked to take the questionnaire immediately after completing the task in VR so as to keep any symptoms fresh.

3.10 General usability questionnaire

To answer the research questions, a general usability questionnaire (GUQ) was created which in part takes inspiration from the questionnaires The Game Experience Questionnaire [13] and System Usability Scale [14]. It was taken after completing the SSQ. The GUQ was designed to assess the user's feelings and thoughts on the usability of the orientation method and how natural it felt. The questionnaire had six items which were ranked in a five-point Likert scale, from strongly disagree to strongly agree. The six items were:

1. I felt I could move in a natural way.
2. I felt aware of my surroundings in the game.
3. I thought this method was hard to use.
4. I felt like I could go where I wanted to.
5. I liked using this method.
6. I think this method made the task harder to complete.

4 RESULTS AND ANALYSIS

4.1 Usability questionnaire

The test results from the first part of the usability questionnaire are visualized in figure 3. Since the data collected from the Likert scale usability questionnaires is ordinal in nature, it was decided that a box plot diagram would be the most representative. The five-point scale was converted to numerical values one to five. The mean scores are visible as 'x' in the diagram for reference. The median was used as the measure of central tendency.

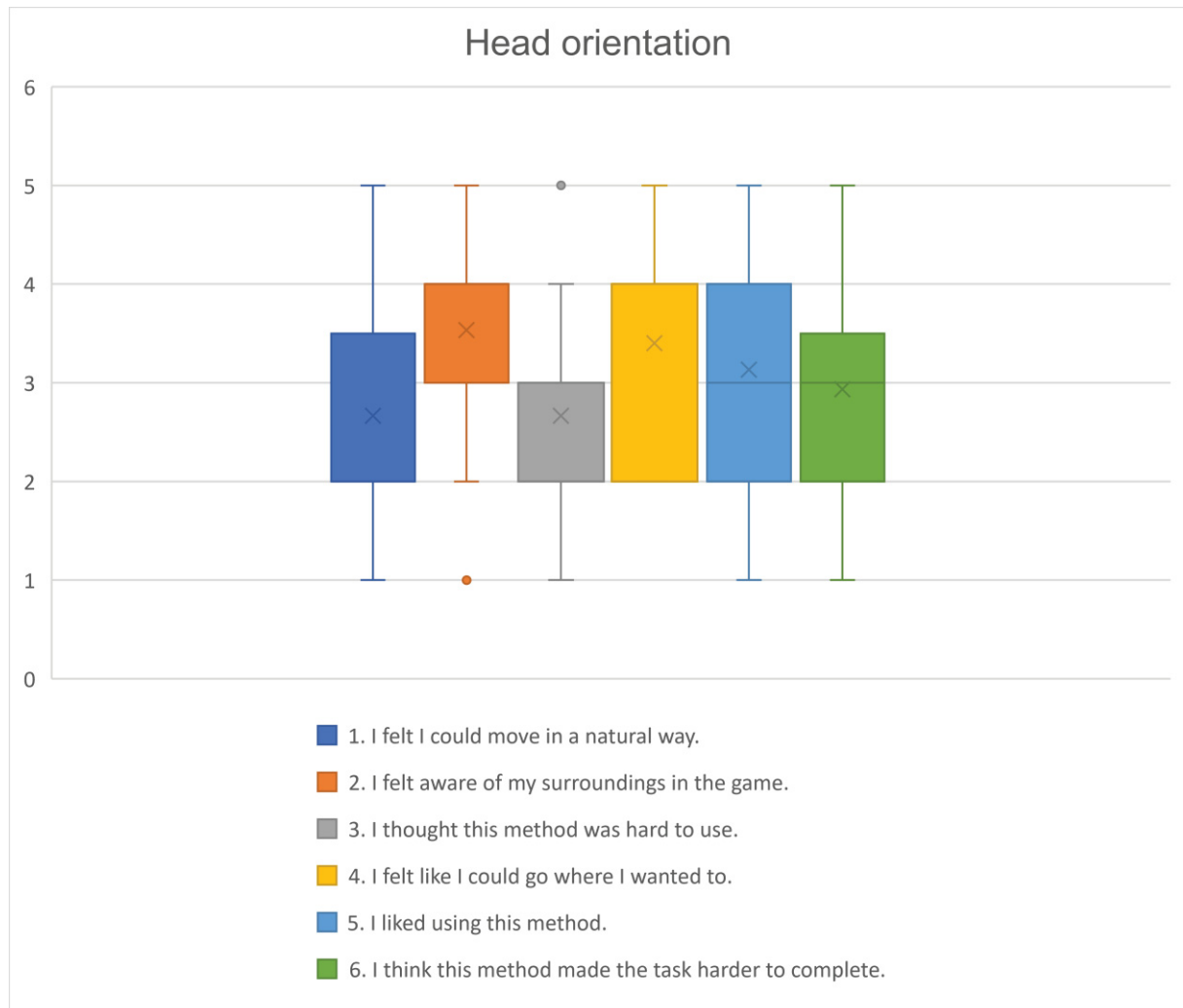


Figure 3. Box plot for usability questionnaire.

The range was high for data points and so was the inter-quartile range. The distribution was also fairly symmetrical. Two outliers were found for item two and three. From the table 1 we can see that subjects tend to disagree with feeling they could move in a natural way and disagreed with the method being hard to use. They generally agreed with being aware of their surroundings but gave a neutral ranking to the other items. Table 2 shows the mean and median values for the questionnaire.

Item	1	2	3	4	5	6
Mean	2.67	3.53	2.67	3.40	3.13	2.93
Median	2 Disagree	4 Agree	2 Disagree	3 Neutral	3 Neutral	3 Neutral

Table 2. Central tendency for head orientation.

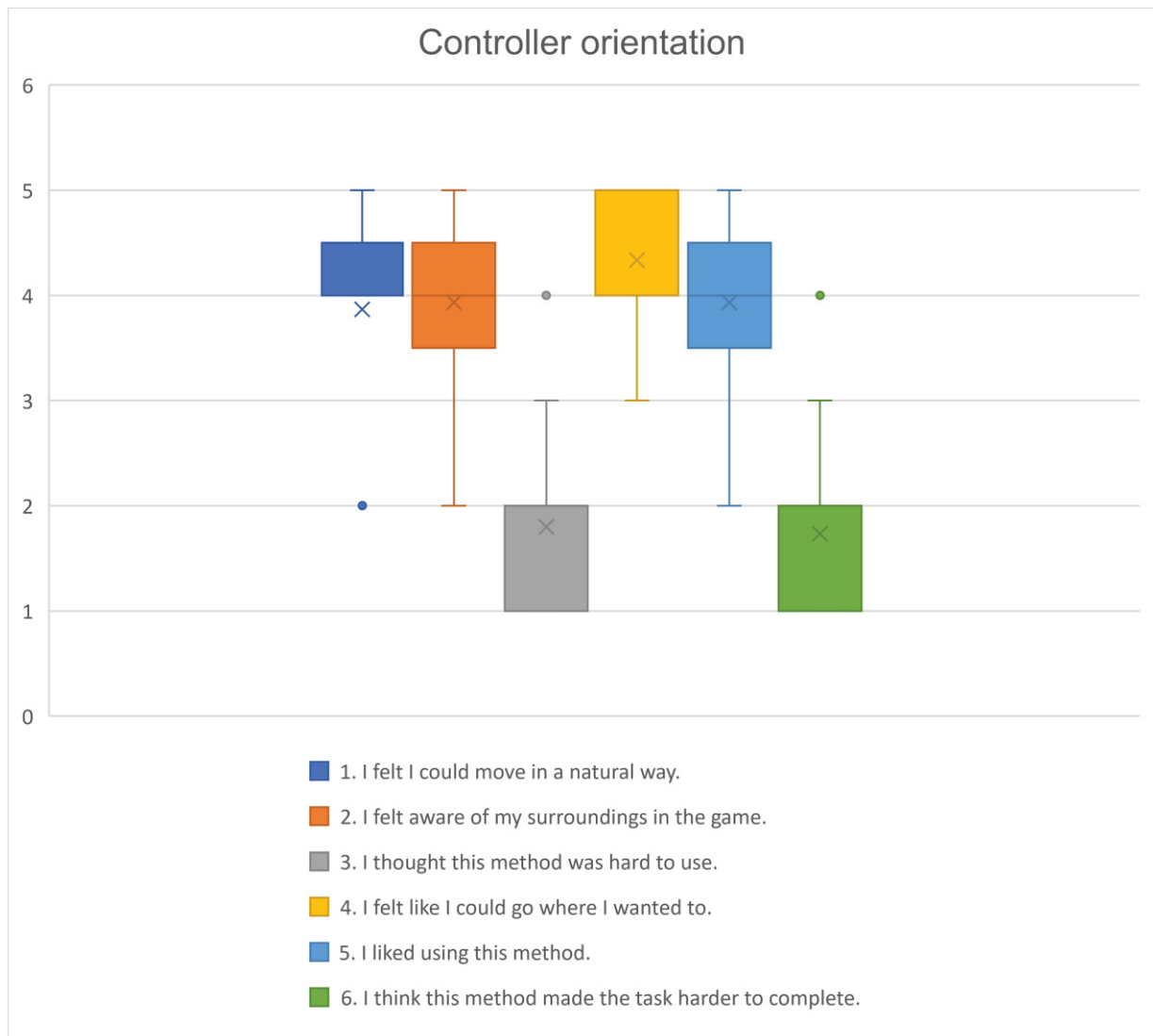


Figure 4. Controller orientation usability questionnaire.

In figure 4 the results from the second part is shown. We can see considerably smaller spread and inter-quartile ranges for controller orientation. The distribution is more skewed than with head orientation. Three outliers were found and was not included in the statistics. The participants gave higher rankings for the method regarding feeling natural movement and for feeling they could go where they wanted. They also liked using this method more and gave the method lower rankings for being hard to use. Table 3 shows the mean and median values.

Item	1	2	3	4	5	6
Mean	3.87	3.93	1.80	4.33	3.93	1.73
Median	4 Agree	4 Agree	2 Disagree	4 Agree	4 Agree	2 Disagree

Table 3. Central tendency for controller orientation.

To test for significance of paired ordinal data, the Wilcoxon signed-rank test was used. The W-value was looked at since it was recommended for $n < 20$. In table 4, the value in parenthesis signifies the critical value for $p < 0.05$ for each item. The size of the critical value depends on how many samples were valid. Only sample pairs that are not identical are considered valid.

Item	1	2	3	4	5	6
W-value	17 (17)	18 (10)	15.5 (13)	12 (10)	16 (13)	8 (13)
Significant	Yes	No	No	No	No	Yes

Table 4. Significant difference in usability questionnaire.

The calculations show that there is a significant difference in the results of items 1. “I felt I could move in a natural way”, and 6. “I think this method made the task harder to complete”.

4.2 Simulator sickness questionnaire

The SSQ total score was calculated using the formula: Total Score = $([1] + [2] + [3]) * 3.74$. [1], [2] and [3] are the total scores in the categories nausea, oculomotor and disorientation. The means and standard deviations are shown in table 5 and figure 5.

	Mean	Standard deviation
Head orientation	19.45	16.97
Controller orientation	18.7	18.65

Table 5. Mean total score for SSQ.



Figure 5. Bar chart of total score for SSQ.

The SSQ is considered to use an interval scale, so to test for significant difference, a t-test was made and compared to a significance level of 0.05. Since the experiment used paired samples, a two tailed paired t-test was used. A t-value of 0.19 and a p-value of 0.85 was calculated, which means there is no significant difference in simulator sickness scores between the two methods. The max possible total score is 179.52 so the means are on the low end. A high spread is observed in the scores relative to the mean. This could indicate that the data is unreliable, or more likely that the sensitivity to simulation sickness is highly subjective.

4.3 Performance

Performance was not a priority for this study since the focus was on usability. Nevertheless, the number of balloons destroyed was used as a measurement of performance. Figure 6 shows that participants who used controller orientation had an average of 11.6 balloons destroyed with a standard deviation of 0.51. This is only slightly higher than head orientation with an average of 11.13 balloons destroyed with standard deviation of 1.13. The values were inserted in a paired t-test, and it returned a t-value of 1.61 and a p-value of 0.13. With alpha at 0.05 it means no significant difference was found in performance.

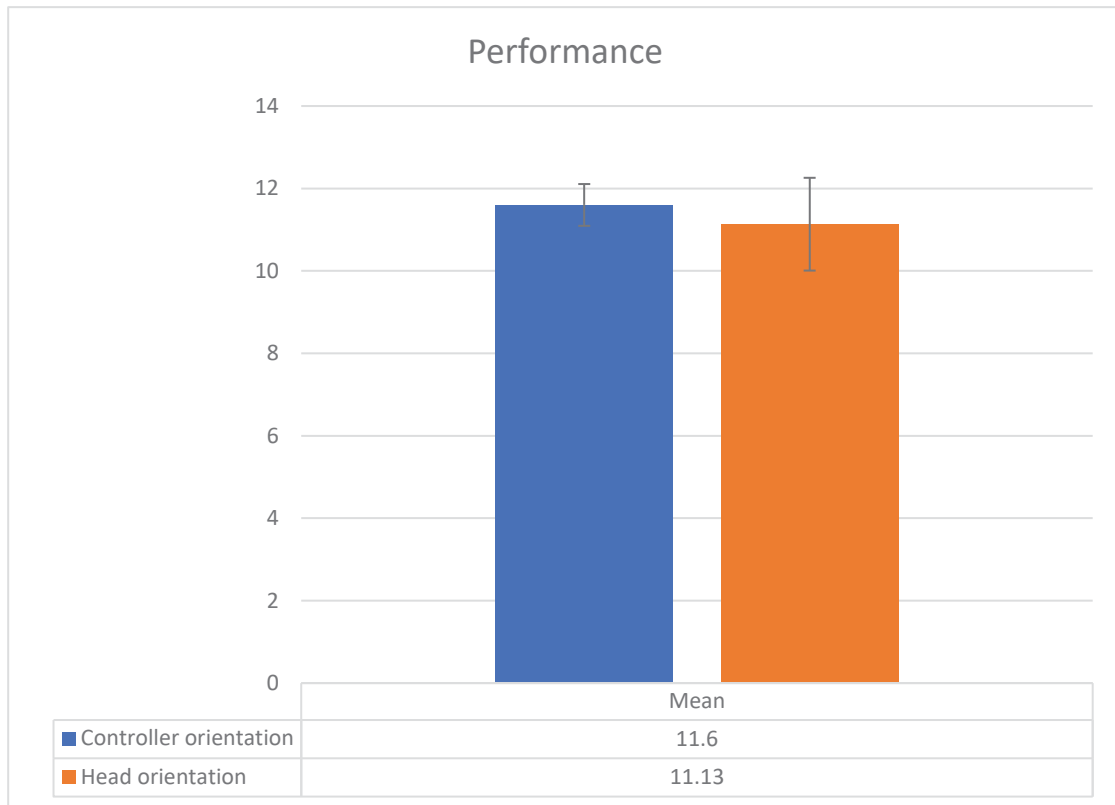


Figure 6. Means of balloons destroyed.

5 DISCUSSION

To reiterate the research questions, they were:

- Which orientation method feels more natural and immersive between head orientation locomotion and controller orientation locomotion?
- Between head orientation locomotion and controller orientation locomotion, which the easiest to use.
- Between head orientation locomotion and controller orientation locomotion, which technique causes less simulation sickness?

To answer the first question, the application in the experiment was designed to be similar to real applications, and most commercial VR applications are games, especially games with some type of gunplay. However, with the limited time at disposal, a lot of mechanics that is common in typical first-person shooter games had to be simplified. There were only static unmoving targets which was one simplification, but in the end, the application did a serviceable job. Since this study was a comparison between two different types of control methods in VR, that aspect had to be focused on in the experiment. This again, is a common component in games where the player has to actively search for the next objective or need to be on the lookout for enemies.

A preference for controller orientation locomotion was expected, since it enables the player to walk and look simultaneously. This was proved by comparing the usability questionnaire, where controller orientation ranked higher in perceived naturalness and likeability, and significantly so in the former. The fact it ranked higher in item 4. "I felt like I could go where I wanted to", can be interpreted as: it felt less restrictive than head orientation. What was not expected was that controller orientation also was easier to use. Users ranked it as less hard to use and there was a significant difference in making the task less hard to complete. Even though it felt less restrictive, it still adds an extra layer of abstraction, as humans probably are not used to pointing in the direction that they want their feet to move in. While only three of them reported they had tried VR previously, the results could be explained by all subjects being young students and therefore might have been used to similar controls from video games.

The samples did have convenience bias, since all the subjects recruited were students at BTH. Ideally, the participants should be from other age groups and demographics as well. Perhaps that would have yielded different results for which method was easiest to use, as individuals without gaming experience or similar technology could have preferred head orientation [10].

For the third research question, there was no significant difference found between the two methods. This was somewhat expected since the experiment was deliberately designed to have a low chance at causing simulator sickness. Smooth locomotion is known to cause simulator sickness, so this was minimized by making the walking speed low. Additionally, there was no time limit so the subjects would not feel rushed.

A timed experiment was initially being considered as another performance metric, but it was decided against, to reduce the chance of simulator sickness. Because of the low walking speed and having no time pressure, the performance between the methods was not expected to make a big difference, so it was not made a priority. Instead the priority was to focus on the usability and the experience. The belief that performance made little difference in this test scenario was confirmed by the performance metric in this experiment, where the results were very similar.

While controller orientation locomotion was as good or better in all categories, head orientation locomotion might still be viable for beginners in VR, where the arguably lower complexity can be a benefit. Also, for low end VR devices, such as mobile phone VR, it is often the only choice for locomotion.

6 CONCLUSION AND FUTURE WORK

Smooth locomotion in VR is not for everyone. It is more prone to cause simulation sickness than teleportation locomotion. But related work has shown that for people who have a high tolerance it might be the most immersive kind of locomotion.

This study shows that the majority users prefer using controller-oriented locomotion over head-oriented locomotion in tasks that involves searching and pathfinding. The results show that it is more suitable for game genres such as first-person shooters or similar. Controller oriented locomotion was ranked higher for perceived naturalness and likeability and was ranked lower for items relating to restrictiveness and difficulty. The reliability of the results could be improved by having a larger sample size and having more variation in the demographics.

Head oriented locomotion is still valid for VR devices with no hand-controller input, such as mobile phone VR. There is related work that show how using lateral movement for locomotion is more immersive than using a joystick.

Future VR-devices might have more tracking devices than the headset and hand-controllers that is standard today. The next step might be experimenting with leg or foot trackers, which will give the true orientation of the users' feet and thereby, in theory, would make it a more natural and immersive experience. There are already products such as the Vive-tracker on the market, but it is decidedly a niche that have not seen many implementations. During research omnidirectional treadmills have also come up. It is unclear if these offer any improvement for simulation-sickness but might be more immersive to use. These units are typically very expensive and cumbersome so they might never be viable consumer products. It is also a question about feasibility, if it is worth using, but only more experiments can answer that.

7 REFERENCES

- [1] Geršak, G., Lu, H., & Guna, J. (2018). Effect of VR technology matureness on VR sickness. *Multimedia Tools and Applications*, , 1-17. doi:10.1007/s11042-018-6969-2
- [2] Thöndel, E. (2017). interactive motion platforms and virtual reality for vehicle simulators. *Acta Polytechnica CTU Proceedings*, 12, 108-111. doi:10.14311/APP.2017.12.0108
- [3] Jorge C. S. Cardoso. 2016. Comparison of gesture, gamepad, and gaze-based locomotion for VR worlds. In *Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology (VRST '16)*. Association for Computing Machinery, New York, NY, USA, 319–320. DOI:<https://doi.org/10.1145/2993369.2996327>
- [4] http://www.cybersickness.org/Simulator_Sickness_Questionnaire.htm
- [5] Reski, N., Alissandrakis, A. Open data exploration in virtual reality: a comparative study of input technology. *Virtual Reality* 24, 1–22 (2020). <https://doi.org/10.1007/s10055-019-00378-w>
- [6] Medeiros D, Cordeiro E, Mendes D, Sousa M, Raposo A, Ferreira A, Jorge J (2016) Effects of speed and transitions on target-based travel techniques. In: *Proceedings of the 22nd ACM conference on virtual reality software and technology—VRST '16*, ACM, New York, NY, USA, pp 327–328. <https://doi.org/10.1145/2993369.2996348>
- [7] Tregillus S, Al Zayer M, Folmer E (2017) Handsfree omnidirectional VR navigation using head tilt. In: *Proceedings of the 2017 CHI conference on human factors in computing systems—CHI '17*, ACM, New York, NY, USA, pp 4063–4068. <https://doi.org/10.1145/3025453.3025521>
- [8] Lanman D, Fuchs H, Mine M, McDowall I, Abrash M (2014) Put on your 3D glasses now: the past, present, and future of virtual and augmented reality. In: *ACM SIGGRAPH 2014 Courses—SIGGRAPH '14*, ACM, New York, NY, USA, pp 12:1–12:173. <https://doi.org/10.1145/2614028.2628332>
- [9] Kennedy RS, Lane NE, Berbaum KS, Lilienthal MG (1993) Simulator Sickness Questionnaire: an enhanced method for quantifying simulator sickness. *Int J Aviat Psychol* 3(3):203–220. https://doi.org/10.1207/s15327108ijap0303_3
- [10] Georgios Lepouras. 2018. Comparing methods for numerical input in immersive virtual environments. *Virtual Real.* 22, 1 (March 2018), 63–77. DOI:<https://doi.org/10.1007/s10055-017-0312-5>
- [11] James P, (2016) 3 Years Ago the Oculus Rift DK1 Shipped, Here's a Quick Look Back. Retrieved from <https://www.roadtovr.com/3-years-ago-the-oculus-rift-dk1-shipped-heres-a-quick-look-back/>
- [12] Liu A. (December 10th 2019) Analytics / Room Scale VR Explained: The Most Important Concept in VR. Retrieved from <https://cognitive3d.com/blog/room-scale-vr>

[13] Poels, K., de Kort, Y. A. W., & IJsselstein, W. A. (2007). D3.3 : Game Experience Questionnaire: development of a self-report measure to assess the psychological impact of digital games. Eindhoven: Technische Universiteit Eindhoven.

[14] Brooke, J B (1986). SUS – System Usability Scale (SUS). Retrieved from <https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html>

