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# INVESTIGATION INTO VIRTUAL REALITY MOVEMENT METHODS

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**Abstract**

*This paper critically examines different methods for traversing virtual reality (VR) environments, providing an analysis of their effectiveness. The primary objective is to outline and assess various locomotion techniques, including, but not limited to, teleportation and joystick-based movement. Each method is evaluated based on key performance indicators: its believability, which measures how well the movement aligns with a user's natural expectations of motion; its smoothness, which speaks to the fluidity and consistency of the movement; and its potential to induce motion sickness, a critical factor for long-term playability and user comfort. Through this detailed comparative analysis, the paper aims to draw a well-supported conclusion regarding the optimal VR locomotion method, identifying which traversal technique offers the most balanced and effective solution for developers and users.*

**CCS Concepts**

• ***Computing methodologies*** → *Perception;* • ***Human-centered computing*** → *Interactive systems and tools;* ***Virtual reality;***

## 1. Introduction

There are many systems which can be utilised within a VR space, such as aiming, communicating, grabbing objects, but in almost any VR environment a method of locomotion will be required. Due to its necessity, a plethora of differing movement methods have been designed, researched, and implemented into VR games and experiences. The goal of this paper is to analyse some of these methods and produce a small project to attempt to assess the factors that make them viable or superior options for games in the future.

A study created by [Bol17] attempted to outline which locomotion techniques had been most studied within research papers, by taking 36 research papers and tracking the various methods those papers studied. Boletsis' study showed that the two most studied and analysed methods were walking in place and joystick movement. These two methods combined were featured in almost half the research methods studied, with some of the studies analysed focused on both methods at once [SSMA*14] [BRKD16] due to their essential nature. These two cornerstones of movement within VR will be studied as a part of this experiment and shall be further outlined below.

A hybrid method of joystick and walking in place was outlined in a different paper [RVB13]. In that paper, in addition to analysing joystick travel and walking-based travel, Ruddle *et al* researched a method known as head mounted display (HMD) view-directional travel. This method simplifies the use of a joystick when moving within a VR space. While with joystick travel the user can use their controller to look around and move in all directions, HMD view-directional travel limits controller interactions to strictly movement. To traverse fully, the player is expected to physically rotate themselves in relation to the direction they are looking. This hybrid locomotion method, designed to combine the two most used methods, will also be analysed in this paper.

A final method to consider is point and click teleportation. Teleportation was outlined by [Bol17] in his analysis of different studied VR locomotion methods, but was not as popular as joystick or walking in place. While teleportation is less studied, teleportation is the standard movement method within the VR games industry [BRKD16], and is shown to be less likely to give people cybersickness [BRKD16]. It is for these reasons that the final locomotion method that will be analysed in this paper will be teleportation.

## 2. Related Work

This section reviews previous research on VR locomotion and looks deeper into the specific areas of interest for this paper including joystick movement, HMD view-directional travel, walking-based, and teleportation.

### 2.1. Joystick Movement

The movement of the joystick in this paper refers to a movement system in which the participant uses a joystick for both translation and rotation, a system sometimes referred to as the translation of the joystick and the rotation of the joystick [BC19b]. The movement of the joystick is the focus of many studies [Bol17], and is used in many games on the market.

Examples of VR games that feature joystick movement are Phasmaphobia (Kinetic Games, 2020), which implements a variety of movement methods. Phasmaphobia is an excellent example for this research paper, as it implements all four methods of VR locomotion being studied. In addition to Phasmaphobia, joystick movement is also used in many VR vehicle driving games, from racing games such as F1® 24 (Codemasters, 2024) to military games such as War Thunder (Gaijin Entertainment, 2013).

Although studies show that joystick movement is more likely to cause a player to be motion sick than other methods [AWBM17], controllers, compared to other methods such as omnidirectional treadmills, are much more affordable. If a player cannot afford or does not have a VR controller, their other option would be joystick movement.

### 2.2. HMD view-directional travel

HMD view-directional travel in this paper refers to a movement system in which the player physically rotates their body to rotate in the game space, while using a controller to move within the game. The controller can move the player in all directions but moves relative to the direction the player is facing.

While a study by [RVB13] shows that HDM view-directional travel has a lower accuracy compared to joystick moveability, a statistic measured by detecting collision time with the environment. It showed participants spent less time stationary – implying that players felt more comfortable and confident with HDM view-directional travel. It is to be noted that in their study, Ruddle *et al* used a variant of joystick movement which was not implemented in a VR space, rather using a flat screen (FS) view.

### 2.3. Walking Based

Walking based movement within a VR space refers to the act of making a player physically walk to move around. This approach can be achieved in two ways, all of which have supporting research showing their benefits. The first approach is to use an omnidirectional treadmill to get the player to walk around while being in a stationary position. In a comparative study undertaken by [Bol17], it was shown that using a "treadmill-like input device" is the most popular locomotion technique. This claim took 11 VR locomotion techniques into account to put forward this claim, having taken all the methods discussed in this paper into account.

For those without the ability to use an omnidirectional treadmill, an alternative method for walking based movement was outlined by [BC19a], in which players would use a mix of arm swinging and walking on the spot to locomote. While arm swinging was a method compared with walking-in-place by [Bol17], this method takes in both the player's arm position and their leg movements to calculate their rate of movement.

### 2.4. Teleportation

Teleportation within the context of this paper refers to the movement method more commonly referred to as 'point and teleport' [Figure 1]. This method involves a player holding down a button, which will highlight the location their controller is pointing at. When the button is released, the player is instantaneously teleported to the highlighted location.

**Figure 1:** *A visualisation of the 'Point and Teleport' movement method [BRKD16]*

Point and Teleport is an industry standard movement method seen in most AAA games, with examples such as Half-Life Alyx (Valve Corporation, 2020) and Phasmophobia (Kinetic Games, 2020). The creation of this method is attributed to [BRKD16], who created a comparative research paper comparing the standards at the time – joystick movement and walking in place – with their newly designed movement methodology. Their experiment showed that users preferred the point and teleport method compared to the other methods studied.

These two papers [FSW17] and [BRKD16] show that a free teleport approach to the point and teleport method is the best to be implemented in this study. It also implies that teleportation could prove to be a more effective locomotion method, making it an excellent approach for study.

## 3. Methodology

Upon the completion of the testing phase of this project, six participants had taken part in the study, with each participant completing all levels in full – responding to the SSQ, IPQ, SUS and DAQ questionnaires after each locomotion method tested, as well as having their number of collisions monitored, plus their internal balance fluctuations monitored using the Nintendo Wii Balance Board.

Participants' feedback has been broken down into the four locomotion methods tested, so that the data can be sorted. The SSQ's results [Figure 2] brought in very similar results across all methods, with a total difference of three between all methods. The highest score achievable on the SSQ was 192 across the four participants, and so even the lowest score, that being 182 from HMD view-directional travel and walking based, is still considered a good score.

### 3.1. Outlining the Optimal Movement Method

There are a range of variables to consider when measuring the benefits and negatives of various VR movement methods. Research conducted by [BC19b] outlines five measures for testing a VR locomotion method. The first method outlined is performance – measuring the speed and efficiency of the test scenario the participants are put in. The next method outlined by [BC19b] was levels of sickness induced, with higher levels of sickness reflecting negatively on the method. To measure sickness a Nintendo Wii Balance Board was used to measure the participants initial sway, then after each test get the player back on the Nintendo Wii Balance Board in their HMD to get a new reading [AWBM17]. Readings were taken with eyes open and eyes closed to show how they swayed in place – showing readings for imbalance and cyber sickness. This method of balance testing was inspired by [CLSG14] who outlined the cost-effective method of imbalance testing.

In addition to using the Nintendo Wii Balance Board to test a participant's sway, levels of sickness will also be recorded using a questionnaire. The primary way of recording a participant's sickness levels is the Simulator Sickness Questionnaire (SSQ). This questionnaire, created by [KLBL93], asks participants to rate various physical symptoms from none to severe in order to outline the severity of "simulator sickness". This questionnaire has proved very applicable to VR cybersickness testing, and has been used since to measure the severity of sickness felt by participants [LEB14]. It is for this reason that cybersickness will be measured with the SSQ in addition to the Nintendo Wii Balance Board

The other variables considered by [BC19b] were presence, usability, and comfort. To measure these values, pre-existing questionnaires and scales were used to gain participant feedback. To measure presence, the Ingroup Presence Questionnaire (IPQ) [SFR01] was implemented, which contained 14 questions answered on a scale of 0-6, giving a total score out of 84.

Usability was measured using the System Usability Scale (SUS) [B*96], comprised of 10 statements to which the player had to show their agreement on a scale of 1-5, feeding back a SUS score ranging from 0-100.

Finally, comfort was measured using the Device Assessment Questionnaire (DAQ) [DKM99]. The DAQ comprises of 13 items, each being scored on a scale of 1-5 similar to the SUS. While [BC19b] altered some of the questions seen in the DAQ, this paper will be using the questionnaire as created as its standard phrasing fits the study well.

To conclude, during the testing process, participants' performances will be recorded, and their balance will be measured before and after using a Nintendo Wii Balance Board, according to the method outlined by [CLSG14]. After the completion of a test, the participant will fill out a questionnaire, which will comprise of the questions outlined in the IPQ, SUS and DAQ. In addition to these questions, minor questions around the topic of cybersickness may be asked.

### 3.2. Testing Methodology

Before testing, the participant will become accustomed to standing on the Nintendo Wii Balance Board, and their base-line internal balance will be recorded. The average balance score recorded on a Nintendo Wii Balance Board fluctuates between 0-2. The participant's maximum balance fluctuation will be recorded.

The project that will be tested is based in a small home containing eight rooms. The participant will spend six minutes with a movement method searching the scene for balls, each just larger than a fist. These balls are hidden with varying degrees of difficulty, with easier ones out on a table and harder ones at the back of drawers.

After six minutes searching, the participant will take off the headset and stand on the Nintendo Wii Balance Board to have their maximum balance fluctuation recorded. The participant will then respond to a questionnaire regarding the six minutes of testing they underwent, using a combination of SSQ, IPQ, SUS and DAQ tests.

## 4. Results & Discussion

After 20 minutes of testing, four of the six participants recorded that they found the non-diegetic UI preferable to the diegetic UI. While this is not a majority strong enough to decisively conclude the best overall UI use, it can be indicative to the opinion of the market.

However, when recording feedback, there were some stances that the entirety of the participants fed back. Firstly, within the context of VR, non-diegetic UI is more understandable and more accessible to the user. Participants stated that this was due to the fact that in order to make UI diegetic within a VR space, it had to be limited to hands or the player's physical body. This made it harder to access during a game, especially during more fast-paced or time sensitive sections – whereas with the information always floating in front of the player it was easier to see.

Furthermore, floating information had significant drawbacks. All six participants agreed that the diegetic UI made for a far more immersive gaming experience. Some participants addressed the ease of use, stating that even though the non-diegetic UI was easier to see and get information from quickly they preferred the harder-to-access diegetic UI, as it made them feel as though they were really within the game.

The SSQ's main focus was how severely sickness was induced among participants and so having all four methods show similar scores implies motion sickness, when considering the four methods, is a too large of a factor to consider [Figure 2]. The other method this paper took to record motion sickness within the participant was the use of a Nintendo Nintendo Wii Balance Board to record the participant's internal balance. It is to be noted that upon taking the average balance fluctuation across participants, the

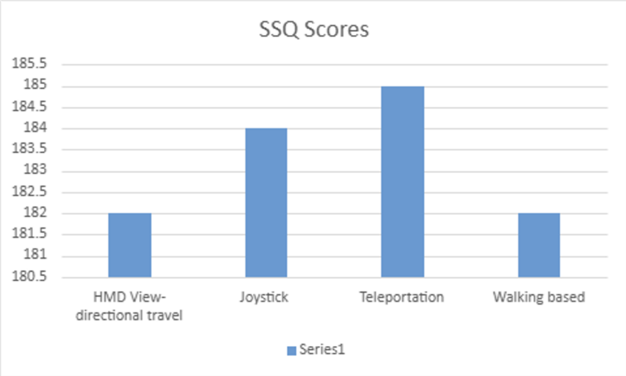


**Figure 2:** *SSQ Scores*

data recorded aligned with the responses to the SSQ. Teleportation, which held the highest SSQ score, showed the least balance change. The highest balance change was shown by walking based locomotion – which scored joint lowest on the SSQ, with HMD view-directional travel scoring a similarly high balance score.

Notable feedback from the SSQ was that the joystick movement scored poorly for general discomfort compared to other methods. In addition, HMD view-directional travel and walking based locomotion showed increased symptoms of vertigo compared to other methods.

The IPQ, on the other hand, showed far more difference between various methods [Figure 3]. Results showed that the walking based method tested extremely highly for immersion compared to other methods – scoring a total of 180 on the questionnaire across the 4 participants. The maximum possible result of the IPQ was a score of 336, and so a score of 180 compared to 117 scored by teleportation is almost a difference of 20% the total possible score.

The aim of the IPQ is to measure the user's presence and immersion in the scene [SFR01], and so the results gathered reflect that the walking based movement method is substantially more immersive than other methods.

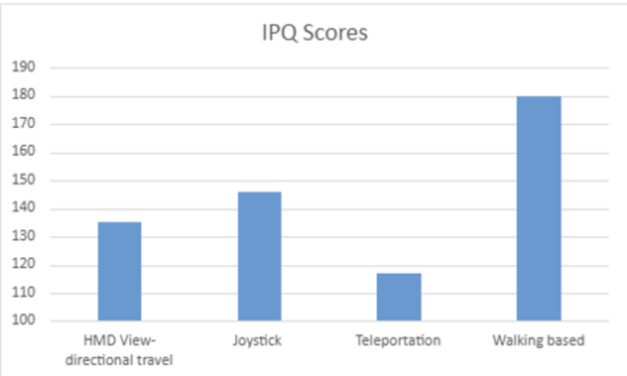


**Figure 3:** *IPQ Scores*

While the IPQ may have reflected well for immersion upon the walking based methodology, the HMD view-direction travel method performed highly on the SUS [Figure 4]. The maximum possible usability score achievable on the SUS across the four participants is 200, and so the score achieved by HMD view-directional travel – 175 – compared with that scored by joystick movement – 141 – is nearly a 20% difference.

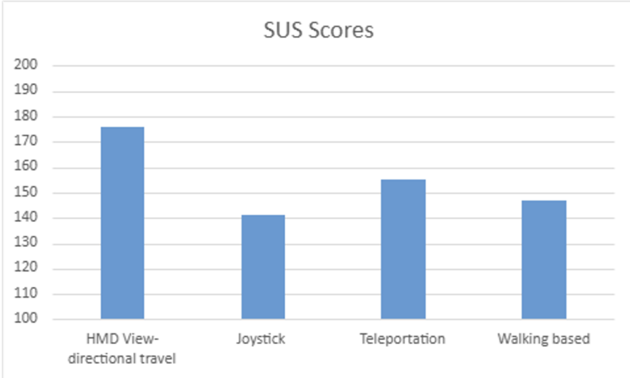


**Figure 4:** *SUS Scores*

The aim of the SUS is to outline how usable a methodology is, and so the high score from HMD view-directional travel reflects that the simple forward/backward control scheme is easy to understand and use quickly. In comparison, the low score of the joystick shows that the additional feature that it contained – forcing the player to rotate with the controller rather than their bodies – was found to be unnecessarily complex compared to HMD view-directional travel.

The final questionnaire, the DAQ, outlined the level of comfort felt by the participant when using the movement method. The highest achievable score across the four participants for the DAQ was 204. Similarly to the SUS, HMD view-directional travel scored highly in comparison to other methodologies, with a score of 192/204. The similarity between the SUS [Figure 4] and the DAQ [Figure 5] is logical, as usability and comfort can often complement one another.

However, it is of note that though Teleportation scored as easier to use than walking based in the SUS, walking based movement was recorded as more comfortable by the DAQ in comparison to Teleportation.

Whilst the SUS and the DAQ implied that HMD view-directional travel was the most comfortable and easy to use, the collisions made by participants during play showed that it was the mode of locomotion that had players moving with the least accuracy. A total of 26 collisions was recorded for HMD view-directional travel across participants. This value was closely followed by teleportation, which saw 24 collisions.

Comparatively, joystick movement saw far fewer collisions, with only 13 – half of that of HMD view-directional travel. Due to how similar joystick movement is to HMD view-direction travel, this value implies that using a joystick to control rotation allows the participant to aim with much greater accuracy. Pairing this data with

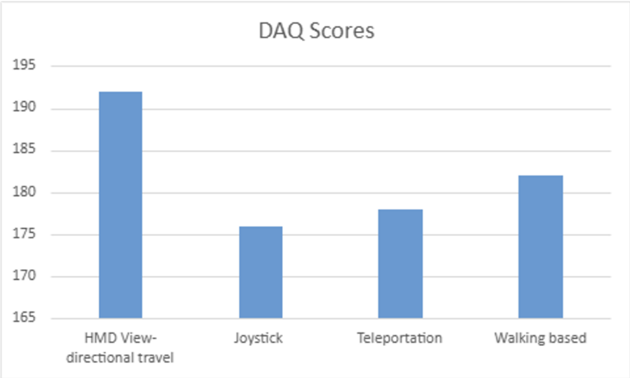


**Figure 5:** *DAQ Scores*

joystick's lower fluctuation in balance when compared to HMD view-directional travel could be indicative that a participant's internal balance can affect accuracy of movement within VR.

Finally, the lowest number of collisions recorded was with the walking-based movement. With only 11 total collisions recorded, it is clear due to the similarities walking has to a participant they have much higher control of where they are moving. Thus, the most accurate movement system is walking based.

## 5. Conclusion

The testing that was performed brought forward a vast selection of data that can be used to analyse which locomotion method is superior to another. Firstly, while the SSQ's results may show that Teleportation and Joystick movement performed better, the difference between the highest and lowest scores on the questionnaire were under 2%. It is for this reason that this paper suggests that cybersickness effects all locomotion methods similarly – and so when deciding which method is superior it should not be heavily considered.

The IPQ, the SUS, and the DAQ on the other hand do show significant differences in data feedback. It is clear from the IPQ that when considering immersion within a game, walking based is clearly the superior method – scoring significantly higher than other methodologies. However, results of the SUS and the DAQ show the higher comfort and usability scores of HMD view-directional travel, showing that it too has larger benefits with VR games. Due to its high score on the questionnaires, it can be concluded that the average VR experience lends itself well to HMD view-directional travel, being easy to understand and use.

This paper concludes that for the average VR experience, HMD view-directional travel is the best option for locomotion. Its ease of use and understanding can make games easy to pick up and play, without too much cognitive effort being required for moving.

## 6. Acknowledgements

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