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Human-Joystick VR Locomotion technique: An empirical approach

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1 Preface

This research represents an empirical study done in Virtual Reality (VR), more specifically in the area of locomotion techniques used in current VR settings. The master thesis was performed during the Spring semester of 2018. It represents additional research work in improving the field of Human-Joystick locomotion technique by providing with additional user-case scenarios. The author was initially introduced to VR Locomotion during the initial stages of Spring semester.

This project was undertaken as a master thesis within the Department of Computer Science (IDI) at the Norwegian University of Science and Technology (NTNU). The targeted audience of this research study includes game enthusiast, particularly in the area of Virtual Reality (VR), who seek to pursue knowledge and further improvement on current VR Locomotion techniques. A background in Computer Science is preferable for understandint many of the concepts explained, however no prior knowledge in Virtual Reality is necessary as many of the key terminologies are explained in much detail.

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A.A.

Abstract

Virtual Reality (VR) has been successfully applied with a broad range of locomotion techniques. Many of these locomotion techniques have different challenges and benefits. In the following thesis, the Human-Joystick (or leaning based) technique is explored in depth. The aforementioned locomotion technique is explored through an empirical approach. This approach is used to assess the underlying challenges that can be present. For this, a prototype of a VR application aimed to assess speed of completion is conceived and tested. A total of 20 users tested the prototype during a two-trial period. Results showed that there is an increase in Speed of completion obtained by the users from the First try to the Second try. This results are to be expected and are well discussed and interpreted. Furthermore, results show that Human-Joystick technique is an efficient locomotion technique in terms of ease of use and speed. Moreover, a qualitative review is done based on the feedback provided by each participant. A significant contribution of the user testing lies in the proposed qualitative challenges that are explained. These qualitative challenges serve as opportunities for future game designers and developers to build upon. Many proposed future work recommendations are done which can benefit game designers, developers and enthusiasts alike.

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2 Introduction

2.1 Topic covered

During the last few years, Virtual Reality (VR) has undergone a major hardware-driven revival, which has had significant effects on the ways users experience and use VR [3]. Hardware upgrades on HMDs [4] and technological advances in human-computer interaction [5] has increased the interest of academics to venture in the VR research spectrum. For many, the introduction of the Oculus Rift Development Kit in 2013 is considered a significant milestone for VR. Thanks to the Oculus Rift Development Kit's release, VR became accessible, up-to-date and relevant again [6, 7, 8]. VR kits such as the HTC VIVE and Oculus Rift provide with low-cost hardware for the enthusiasts and/or researchers to build different solutions. On top of that, the quality of virtual environments has increase due to the rapid development of better and more realistic graphics [9].

Currently VR is still undergoing a lot of changes in different features hardware and/or software related, among one of them is the research done regarding locomotion (another word for navigation) in Virtual Environments. Current VR kits provide with sensors that detect the position of the HMD and its peripheral devices. This provides with a basic walking locomotion technique (better known as Walk In Place), however, limitations on the amount the user can walk are perceived based on the physical space. In order to tackle this problematic, several locomotion techniques have been proposed. One of the most common techniques used by today's games is the teleportation, which proves to be quite useful in many game contexts. However, one of the main goals of Virtual Reality is to immerse the user in the world, not only visually but by actions as well. As such, different devices are used in order to build prototypes and test the techniques.

Costas et al [3] performed a systematic literature review on all of the different locomotion techniques from 2014-2017. The review analyzes the VR locomotion techniques that have been studied, their interaction-related characteristics and the research topics that were addressed in these studies. 11 VR locomotion techniques were identified. Consequently, the 11 VR locomotion techniques were classified and a new proposed typology was presented. This typology classifies the VR locomotion techniques as follows:

- Motion-Based: Walk-In-Place (WIP), Redirected Walking, Gesture-Based, Arm-Swinging, Re-orientation.
- Room Scale-Based: Real-Walking
- Controller-Based: Joystick, Human-Joystick (Leaning-Based locomotion where the person acts as the joystick alongside a sensored base), Chair-Based, Head-Directed
- Teleportation-Based: Point and Teleport

The considerable advances in current VR technologies has opened up the discovery of such novel solutions to high complexity problems that were previously unsolved or ignored. However, despite this advancements, many VR locomotion techniques have been struggling on achieving high levels of quality and performance accuracy. Some VR Locomotion techniques like Walk-In-Place (WIP) and Controller/Joystick have been abundantly researched.

However, other techniques like Reorientation and Human-Joystick are still open for more research to be done in order to assess or discover their full potentials. Many studies have used a comparative approach to determine which VR locomotion technique is "superior". However, insufficient research is done to fully determine positive and negative features of each technique, rather than searching for the best VR Locomotion technique. Therefore, an empirical approach on Human-Joystick VR Locomotion technique will be used to evaluate the advantages and disadvantages that can be found. This research study is primarily focused on investigating the potential of using the Nintendo Wii Balance Board and HTC Vive in different Virtual Scenarios. The investigation will try to assess accuracy and speed of completion. A serious game approach will be used to determine the aforementioned features. As such, we investigate on game design elements and techniques to intrinsically motivate users to engage in the locomotion activity without any additional incentive or prize to be gained. Finally, the data collected shall be used and analyzed so that a clear view on how effective current devices are on assessing the Human-Joystick technique.

2.2 Keywords

Virtual Reality; Locomotion; VR Locomotion; Wii Balance Board; Human-Joystick Technique

2.3 Problem Description

This research study will try to answer the problems identified in the literature. Human-Joystick VR Locomotion technique is one of the Controller-based techniques which has been done very little research, as shown by Boletsis et al [3]. According to the chart and typology that Boletsis proposed, there are very few papers released with topics covering Virtual Reality Humnan-Joystick technique(see Figure 1). Therefore, more research is needed to address current underlying benefits and challenges that the Human-Joystick technique might have. This problem of lack of research is proposed to be eliminated by doing an empirical research on the aforementioned technique, therefore building a prototype that will be observed, tested and the results documented. If the potential for immersive VEs is to be realized, a perceptually accurate interface that allows virtual within the constraints of everyday space must be developed. Finding ways to spatially navigate in VEs that perform comparably to the way we navigate in the real world is a challenging and important problem

2.4 Justification, Motivation and Benefits

The overall challenges that current Virtual Reality locomotion techniques have provided with enough justification for the conception of this thesis. Furthermore, thanks to technological advances in cur-

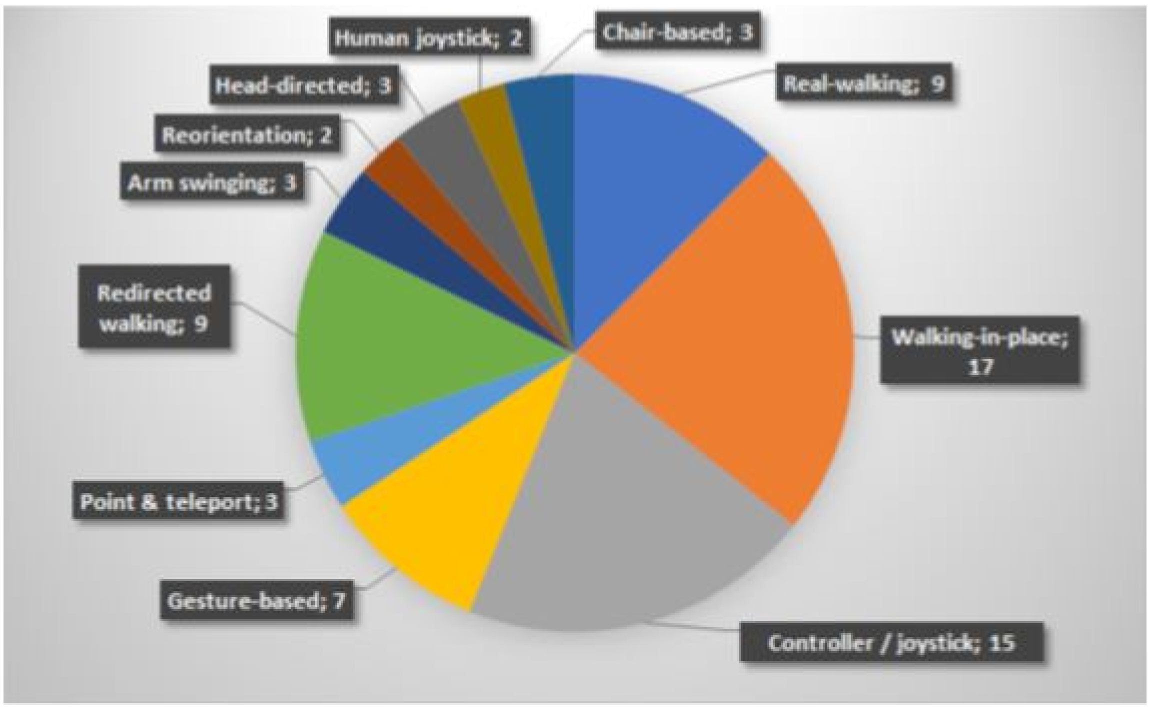


Figure 1: 11 Locomotion techniques and their number of instances, as documented by Boletsis [3]

rent Virtual Reality sets provided with many uncovered grounds for many researchers to venture and investigate. Developing a prototype which can be run using the Human-Joystick locomotion technique, represents an additional approach of development and application interaction. The opportunity to work on such a novelty topic provides with enough motivation to the author for this thesis to be conceived. Furthermore, the sole fact that Virtual Reality is still in a development phase provides with more motivation. Thorough research and a comprehensive experiment on the VR locomotion technique, as presented in this thesis, will give a better insight on this topic and create extensive future research opportunities. This will provide with additional ground so that future researchers can continue working on refining the technique for the benefit of end users. Generally the stakeholders to benefits from this thesis are VR enthusiast/developers altogether. VR enthusiasts will have an application groundwork which they can build upon in their free time. Game designers and developers will benefit from this as many qualitative insights will be provided that will be helpful for their design and programming needs. Many of the discussions that will be done here will serve as guidelines for future games to be designed or developed without the need for trial and error.

2.5 Research Question and Hypothesis

Some VR locomotion techniques have been appropriately researched by previous studies, therefore, the focus of this research is not to directly improve said studies. Instead, we focus one particular VR locomotion technique, the Human-Joystick. The focus will be on adding one more scientific contribution on the aforementioned technique. With this being said, our main focus is finding and documenting different features that are not documented in previous researches. The following research questions and hypothesis will help us conclude whether using serious games in the game design is a suitable approach for improving the quality of usage in the Human-Joystick technique regarding VR locomotion:

- **RQ1**: What underlying challenges are present using the HTC Vive and Nintendo Wii Balance Board as a Human-Joystick VR Locomotion Technique?

- **H0 (Null Hypothesis)**: Undertaking more than one trial on Human-Joystick technique has no effect on the user's performance, in terms of speed.
- **H1 (Alternative Hypothesis)**: Undertaking more than one trial on Human-Joystick technique has a positive effect on the user's performance, in terms of speed.

To test the hypothesis proposed this thesis will provide with a Speed of Completion experiment. The experiments will measure speed and Ease of Learning of the users when employing the Human-Joystick technique. User comfort will be evaluated in a qualitative way, while the speed and Ease of Learning will be measure quantitatively. The VR environments where the users will be tested will be designed with those variables in mind.

2.6 Contributions

First and foremost, this research study contributed to the research field by elaborating and unfolding aspects of serious games that are used in Virtual Reality contexts. As it is an empirical research it will contribute with additional experimentation in the area of Human-Joystick technique, area which very much needs more research to assess its full capabilities. Currently there are not many empirical researches done on the topic. As such, our primary contribution is to provide with additional scenarios where Human-Joystick technique is applied in order to test its effective attributes and determine the feasibility of this option in Virtual Reality environments. In order to do this the design of a Serious Game VR environment that engages players is proposed. The design and task-oriented features contribute in a major way for the player's intrinsic motivation and aids in determining different underlying benefits and challenges that may be featured in the locomotion technique currently researched.

2.7 Thesis Structure

In order to understand how well the Human-Joystick technique is performed under current virtual reality setups as well as understanding the underlying theoretical models and approaches used to build such technique, a theoretical background explaining notions and concepts with regards of VR locomotion techniques, Wii balance board features and Serious Games is necessary. Chapter 3 provides with the theoretical background on which the work of this thesis is build upon. Chapter 4 goes into a detailed explanation on the elaboration on the method, questionnaire selection, setting up and conducting experiments. Chapter 5 gives a detailed overview on the implementation process of the research. Results are shown in Chapter 6. Chapter 7 provides with a detailed analysis and discussion on current results found during the experiment. Chapter 8 concludes our work and looks upon potential future work to further advance the field and provide with recommendations for engaging in such research.

3 Related Work

3.1 Virtual Reality (VR)

Virtual reality (VR) is the computer-generated simulation of a three-dimensional image or environment that can be interacted within a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors (Figure 2). Under this definition, VR is also referred to as Virtual Environments, Virtual Worlds or Microworlds. The goal in Virtual Reality is to create an immersive experience for the user. This reality is presented in a synthetic 3D-world which generally is presented on a stereoscopic head mounted display (HMD), and some applications also offer haptics or tactile feedback to enhance the reality.

Today's virtual reality technologies build upon ideas that date back to the 1800s, almost to the very beginning of practical photography. In 1838, the first stereoscope was invented, using twin mirrors to project a single image. That eventually developed into the View-Master, patented in 1939 [10] and still produced today. The first ever patented Head-Mounted display device was done by Morton Helig in 1960 [11]. "The spectator is given a complete sensation of reality, i.e. moving three dimensional images which may be in colour, with 100 percent peripheral vision, binaural sound, scents and air breezes," read the patent filing.

The launch of the Oculus Rift, HTC Vive, Gear VR and Playstation VR headsets in relatively quick succession has reinvigorated the academic and commercial interest in immersive virtual reality experiences [12].

The main goal in Virtual Reality is to create an immersive experince for the user. Users often show a strong reaction when experiencing immersive VR for the first time, particularly in motion sickness [13]. This experience is quite different from the one of interacting with 3D applications on a desktop or gaming console. Ever since the inception of VR, it has faced many challenges in cost, usability and fears by the users [14].

Current technologies like the HTC Vive or Oculus Rift are becoming more accessible and available for users. Thanks to this, users are gaining a lot more VR experience and with this, their immersiveness demands are getting higher. One particular demand is for new or improved VR locomotion techniques to be applied in current game contexts. Games have increased in quality and size of the virtual maps, therefore traditional walk-in methods are becoming very difficult for the full interaction of the user in the virtual world to take place.

3.2 Serious Games

A serious game or applied game is a game designed for a primary purpose other than pure entertainment. The "serious" adjective is generally prepended to refer to video games used by industries like defense, education, scientific exploration, health care, emergency management, city planning,

Figure 2: HMD with Gloves fitted with sensors

engineering, and politics. As stated by Zyda et al. [15] a Video Game is a "Mental contest, played with a computer according to certain rules for amusement, recreation of winning a stake", whereas a serious game is a "Mental contest, played with a computer in accordance with specific rules that uses entertainment to further government or corporate training, education, health, public policy and strategic communication objectives". In other words a serious game is a game where the main objective is to educate users, and not to entertain them [16]. They also point that VR researchers who want their work to remain relevant must realign to focus on game research and development.

3.3 Immersion

Immersion details how hardware quality in addition to how the experiences are designed affects the immersion factor. One clear definition is the one provided by Slater and Wilbur [17], which defines immersion as a description of a technology, to which extent a computer display can deliver an inclusive, extensive, surrounding, and vivid illusion of reality to the senses of a person. A similar description is given by Bowman and McMahan [18], in which they state the goal of immersive virtual environments is to let users experience a computer-generated world as if it were real and "being there" (term used for spatial presence in the VE).

Sanchez et al [19] defined the term playability as a wide-ranging description to what degree users can reach effectiveness, efficiency, satisfaction and fun in a playable context. Immersion is a part of playability described as the capacity of the video game contents to be believable, such that the player becomes directly involved in the virtual game world [20]. The term is further characterized under the following properties:

- **Conscious Awareness**: The degree to which the player is consciously aware of the consequences of their actions in the virtual world, understanding the game's objectives, goals, challenges, controls, rewards, and any factor which may affect gameplay. Understanding what happens because of carrying out an action helps the player imagine what to do next and to develop the necessary abilities to overcome challenges.
- **Absorption**: A player who is completely absorbed in the gameplay is involved to such a degree that they focus all their abilities and attention on beating the game's challenges.
- **Realism**: The capacity of the video game contents to be believable for players. The more realistic a video game is, the greater the Immersion of the player we obtain thanks to consistent sceneries, mechanics and rules for players when players are interacting with them within the virtual game world. Realism helps the player focus on the game's challenges, rules and objectives.
- **Dexterity**: Refers to the player's dexterity in carrying out different movements and actions in the virtual world in which they are immersed with the help of game controls. Interactive and virtual dexterity is the difference in manipulating the game controls in the real world versus the virtual world, for high immersion to be achieved the interaction between interactive and virtual dexterity needs to be as similar as possible.
- **Socio-Cultural Proximity**: The metaphors and atmosphere used in the game as related to the

player in terms of age, gender and cultural characteristics.

Presence is the sensation of feeling physically present in remote environments displayed by technical interfaces rather than in the actual physical environment [21]. Bowman and McMahan [18] considers presence to be an individual and context-dependent user response, related to the experience of “being there.” Different users can experience different levels of presence with the same VR system, and a single user might experience different levels of presence with the same system at different times, depending on state of mind, recent history, and other factors. Slater [22] equates presence to the term place illusion which is described as the strong illusion of being in a place despite the sure knowledge that you are not there. There is no way of directly measuring presence, however questionnaires can be used to gather user responses based on real experiences. A study on presence using questionnaires to gather responses conducted by Usoh et al. [23] found that awareness of the cables of a HMD caused a break-in-presence for 30% of the subjects while 15% became more immersed after they stopped receiving instructions. It was found in general that females had a higher sense of presence than males.

3.4 VR Locomotion

As stated in the introduction section, locomotion is another word for navigation in a Virtual World. The user moves around physically with sensors placed in room-scale, this is the basic locomotion technique called Walk-In-Place (Figure 3). Locomotion in virtual reality presents many problems and many opportunities to innovate. Aside from traditional input devices like mouse, keyboard and gamepad, the most obvious method of locomotion is simply walking around within the range of the positional tracking devices. Another well used locomotion technique is through teleportation, which can be either free teleport or fixedpoint teleport [24].

HTC Vive is the first consumer VR Device to offer a room-scale experience. Oculus Rift CV1 and PlayStation VR emphasize more of a seated experience. Due to the inception of the aforementioned VR companies, real-walking locomotion techniques are now coming out-of-the-box with commercial headsets [25]. However, open-world games are one of the main reasons more VR locmotion techniques are still researched. Another reason for the further research of VR locomotion techniques is the technological change current VR systems have experienced. With this in mind, several other locomotion techniques have been researched in order to mitigate this limitations. One problem presented by "walking" is the available space of the room. Physical obstacles such as walls and objects will prevent the user from advancing. Free roaming systems also require too much space for average home use, so ‘fixed-position’ configurations used in a stationary standing or seated position are likely to remain relevant for some time [12]. One solution to this problem is a omni-directional treadmill [26]. Other options are the use of treadmills [27], bicycles [28], and wheelchairs [29] to virtually transport the user to a new environment while keeping the physical space the same.

3.4.1 Background

Since the development of VR, various locomotion techniques have been developed and studied. Many theoretical models and/or classifications were developed to establish a solid basis on the

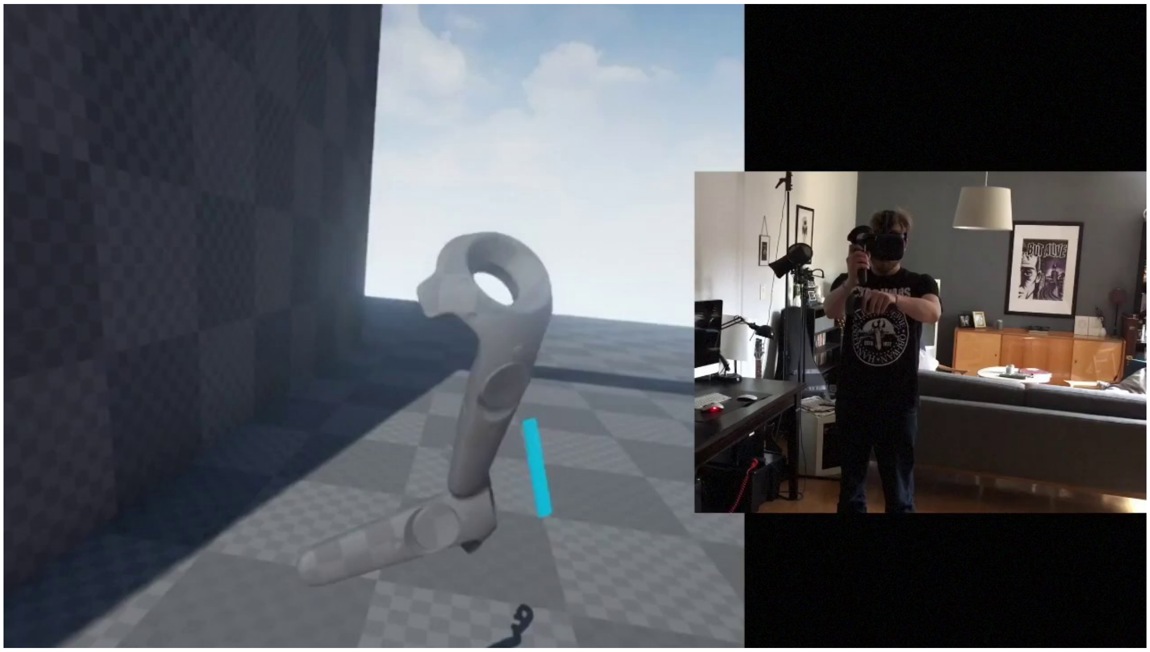


Figure 3: Walk In Place Locomotion with HTC Vive

locomotion techniques, therefore providing with a ground for many researchers to propose their techniques in a classified manner. Good examples of this are the taxonomies proposed by Bowman et al [30, 31], Arns [32] and currently the typology proposed by Boletsis [3]. Being able to move effectively in a VR environment is a key element in the establishment of a sense of immersion, or presence. Locomotion techniques should minimize the amount of mental resources required so there is more available for the user's primary task. When evaluating locomotion techniques, one should consider eight performance metrics:

- **Speed**: how fast a task can be completed.
- **Accuracy**: Proximity to a desired target.
- **Spatial orientation**: Having the knowledge of one's position and orientation within the environment during and after travel.
- **Ease of learning**: The ability of a beginner to use the travelling technique.
- **Ease of use**: The complexity or amount of mental resources required when travelling.
- **Information gathering**: The ability to obtain information from the environment during travel.
- **Presence**: The sense of immersion or of "being within" the environment due to travel.
- **User comfort**: Lack of simulator sickness (SSQ test related) and symptoms such as dizziness or nausea.

3.4.2 Wii Balance Board

The Wii Balance Board (Figure 4) is balance board accesory created by Nintendo for the Wii and Wii U game consoles. It was introduced in 2007 and it is mostly used for exergaming applications, mainly the Wii Fit. It is shaped like a household body scale, with a plain white top and light gray bottom. The board uses bluetooth technology and contains four pressure sensors that are used to measure the user's center of balance (location of the intersection between an imaginary line drawn vertically through the center of mass and the surface of the balance board) and weight. The sensors on the board can accurately measure up to 150kg, however the actual physical structure can withstand much greater force equivalent to around 300kg.

The balance board should be used with the player's bare feet, for grip purposes. The Wii Balance Board has become a proven tool for assessing center of pressure displacement. It has proven to be both valid and reliable. Clark et al [33] performed a study to assess the validity and test-retest reliability of the sue of the Balance Board. Four standing balance tasks were used in this study including a combination of double stance, single stance, eyes open, and eyes closed. Throughout these tests the center of pressure path length was measured and compared these data to an identical study on a laboratory-grade force platform [34]. Clark et al concluded that the balance board measurements are reliable and repeatable.

3.5 Controller-based Technique: Human-Joystick

The Human-Joystick technique (or leaning based), as explained in the introductory section, is a navigation technique that uses the human body as a joystick. The person is placed in a platform and through leaning, navigation can be reached. This locomotion technique is compared to the Segway or Hoverboard. According to Boletsis [3], from 2014 until 2017 only two studies have been done regarding the Human-Joystick locomotion technique. The studies are as follows:

3.5.1 Harris et al [1]

In their work, titled "Human Joystick: Wii leaning to Translate in Large Virtual Environments" the authors present an inexpensive method of exploring large Virtual Environments. Their study focuses on comparing Human-Joystick method with regular Joystick and Walk-In-Place locomotion methods.

Their Wii-Leaning algorithm works by tracking the user's center of mass across a plywood platform. If the user's center of mass moves from the center of the board, then their algorithm detects a lean and translates the user 3m/s in the direction the user is gazing until their center of mass is back in the center of the board. In their system, physical rotations represent virtual rotations. Their Wii-Leaning platform consisted of two Wii Balance Boards (Figure 5). The authors felt that once Balance Board was too small to implement a reasonable leaning algorithm. Furthermore, to give the participant more space to lean, the Wii Balance Boards were placed side by side. The authors calculated the user's center of mass, or centroid, using the data obtained from all 4 corners of each Wii Balance Board. Additionally, to detect a lean, the lean detection (displacement of weight from the center of the board) had to be within 30 degrees of the viewing yaw angle. The authors used a

Figure 4: Wii Balance Board

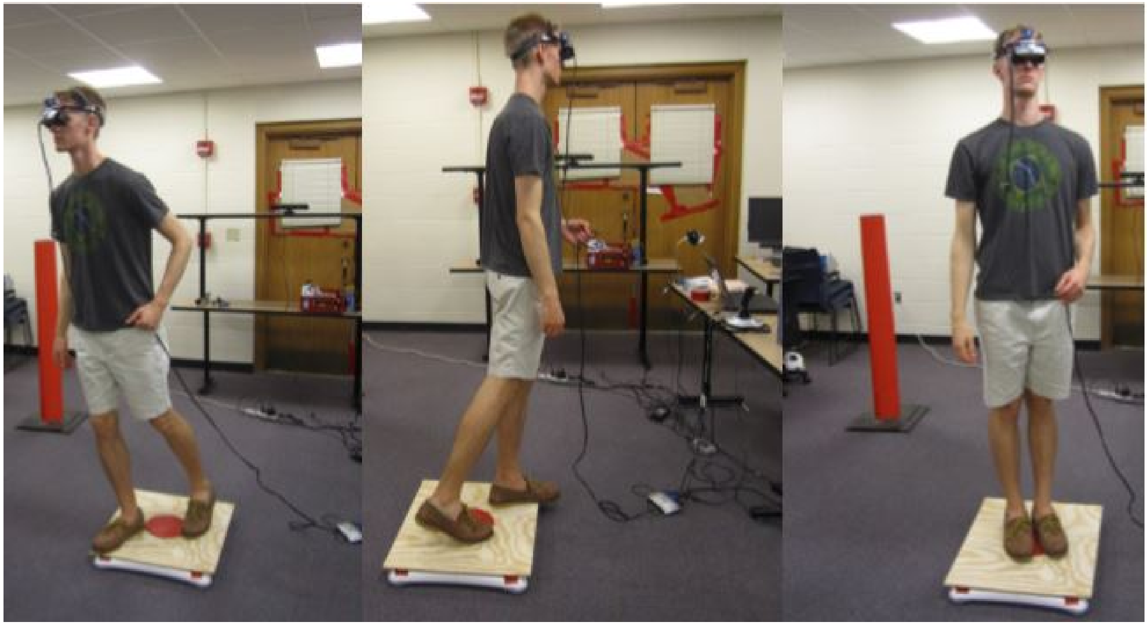


Figure 5: Demonstration of Wii-Leaning method by Harris et al [1]

3 m/s speed, mostly because users found that slower speeds were boring and inconsistent with the method of leaning. The authors also investigated the idea of varying the speed based on the extent to which the user was leaning, but this proved difcult to control due to the relatively small size of the platform.

In the first experiment, the authors compare Wii-Leaning (Human-Joystick) with Joystick techniques. In each condition the users are asked to remember the location of six different objects in a large virtual outdoors environment. Then, to test spatial orientation, the authors asked the users to move (by leaning or Joystick) to a new point of observation and were instructed to turn so that they would face in the direction of the target from memory without vision. Speed and accuracy were measured to define spatial orientation under each locomotion condition. In both conditions, physical rotation matched rotation in the Virtual Environment. In the joystick condition, participants rotated physically and moved in the direction of their gaze by joystick translation. This experiment found that participants in the Leaning condition responded more accurately than those in the joystick condition.

In the second experiment, the authors compare Wii-Leaning (Human-Joystick) with Walk-In-Place with the Kinect in terms of spatial orientation and user preference. In both conditions, physical rotation matched rotation in the Virtual Environment, and participants moved in the direction of their gaze. As in the previous experiment, a 3 m/s speed was used. Regarding the Walk-In-Place kinect condition, the step results in 3 m/s optical flow. The experiment found that participants in the Walk-In-Place Kinect condition responded faster than those in the Wii-Leaning condition. However, when asked which method they preferred users answered the Wii-Leaning condition (8 out of 12 participants).

The authors find that physically leaning to explore a Virtual Environment does aid in spatial awareness over Joystick exploration. They also find that the Wii-Leaning method is similar to Walk-In-Place in terms of spatial awareness. They concluded that Wii-Leaning method is very effective in terms of spatial awareness and that with few enhancements, it cna be the go-to option for most users.

3.5.2 Kruijff1 et al [2]

The following study focused more on enhancing locomotion techniques through a variety of multi-sensory stimuli. Auditory cues such as footstep sounds, visual cues such as bobbing head-motions from walking, and vibrotactile cues (bass shakes in the users feet) were tested to enhance the participant's sensation of self-motion.

Results showed that both self-motion perception and involvement/presense could be significantly enhanced by adding walking-related vibrotactile cues, auditory cues, as well as visual cues. The outcomes of the research support the assumption that haptic and proprioceptive cues experienced during natural walking can at least to some degree be replaced for by other feedback channels such as vibrotactile feedback, and can be further supported by audio-visual cues.

Participants self-reported ability to judge self-motion velocities and distances travelled was enhanced by adding footstep sounds and vibrotactile cues. One of the key findings in the research was that leaning while standing improved self-motion perception significantly compared to seated users using a joystick, even though participants had no experience in leaning-based techniques (Figure 6).

Figure 6: Seated Leaning and Standing Leaning by Kruijff et al [2]

4 Methods

4.1 Experiment Setup

The HMD used for the experiment was the HTC Vive. One of the reasons to use it was its availability in the university and also because it is one of the current State-Of-The-Art technologies. Currently there is a new version called HTC Vive Pro, but its wireless capabilities will be released by mid 2018. More technical information on the HTC Vive will be specified in the Implementation section 5.1.1.

For the artificial controller device the Wii Balance Board was used. Currently there is no updated version of the Wii Balance Board. However, the device proves to be still useful and reliable for today's experiments. More technical information on the Wii Balance Board is specified in the Related Work section 3.4.2.

For the setup of the experiment not much space was needed. The only requirements were to have a space for the Wii Balance Board to be placed. One additional requirement was that it should be at a short distance from the PC and HMD. The reason for this space requirement was to avoid any potential chord pulling if the user makes a bad move that might make them tilt or fall away from the Wii Balance Board (Figure 7).

The laptop used to run on the experiment had the following hardware specification:

- Processor: Intel Core i7 6700HQ @ 2.60GHz
- Operative System: Windows 10
- RAM Memory: 16GB
- Hard Disk Drive: 256gb SSD
- Graphics Processor Unit: NVIDIA GeForce GTX 1060 6gb GDDR5

For sound the users were provided with a pair of headphones, this was mostly used as an aid for distraction when navigating the distances and to avoid any sense of boredom from the participants.

4.2 Questionnaire

Prior to the start of the experiment the user had to fill a questionnaire. The questionnaire used was inspired by Kennedy et al. [35] Simulator Sickness Questionnaire (SSQ). This questionnaire was selected because it fits on providing valuable information when experimenting with Virtual Reality. The questionnaire was composed of a three sections.

The first section was used for Demographic information. This section was composed of 9 questions.

- ID (Information not filled by the user)
- Gender

Figure 7: Virtual Environment Set up Head Mounted Display, Wii Balance Board and VR capable laptop

- Age (marked through Age ranges for every 10 years)
- Do you use any vision correction?
- If you are using corrective lenses are you able to wear them in the VR headset?
- How much digital experience do you have? (More oriented to digital games)
- How much VR experience do you have?
- Do you believe there is a reason that your results would not be valid in this study?
- In case of yes or maybe was given above would you please elaborate?

Last two questions were done in order to assess any background from the user that might harm the validity of the experiment, for example, a user that already has a lot of experience using the Wii Balance Board would always result in a positive outcome or efficient execution of the activities.

The second and third section were used for Simulator Sickness Pre-Test and Post-test. This test was done in order to assess any preconception that the user might have regarding the use of Virtual Reality. The post test assess any post feelings the user might have experienced during the VR testing phase. The section was composed of 16 questions. The answers ranged from NONE, SLIGHT, MODERATE, and SEVERE.

- General Discomfort
- Fatigue
- Headache
- Eye strain
- Difficulty focusing
- Salivation increasing
- Sweating
- Nausea
- Difficulty concentrating
- Fullness of head
- Blurred vision
- Dizziness with eyes open
- Dizziness with eyes closed
- Vertigo
- Stomach awareness
- Burping

A sample of the questionnaire can be found in the Questionnaire Appendix A.

4.3 Experiments

The goal of this user empirical study was to explore the effects Human-Joystick controller based locomotion technique on player experience and performance. For this ta prototype was developed that evaluated speed and accuracy of completion of tasks. Before starting the experiment the participants were given a quick tutorial on the environment they were gonna navigate through. Also they were shown which are the controllers and the directions they went, alongside with a practice test. Users did several trial sessions without timer to give them a sense of familiarity with the setup and experimental design. In case some instructions were not clearly understood, the author would provide with additional information or re-explain the instructions to the user. Instructions can be checked in the Appendix B

4.3.1 User Selection

As this is meant to be an empirical study and the goal is to observe a variety of users and how they develop in the same Virtual Environment, no criteria was made when selecting the users. Many of the users were contacted through social media sources and others were referred by the previous users. Most of the users were people that study Applied Computer Science. A message board was created to recruit users for the testing. Additionally, those that responded to the message board were encouraged to refer others for the testing. Very few users were non computer science related. A total of 20 users were selected to proceed with the experiment. Users' age ranged from 20 to 35 years of age. Additionally, all of the users were quite accustomed to technology and therefore did not see Virtual Reality with a sense of fear, but rather with a sense of excitement (this proved to help a lot in their motivation to participate).

After the instruction phase, the users proceeded to do the following experiment:

4.3.2 Speed of Completion Experiment

The following experiment had the objective of accepting or rejecting the null hypothesis proposed (H0). Additionally, this part of the experiment was intended to be tested in a quantitative manner, therefore it was a timed experiment (measured in seconds). The experiment was done twice per user (in different times) and both data were used for the T-test paired means. The experiment tests the user's speed of completion when performing a task. The task that the users were assigned to was to reach from Point A to point B in a fast manner. The speed of the user tells how spatial oriented the subject are under a locomotion condition, this insight was taken from the work from Harris et al. [1], with the slight difference that they used a comparative approach, whereas the author used an empirical approach, therefore observation and feedback were crucial during the experiment phase.

A total of 20 users participated in the experiment. Some subjects were unfamiliar with the experiment and virtual environments, and some were accustomed to previous experiments but not with the aforementioned locomotion method. The virtual environment (VE) was viewed through the HTC Vive Head Mounted Display, and the author was observing the performance through the laptop screen. The virtual environment used in the experiment was a 50m by 50m plain with a generic backdrop depicting the sky (Figure 8). A total of 8 targets were placed that served as Point A and point B, each time the user reached the target the new point was generated so that the user navigated towards it. The random order of trails and the different targets concealed the fact that the arrangement was the same throughout the experiment. Targets were expressed as a cylinder with an arrow to indicate the position and orientation, respectively. In the experiment,

Figure 8: Overview of the testing Virtual Environment and target cylinder

the user translated forward at an optical flow of 3 m/s. This speed was chosen because the testing environment was considerably large. Besides, Harris et al [1] proved this was an adequate speed for testing in large Virtual Environments. Participants' spatial knowledge was tested from four different locations. Participants were instructed to navigate to the target position and then to turn to face the next target. Subjects were encouraged to re-orient themselves after reaching the target. The order of testing locations was randomized per condition per subject so that the subject could not tell that the conditions were similar.

The trials were designed so that the disparity of the Virtual Environment was evenly distributed in the range of 20-180 degrees. The testing locations were positioned in such a way that they would never turn to face a target object closer than 0.8m. Unlike the experiment in Harris et al. [1], no latencies or turning errors were measured since there is no need for that in a non-comparative study. Furthermore, Harris et al. found no effect of latency across the conditions established in their experiments. The subjects indicated to the experimenter that they reached to pointed target by verbal instruction, and the reaching of the point was confirmed by the experimenter. Subjects were encouraged to respond as rapidly as possible while maintaining accuracy, which was also measured during the same procedure.

5 Implementation

This section will cover the features and challenges that were faced during the development of the application in order for it to be fit to run the experiments. The prototype of the simulator was implemented with Speed of completion in mind. Speed of completion will then assess the Ease of learning and Ease of use which are variables mentioned in the Methods Chapter 4

5.1 Unity Engine implementation

When creating an application in Unity the game is organized in scenes. Each unique scene can be thought as a unique game level. The scenes may contain a variety of GameObjects that are containers for components that can be attached to the object to be used. Through a well documented API (Application Program Interface) it is possible to access and manipulate the GameObjects and other components via scripting. The scripting programming language used was C#.

5.1.1 HTC Vive

For the experiment the Virtual Reality set that was used was the HTC Vive. THe HTC Vive (Figure 9) is a virtual reality headset developed by HTC and Valve Corporation. It features 2160 x 1200 pixels combined (1080 x 1200 pixels per eye). Additionally it provides with 110 degree field of view and 90HZ refresh rate, which by today's standards is State-of-the-Art. As of April 2018 a new HTC Vive has been released, called the HTC Vive Pro. This new version provides with 2880 x 1600 pixels combined (1440 x 1600 pixels per eye). Besides those technical aspects the HTC Vive Pro promises to offer wireless support for its HMD by mid 2018. For availability purposes the HTC Vive was used. Besides, for the testing purposes (the movement will not be physical but with a Balance Board) the HTC Vive is sufficient to test the VR Locomotion technique.

5.1.2 SteamVR SDK

In order to connect the HTC Vive in Unity engine the SDK used was the SteamV. SteamVR SDK is an official library made by Valve that makes it easier to develop for the Vive. It's free on the Asset Store and supports Oculus Rift and HTC Vive. It is presented as a SteamVR Plugin that is imported into Unity as a package. Once installed it adds three VR GameObjects, namely [CameraRig], [Status], and [SteamVR]. For prototype purposes the [SteamVR] GameObject was used to detect the Head Mounted Display (See Figure 10).

5.1.3 Connecting Wii Balance Board

The Wii Balance Board is connected to the computer via Bluetooth. A software was used in order to connect the Wii Balance Board with the Unity engine. The program is called Wii Balance Board Walker. Wii Balance Board walker allows the user to use the balance board as a foot input device.

Figure 9: HTC Vive Full Set

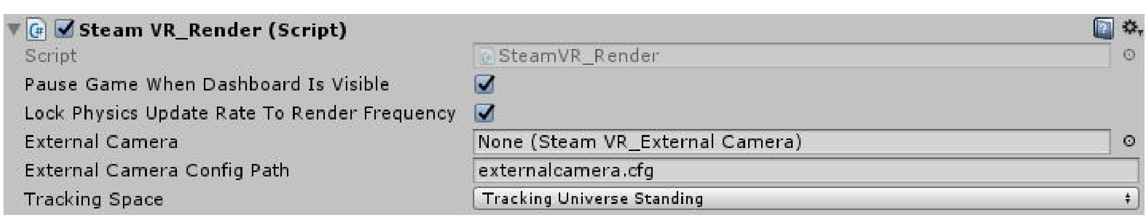


Figure 10: SteamVR Head Mounted Display configuration in GameObject

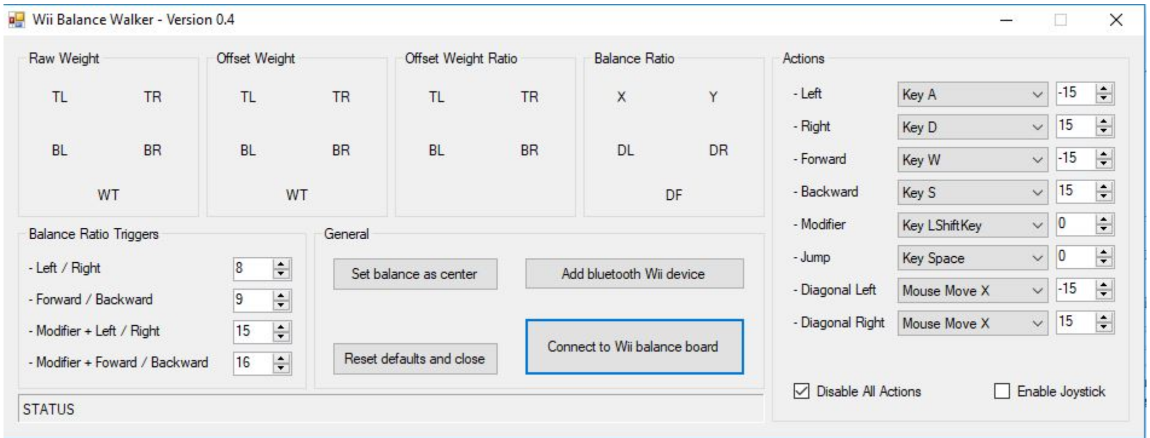


Figure 11: Wii Balance Walker Interface: Inactive

Additionally, the Wii Balance Board walker allows the Wii Balance Board to communicate effectively with Unity engine.

For the experiment purposes, a food input device was more than necessary as this is a locomotion testing. The input devices works by sending key presses and mouse clicks to the application. This actions are triggered by certain customizable thresholds. For the application purposes the forward, backward, left, and right triggers were used for the actions done in the Virtual Environment (as seen in Figure 11 for inactive, and Figure 12 for active). This approach required less scripting in Unity than it would have been without it. The events from Wii Balance Walker were handled as regular key presses in the **FPSInputManager**.

5.1.4 Virtual Environment

The Virtual Environment was designed with the Human-Joystick locomotion technique in mind, however, it can also be applied to any other locomotion technique available. As mentioned in the methods section, the terrain is a 50m by 50m terrain with targets that the user had to reach in a timed manner (Figure 8). Through the HMD the user had a clear view of the terrain and background that added a friendly environment for the user to test the locomotion technique (Figure 13). Many visual cues were placed so that distraction could be assessed qualitatively.

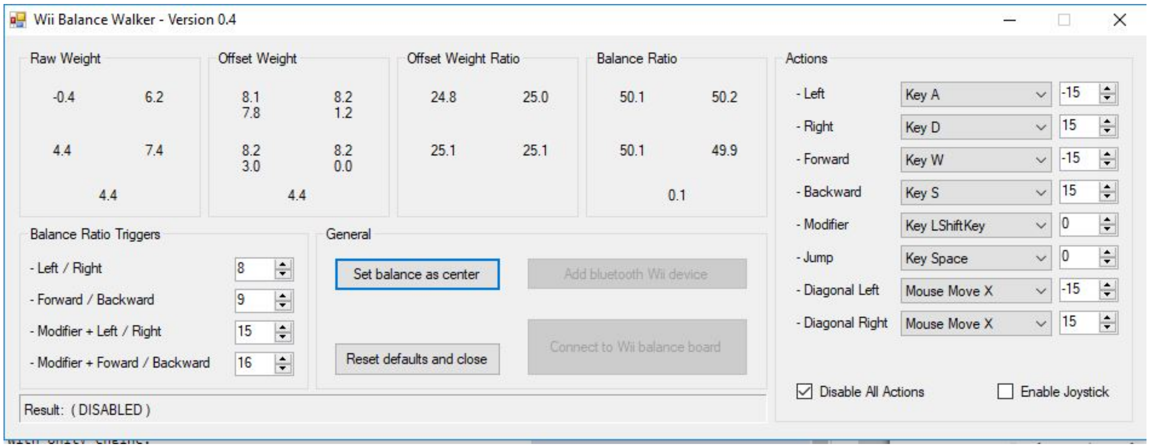


Figure 12: Wii Balance Walker Interface: Active

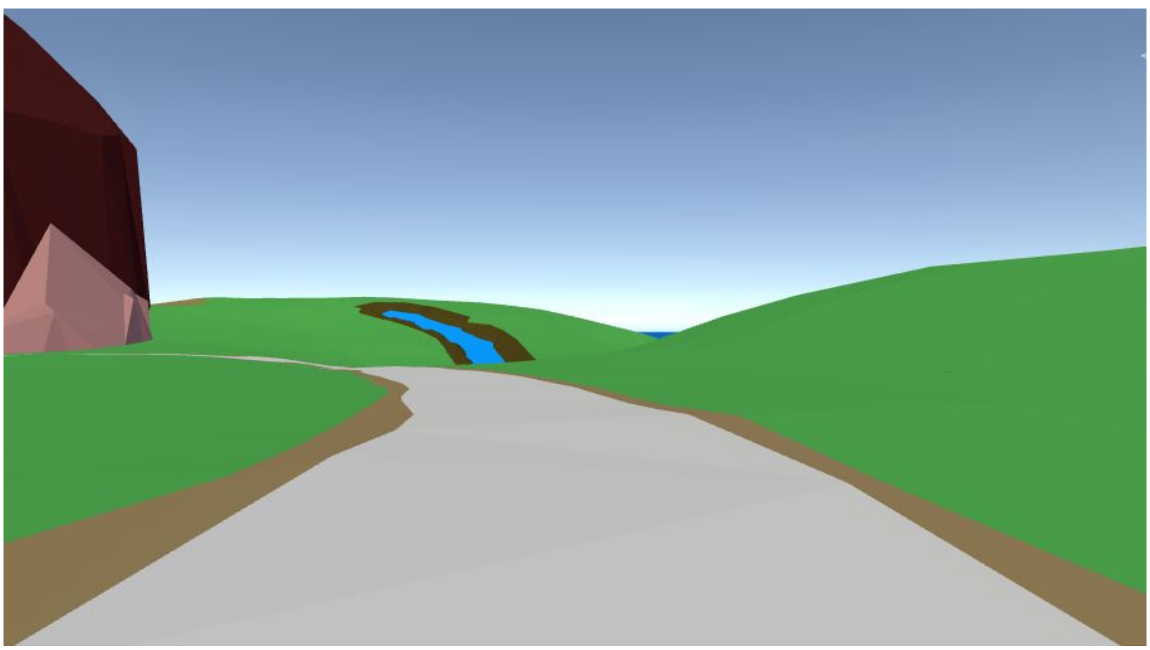


Figure 13: Virtual Environment as seen through the HMD

6 Results

This chapter contains the main results from the experiment described in the method chapter 4. The raw data can be found in the Appendix C.

6.1 Simulator Sickness

6.1.1 Demographic Results

The following results were found regarding Demographic data, for an detailed explanation please refer to Table 1.

- A total of 20 users were given the questionnaire prior to the engagement of the experiment. A total of 4 Female (20%) and 16 Males (80%) participated in the experiment. See Figure 14
- Regarding visual correction, a total of 10% said they needed Visual correction for their daily activities. See Figure 15
- Regarding the use of lenses, a total of 5% said they needed those while on the experiment. See Figure 16
- Regarding Game Experience a vast majority of the users had previous Game Experience. 16 Users (80%) had an input of 4 meaning they had a lot of experience in Games, not particularly related with Virtual Reality. See Figure 17
- Regarding Virtual Reality experience a vast majority of the users had previous experience, 16 users (80%) had an input of 4 meaning they had plenty of previous VR experience. Having a Score of 4 meant that the user had a high level of VR experience, having a score of 3 meant that the user had an average level of VR experience, having a score of 2 meant that the user had a slight level of VR experience, and having a score of 0 meant that the user had no VR experience whatsoever. See Figure 18
- Regarding the completion of the experiment, all of the users were successful on it. Some had more difficulty than others but everyone could complete the tasks.

6.2 Performance

The following results were found regarding the data from the Speed of Completion, for a detailed explanation please refer to Table 2 and Table 3.

6.2.1 Evaluating Speed of completion: First Round

- A total of 20 users participated in the first round, everyone completed the 8 targets of the locomotion task.
- Fastest time was 81 seconds.
- Slowest time was 183 seconds.

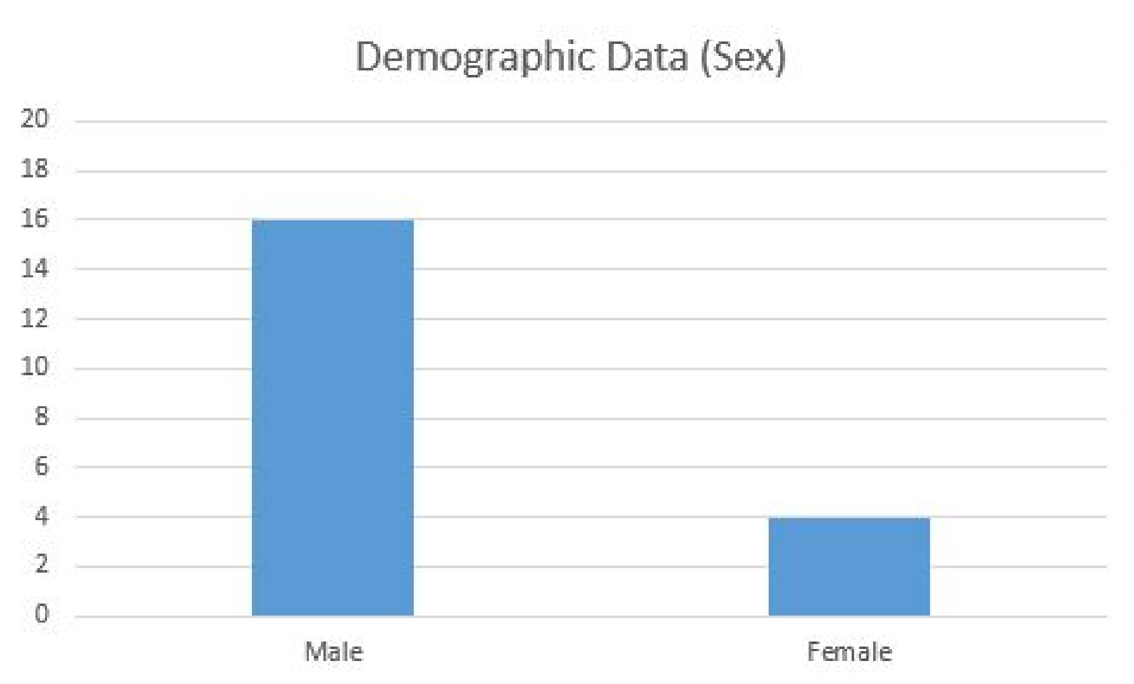


Figure 14: Simulator Sickness Demographic Data Sex

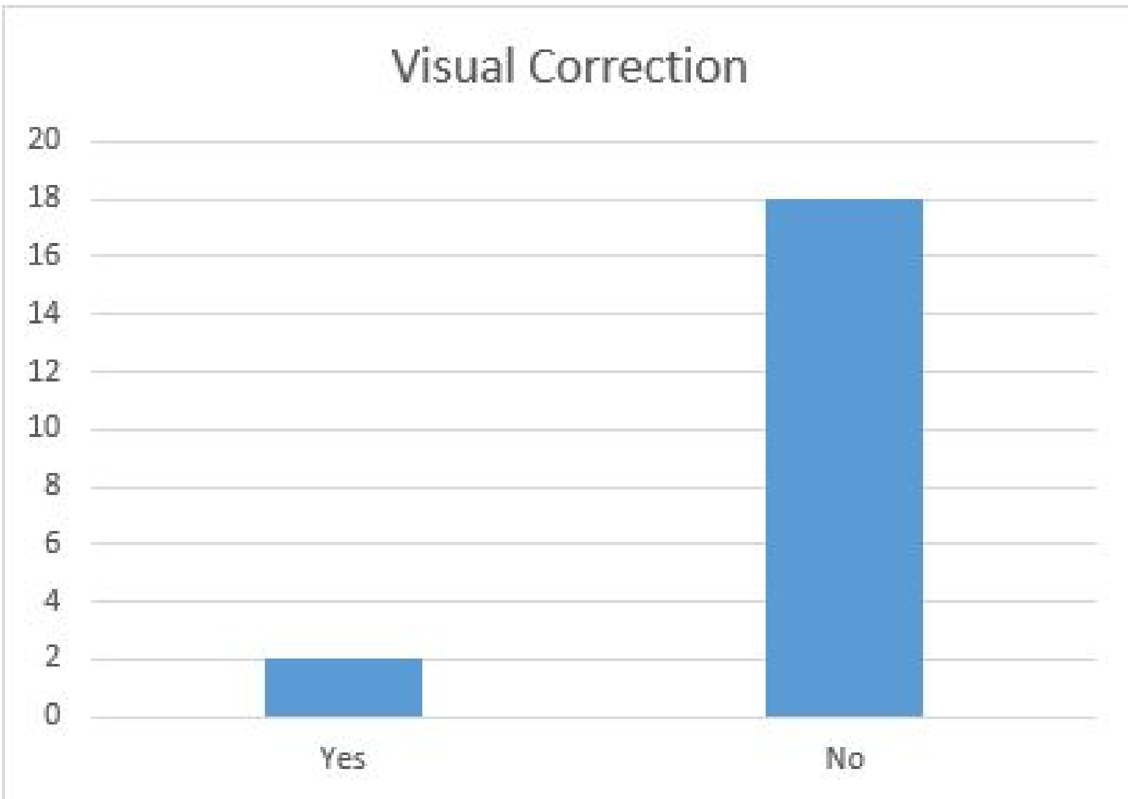


Figure 15: Simulator Sickness Visual Correction

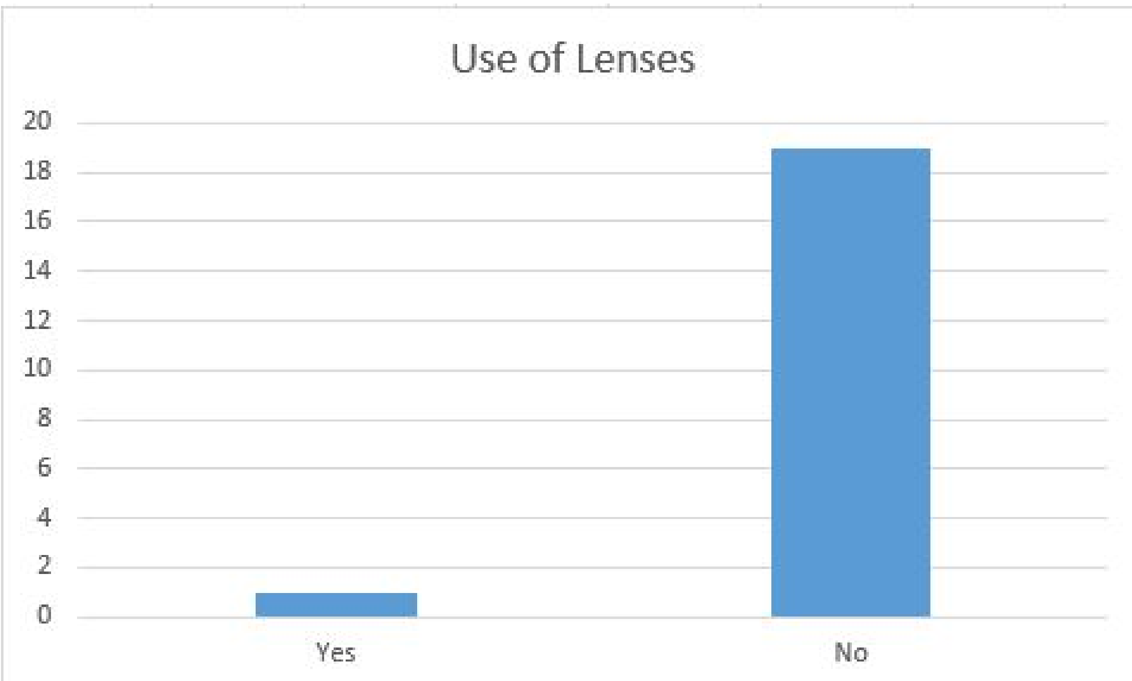


Figure 16: Simulator Sickness Use of Lenses

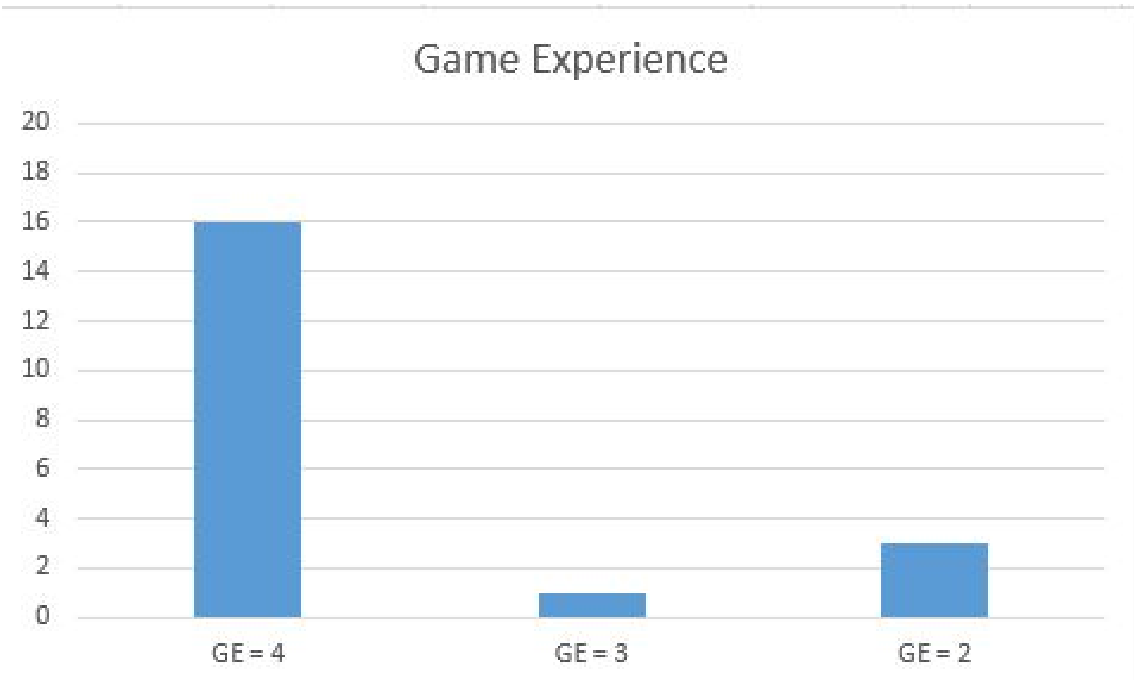


Figure 17: Simulator Sickness Game Experience

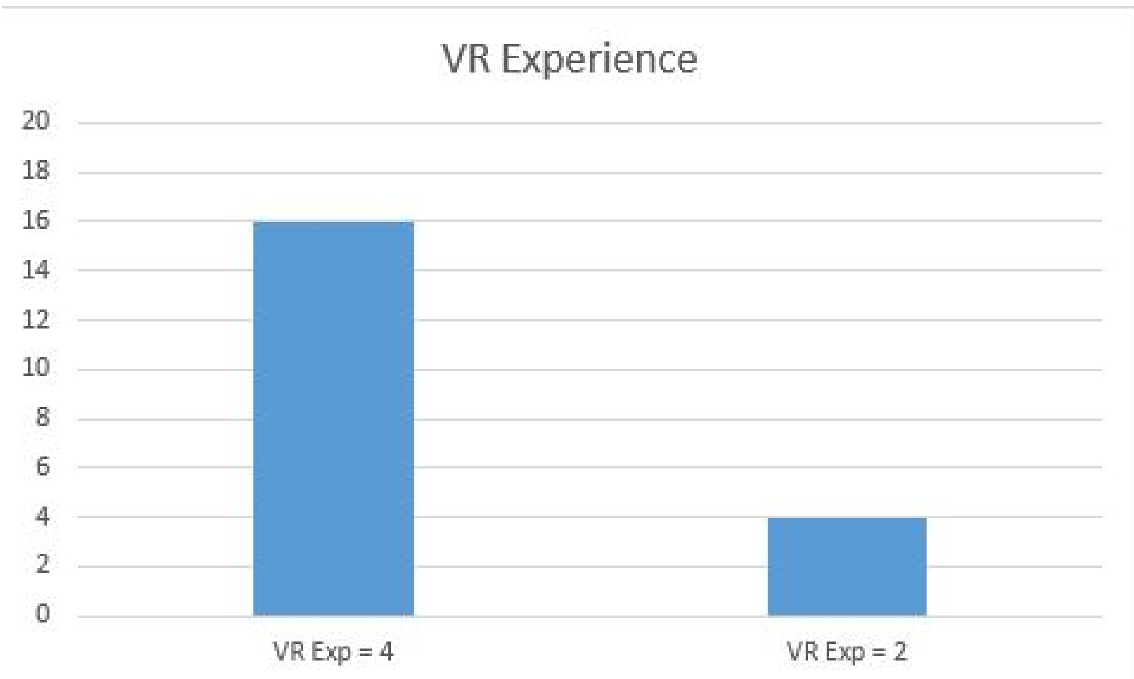


Figure 18: Simulator Sickness Virtual Reality Experience

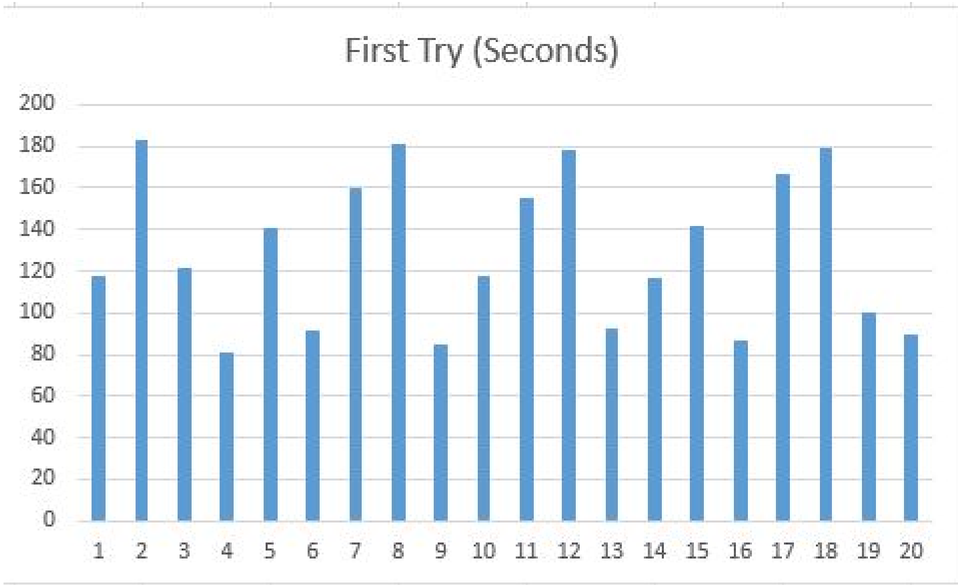


Figure 19: Speed of completion Experiment: First try

6.2.2 Evaluating Speed of completion: Second Round

- A total of 20 users participated in the first round, everyone completed the 8 targets of the locomotion task.
- Fastest time was 75 seconds.
- Slowest time was 184 seconds.

Detailed totals of each participant for the first try can be seen in Figure 19
Detailed totals of each participant for the second try can be seen in Figure 20

6.2.3 Aggregated Data

Based on the results for Speed of Completion it can be inferred that there was an increase in the Ease of Use from the participants. For that a classification on the speed of completion Seconds was done. It was classified into 3 categories:

- Below 90 Seconds
- Between 91 and 140 Seconds
- Over 140 Seconds

The difference can be noticed from First try and Second try. During the first try:

- A total of 4 users completed the task below 90 seconds.
- A total of 7 users completed the task between 91 and 140 seconds.
- A total of 9 users completed the task over 140 seconds.

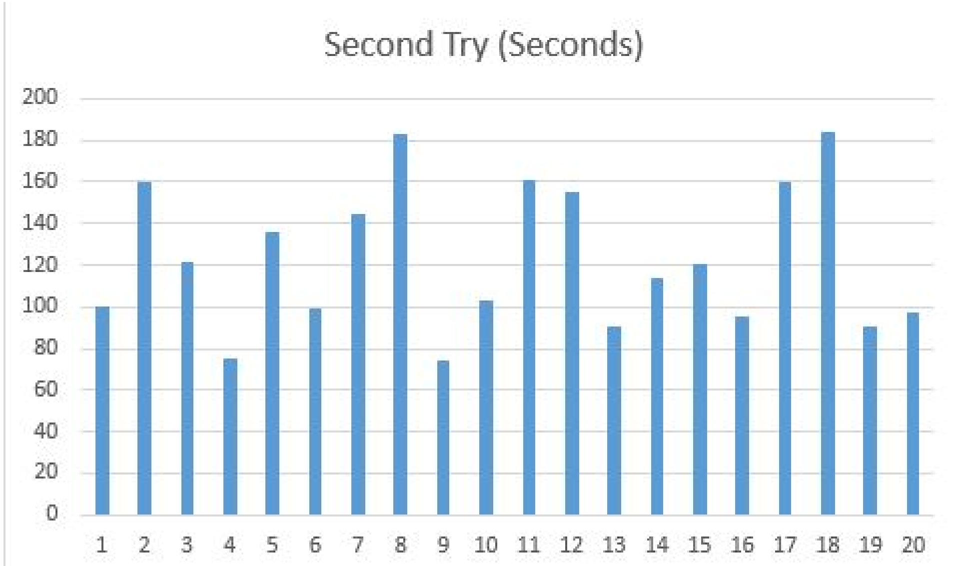
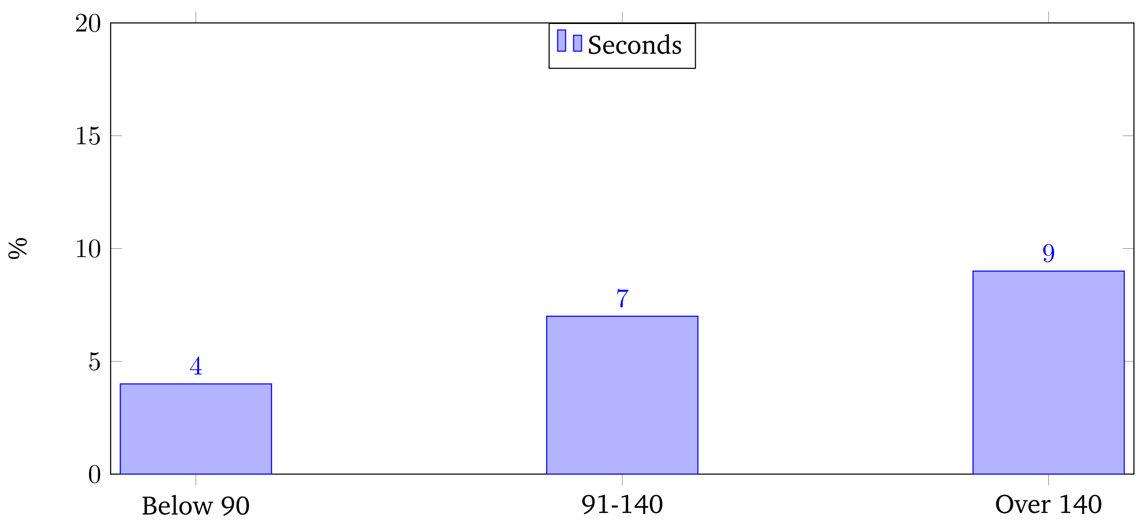
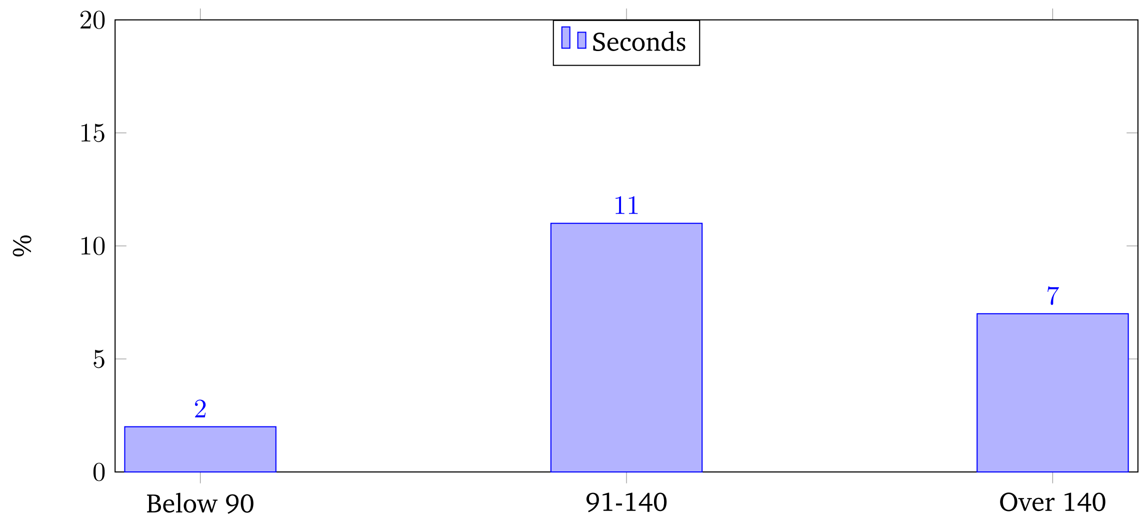


Figure 20: Speed of completion Experiment: Second try



Whereas, during the second try:

- A total of 2 users completed the task below 90 seconds.
- A total of 11 users completed the task between 91 and 140 seconds.
- A total of 7 users completed the task over 140 seconds.



The increase in speed and ease of use is something to be expected, due to the fact that people get better with each try. The difference yields in the displacement of the population from one category to another. In the first try the highest category was the one Over 140 seconds. Furthermore, during the second try the displacement can be seen, where the majority of the population moved into the between 91 and 140 Seconds category.

Most of the users explained they felt the locomotion technique was easier to use with time. This aligns perfectly with the data obtained. One particular case where the user fell from the Wii Balance Board can be noted. The fall took place due to the immersiveness effect produced by the action, the user leaned too forward and thus fell. This can be contained into one case, since the other users did not had this problem at all. However, this is an important discovery since this can be a design issue that can be solved in the future.

Additionally, the fact that all of the users completed the 8 target-task means that Human-Joystick locomotion technique is a great option for navigation as well as for completion of task along the navigation. This of course does not mean it is the best option available but it shows that it is a viable option when it comes to task completion in large Virtual Environments as can be seen in Figure 21. A variety of additional research can be done engaging the users in different tasks while intrinsically motivating them to accomplish them.

6.3 T-test paired two sample values

In order to assess the validity of the proposed results, a T-test two sample for means statistical result was needed. The t-test values were compared in order to reject or accept the Null hypothesis. The paired T-test was done in order to test the means of the population between the First and Second try. Based on the results obtained this were the findings:

- First try yielded a mean value of 129.4
- Second try yielded a mean value of 123.2

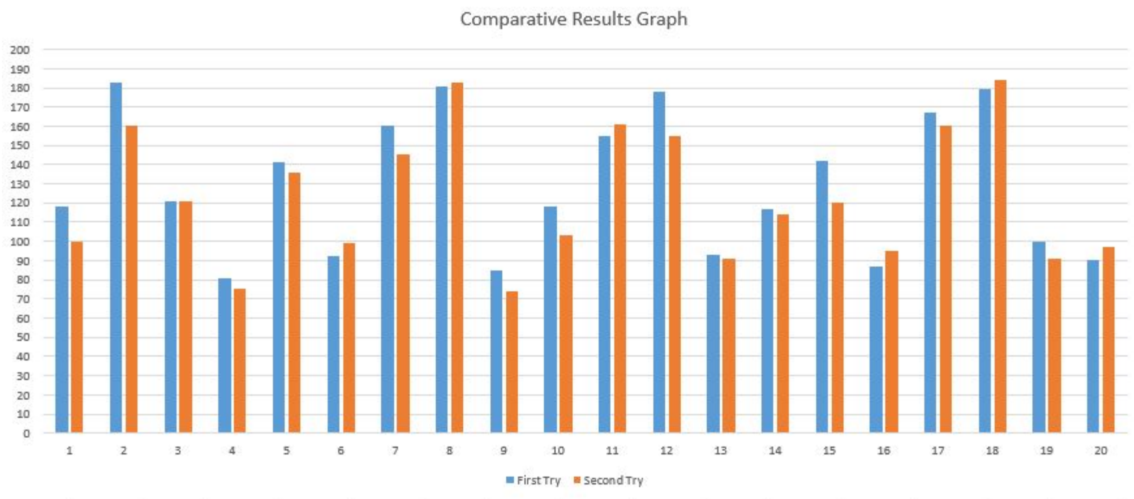


Figure 21: Comparative Result of First and Second Try

- The value of P(T<=t) is equal to 0.016216604, which is less than 0.05.

A in depth detail of the T-test can be found in Appendix C.3.

t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	129.4	123.2
Variance	1336.463158	1210.063158
Observations	20	20
Pearson Correlation	0.95779437	
Hypothesized Mean Difference	0	
df	19	
t Stat	2.637889377	
P(T<=t) one-tail	0.008108302	
t Critical one-tail	1.729132812	
P(T<=t) two-tail	0.016216604	
t Critical two-tail	2.093024054	

Figure 22: Speed of completion Experiment: T-test pair First and Second try

7 Discussion

7.1 Quantitative Interpretation of Results

THe author proceeded to do an interpretation of results to observe changed in performance in different ways. One particular thing to note is that on the second try less users completed the task below 90 seconds, but this has no effect on the end result mainly because it was due to randomness. On of the users completing the task below 90 seconds indicated that the game design made it impossible not to "enjoy the view", thus begin distracted from the required task. This can be interpreted as a distraction but also can indicate that users are not solely focused on the locomotion action per se.

7.1.1 Line Chart

The first and second try results were ordered in an ascending manner before the creation of a line chart. Through the creation of a line chart of each completion try the author found the following discussions (See Figure 23):

- Is it notorious that there is an increase in efficiency between the two tries.
- However, this is a result to be expected due to the fact that people get proficient in a task the more they do it.
- The most difference noticed is in the middle part, which means this is the common ground of improvement for most of the population.
- As a discussion, speed of completion is not changed drastically, which means this timing can be called as average.
- In the chart between the third and the seventh participants an increase in time spent during the task can be performed. This is worth discussing because this also adds to the fact that randomness in performance is noticeable and will happen in every locomotion technique research.

The creation of this chart aimed to check if there is a significant difference between the two tries, which shows there is not a significant difference. While H0 can be rejected this chart shows that randomness is an important factor to be considered when doing an experiment. As a retrospective more tries could have been implemented to check if the speed of completion time shows a significant change, whether this change results in a increase or decrease.

7.1.2 Bell Curve

Based on the raw data obtained from the experiment, the mean and Standard deviation was obtained and from there a normal distribution was obtained to calculate the bell curve. To have a different point of view on the results obtained, a bell curve was made for each try. The following

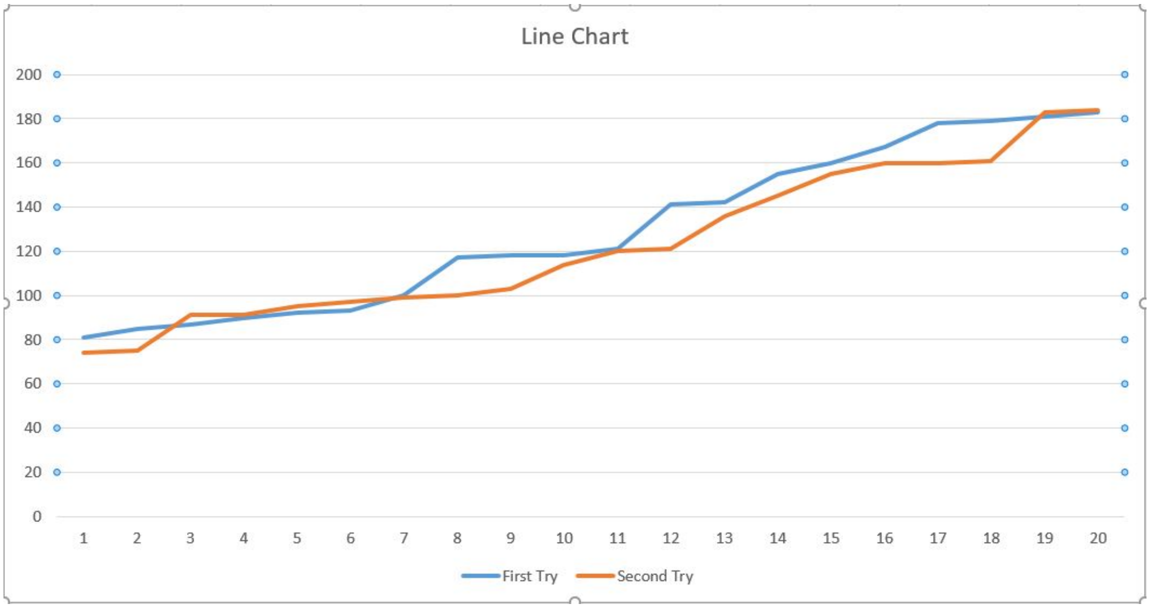


Figure 23: Line Chart of First and Second Try

discussions were found:

- After each try, the bell curve looks more natural, which confirms the alternative hypothesis. Moreover it shows that naturally population distribution is normalized with each try.
- In the first try there seems to be two tipping points, whereas in the second try there is one tipping point. Displacement of population is clearly shown here. (See Figure 24)
- There is not much difference between bell curves, which confirms the slight change in speed of completion is not significant. In the future a bigger user sample can be used to determine if there is a significant change. (See Figure 25)
- The tendency of both curves shows that the average speed of completion is between 115 and 145 seconds, this is where most of the population displacement occurred.

7.1.3 T-test Results

Based on the results obtained from the T-test: paired two sample, it is safe to say that the Null hypothesis (H0) is rejected and the Alternative Hypothesis (H1) is accepted. This can be clearly seen because there is an increase in efficiency by the user's performance in terms of speed, as it can be clearly seen from the comparative results from Figure 21. There is a decrease in the time it took some of the users to complete the tasks, therefore an increase in performance from the first try to the second try. Furthermore, the charts provided early can confirm the results obtained, the population distribution moved from being Over 140 seconds to between 91-140 seconds. It is worth noting that randomness could have also played an important role in the performance of the

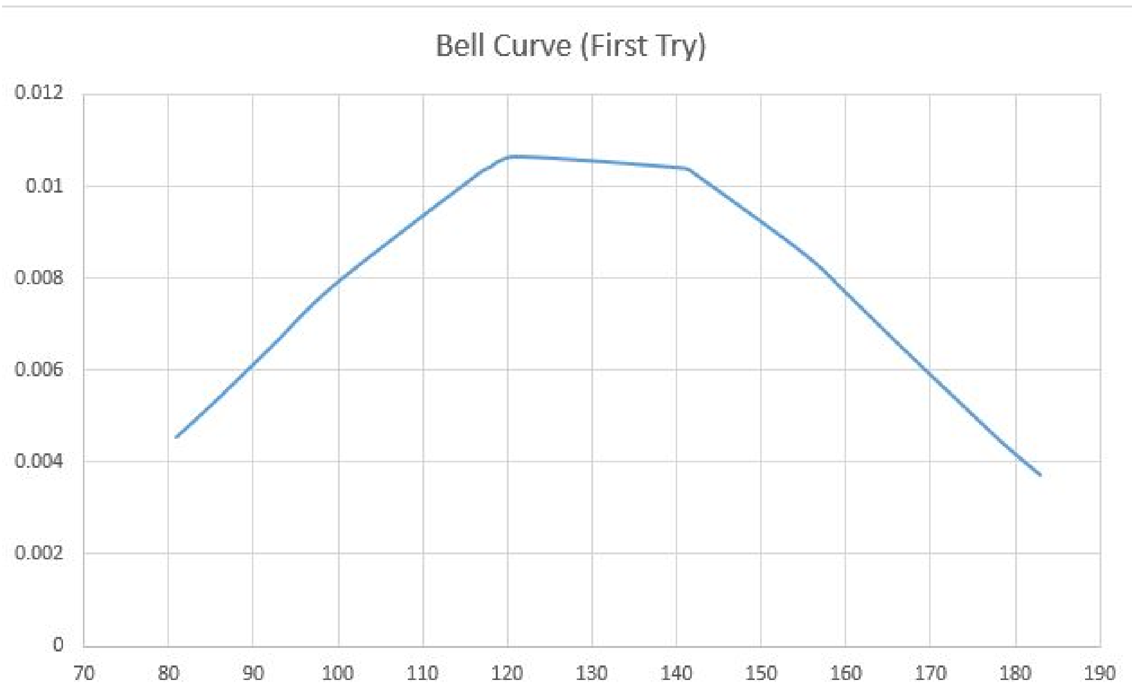


Figure 24: Bell curve First Try

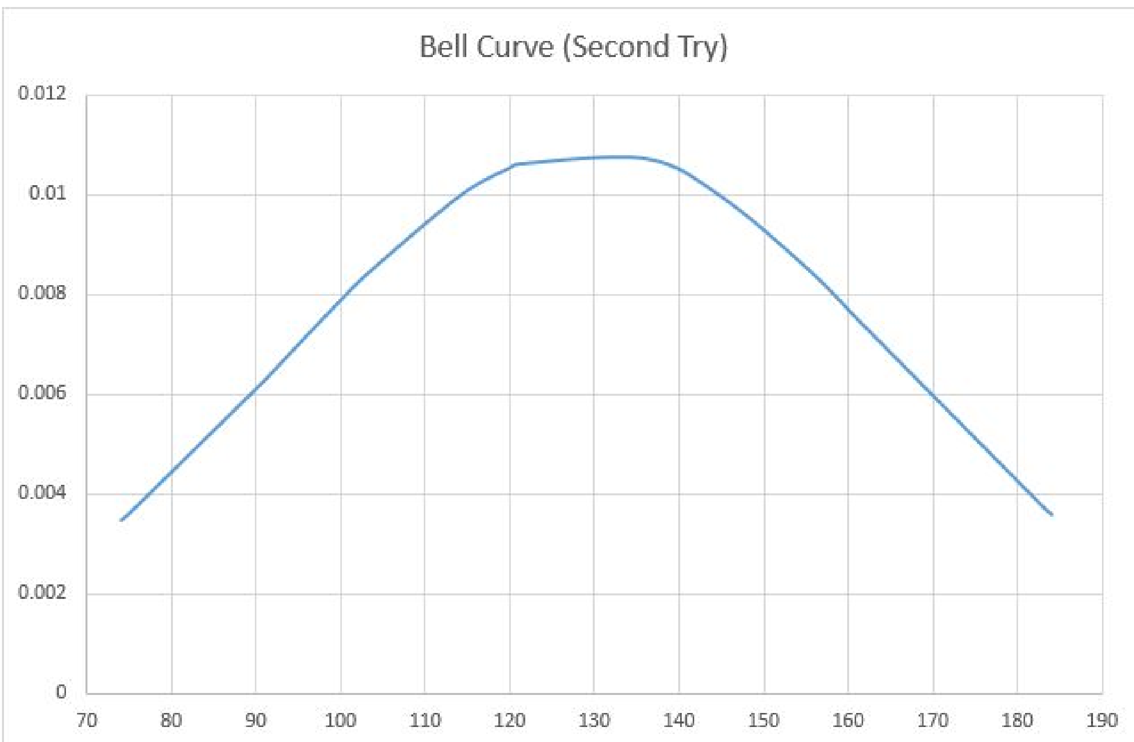


Figure 25: Bell curve Second Try

users. Since both tries were done in different times, users had a lot of time to forget their previous completion time.

Most of the qualitative results are not significant, however this also provides with examples on how not to approach an experiment. A good recommendation for future experiments is to increase the sample size if a quantitative research is to be done, specially for user testing. This will result in clearer results, therefore clearer discussions and conclusions in the quantitative area.

7.2 Qualitative Interpretation of Results

7.2.1 Users Feedback

Many of the users said they found the task easier when done more than once, hence confirming that undertaking more than one trial on Human-Joystick technique has a positive effect on the user's performance (in terms of speed). This does not mean that proficiency can be achieved with each try, as seen in the comparative line chart. In fact, some users did worse on the second try. The feedback of the users who did bad on the second try was the following:

- Users did not find the task to be motivating enough.
- Users were easily distracted by details in the environment.
- Because of randomness, users took longer in the second try.

7.2.2 Distractions

Qualitatively this results show that design in the game is significantly important depending on the context. Particularly one user mentioned that he was more focused on the view rather than on the task. In retrospective, the design of the serious game could have been more simple so that users were not easily distracted.

However, in today's games detail is everywhere in the Virtual Environment. Having a user complete tasks within the VE through the locomotion method was not the adequate approach for the locomotion technique. As mentioned previously, the aim of the study is to assess speed of completion which was measured in a task.

In order for this to function properly the environment must be not open and full of distractions. however, this leaves space for future research to be done by relating locomotion with variables such as distraction. This can be closely compared to a treadmill run inside a gym. When the user is constrained to the treadmill to run, the running becomes a monotonous activity. On the other side, if the user runs in an open environment it is more prone to distractions due to the varying nature of the environment. The same principle can be discussed in the experiment done, the distraction of the users can be closely related to the design of the environment.

7.2.3 Spatial orientation

Prior work has shown that users have difficulty maintaining spatial orientation in a Virtual Environment [1]. In this research it was confirmed that spatial orientation is a current challenge. Moreover, under certain circumstances users take significantly longer to learn Virtual Environments than comparable real environments [36] and more often produce large random and systematic errors in locomotion [37]. Finding ways to spatially navigate in Virtual Environments that perform closely related to the way we navigate in the real world is an underlying challenge which must be solved by game designers and game developers. Based on the feedback provided by users in the experiment done, a great majority had problems with spatial orientation. The reason can be that the design of the game was aimed for task completion. Therefore it is of utmost importance for future work to take into account the creation of spatial orientation cues that can aid the user inside the Virtual Environment.

7.2.4 Multisensory cues

Multisensory cues were not implemented in the current research. However, as concluded by Kruijff et al [2], multisensory features such as vibrotactile, auditory, as well as visual cues enhanced significantly the locomotion experience. This conclusion was also noticed in the current experiment, particularly in the user feedback. Many users stated that if there was a visual or auditory cues, their experience could have been more immersive, in comparison to no cues. This aligns with the discussion made related to spatial orientation, specifically the part of closely relate virtual environment experience with that one of a real world experience. Based on the feedback provided by users, having step sounds could not only enhance their locomotion experience but also provide with a way to regulate the speed of navigation. In the case of Human-Joystick technique, the sound of a hoverboard can provide with a more immersive experience. Having the leaning of the user affect directly the speed and sound of the locomotion execution can result in more awareness from the user. Mentioning the previous special case of the user falling due to over-leaning, this could have been avoided if there was a auditory cue that alerted the user.

7.2.5 Motivator: enjoy the view

As mentioned, one particular user mentioned being distracted because he was "enjoying the view". While this can be taken as a design challenge, it can also be an motivational opportunity. Essentially, when exploring large Virtual Environments, users tend to see the big picture of the environments they are located in. This opportunity of enjoying the ride can help mitigate problems such as nausea, specially when using a HMD for a long time. A carefully crafted environment can provide with a visual solution to what many users experience as nausea, while at the same time providing with a powerful distraction while the user navigates the desired environment.

8 Conclusion

In the following research an empirical approach on the Human-Joystick technique was done in order to determine any underlying benefits or challenges that have not previously been assessed by previous studies related on the topic. For this study the combination of the Nintendo Wii Balance Board and the HTC Vive was used, being Unity the engine where the experiments were developed. Two experiments were created with a Serious Game approach. Experiment1 was used to determine the speed of completion of a task using the aforementioned tools. The task for experiment1 was to reach from point A to point B in an open virtual environment. Experiment2 was used to determine the accuracy of completion of a task. The task for experiment two was to grab different objects and take them from point A to point B, this time in a closed virtual environment. The results found show that:

For Speed of Completion Experiment: - In the first round, the fastest time to complete the course was 1 minute and 21 seconds and the slowest time to complete the course was 3 minutes and 03 seconds, this gives an average of 2 minutes and 12 seconds. Out of the 20 participants, a total of 11 completed the task faster than the average, representing 55% of the total.

- In the second round, the fastest time to complete the course was 1 minute and 15 seconds and the slowest time to complete the course was 3 minutes and 04 seconds, this gives an average of 2 minutes and 10 seconds. Out of the 20 participants, a total of 12 completed the task faster than the average, representing 60% of the total.

- Nausea effects were perceived, however in a slightly manner. This concludes that many users felt the difference of using Human-Joystick technique. It is worth noting that most users that had experience in VR were accustomed to using it with the Walk-In-Place technique and had no nausea trouble there whatsoever. Besides, the fact that the users completed the task faster in the second try could influence a lot in the nausea effect (having a little more pressure the second time). Furthermore, nausea was perceived as uncomfortable. This aligns with the findings of Kruijff et al [2] which also found that motion sickness was an issue for some users. As mentioned in the discussion part, the careful crafting of detailed environments can serve as a double edged sword, being a powerful distractor for when completing tasks. However, when navigating a large environment, it can serve as a powerful mitigator of feelings of nausea and that is a positive effect that has to be highly taken into consideration by the game designers.

- Regarding the Post-Disorientation, many users felt a little disoriented, this can be seen in Table **??**, many users input was higher than 1 meaning SLIGHT and MODERATE disorientation was perceived. This can be mainly because of the effect of using a VR headset and combining it with the use of the Wii Balance Board, many users were accustomed to use the Wii Balance Board by itself and had no problem. The effect of a HMD over the orientation of the user when engaging in the actions in the Wii Balance Board proved to be a little difficult. For future work this problem can be tackled by creating a visualization of the actions that the user is doing so that they have a sense of orientation without having to take the HMD to see where their feet position is.

Based on the T-TEST that was done, it can be concluded that the null hypothesis H0 is rejected. This means that Undertaking more than one trial on Human-Joystick technique has a positive effect on the user's performance(in terms of speed), therefore H1 can be confirmed.

8.0.1 Contributions

It is shown that spatial awareness is highly perceived by the users when using the Human-Joystick technique. This is an important finding because it could inform the design of future Virtual Environment locomotive devices.

It is also worth noticing that the design of the Virtual Environment can be closely related to the amount of distraction the user might get, and therefore this can be detrimental for the purpose of completing a task in a timed manner. Game designers should have this in mind if their goal is to design an environment where the user has to complete a task. Avoid as many distractions as possible and the task will be completed in an efficient manner. This is an underlying challenge obtained from the discussion and review of charts shown in the discussion Chapter 7.

Another constant challenge when engaging in the research of a locomotion technique is spatial orientation. Previous studies have had the same problem [1, 38]. This is a challenge for current game developers to try to mitigate. While it has not been a major cause for problems for the users when performing, if there is an adequate level of spatial orientation that can be beneficial for future experiments. This is an underlying challenge that many experiments face. Finding an way to simulate a Virtual Environment performance closely related to the one in the real environment is a challenge for game designers that could prove to be useful not only for experiments but also for games alike. A good recommendation for developers is that when developing a locomotion algorithm, first test the same approach in a real environment. This will help developers perceive different variables of interaction that they later can translate into the Virtual Environment performance.

Another key finding of this research is that Human-Joystick technique is very well received. This can be shown based on the completion of tasks. Moreover, the user feedback regarding the locomotion technique was always positive and many mentioned that it is convenient, specially when navigating through large environments. Many were eager to watch a mixed locomotion technique and mentioned that it could be similar to having a hoverboard in the virtual world constantly. This is an opportunity for game designers and developers to venture on combining mixed locomotion techniques. One particular example mentioned by users is the one where users can call a virtual hoverboard anytime, and when desired just discard it and continue the navigation by walking.

In general, many of the claims stated in the introductory part of this research have been reached.

In retrospective, a different approach can be done to determine more challenges and thus giving more contributions to the locomotion technique studied. Qualitatively results were aligned with the alternative hypothesis, but a bigger sample can yield in more valid results. Qualitatively, through observation and user feedback a variety of underlying challenges were found, meaning there is more findings in the qualitative spectrum rather than the quantitative one regarding this study of locomotion technique.

8.1 Future Work

More research on Human-Joystick technique is needed to assess many other variables that were not contemplated in this thesis. Variables such as accuracy, presence and information gathering (as presented in the background related work section 3.4.1 can be assessed and measured through a variety of experiments.

Additionally, the current devices used are becoming old and new devices are coming. Regarding the Wii Balance Board, no related news regarding an upgrade have been released by Nintendo. However the Wii Balance Board capabilities, as shown in this experiment, are still current and can be merged with new HMD devices to do some novelty testing. Regarding the HTC Vive, the new version promises to release a wireless plugin by mid June. With this in mind, the necessity of cords can be something of the past and provide with new opportunities for the Human-Joystick technique to be explored.

Furthermore, as seen in Chapter 7, the ease of use, ease of learning can be intrinsic motivators for the user to immerse itself in the locomotion technique. With this in mind, additional tasks could be prototyped and experimented to further assess the validity of this statement. Users find themselves motivated when the completion of tasks is positive and we are very much eager to see what will be the user's reaction if the task are not completed (Will this decrease their motivation or increase it?). Maybe a serious game approach is not the correct way to empirically researched a locomotion technique, nonetheless it yielded with a lot of insights. Additionally, improvements on the method can be done by allowing users to change their speed based on how much they lean. Also adding sensory stimuli could enhance the immersiveness of the user's perception of the Locomotion in the Virtual Environment, and that is a topic of further research. Extended work can also be done in the area of multisensory cues to enhance the immersiveness in the locomotion technique. Additionally, motion sickness mitigation can be a focus topic to be researched in the future. Novelty approaches on how to assess speed and accuracy can be done so that different empirical approaches are researched.

Finally, more work can be done into the area of mixing locomotion techniques. Mixing locomotion techniques mean the use of two ore more locomotion techniques within the same Virtual Environment applications. An example of this can be the use of Walk-In-Place technique mixed with Human-Joystick. The user inside the virtual world could have a command that enables the merging of the HMD tracking device with the Wii Balance Board GameObject so that both can move long distances; and in the case of wanting to explore by foot (Walk-In-Place) a command can be done so that the HMD tracking device is detached from the Wii Balance Board GameObject and thus exploring. Examples like this can prove to give new opportunities for mixed locomotion techniques to be used in future game contexts. Future researchers and enthusiasts can and should quantify the qualitative challenges found so that more challenges could be potentially found.

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A Questionnaire

The following pages contain the pdf of the questionnaire given to participants in the experiment.

Demographic Questions

Some questions about you the paritcipant

* Required

1. **Id** *

____

2. **Gender** *

Mark only one oval.

- ◯ Female
- ◯ Male
- ◯ Prefer not to say
- ◯ Other: ______________________________

3. **Age** *

Mark only one oval.

- ◯ < 20
- ◯ 20 - 30
- ◯ 30 - 40
- ◯ 40 - 50
- ◯ > 50

4. **Do you use anything for vision correction?** *

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Maybe
- ◯ Prefer not to say

5. **If you are using corrective lenses are you able to wear them in the VR headset?**

Mark only one oval.

- ◯ Yes
- ◯ No

6. **How much digital game experience do you have?** *

Mark only one oval.

- ◯ I have not played any digital games
- ◯ I have played a small variety of digital games on a few platforms
- ◯ I have played a variety of digital games on several platforms
- ◯ I have played a large variety of digital games on most platforms

7. **How much VR experience do you have?** *

Mark only one oval.

- ( ) I have not tried a VR headset
- ( ) I have tried a VR headset once for a few minutes
- ( ) I have used a VR headset a couple of time for a few minutes
- ( ) I have used a VR headset multiple times and used it for a long session

8. **Do you believe there is a reason that your results would not be valid in this study?** *

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) Maybe

9. **In case of yes or maybe was given above would you please elaborate?**

____

____

____

____

____

Simulator sickness pre test

A set of questions to get a benchmark on your current degree of simulator sickness.

10. **Questions** *

Mark only one oval per row.

	None	Slight	Moderate	Severe
General Discomfort	( )	( )	( )	( )
Fatigue	( )	( )	( )	( )
Headache	( )	( )	( )	( )
Eye strain	( )	( )	( )	( )
Difficulty focusing	( )	( )	( )	( )
Salivation increasing	( )	( )	( )	( )
Sweating	( )	( )	( )	( )
Nausea	( )	( )	( )	( )
Difficulty concentrating	( )	( )	( )	( )
« Fullness of the Head »	( )	( )	( )	( )
Blurred vision	( )	( )	( )	( )
Dizziness with eyes open	( )	( )	( )	( )
Dizziness with eyes closed	( )	( )	( )	( )
Vertigo	( )	( )	( )	( )
Stomach awareness	( )	( )	( )	( )
Burping	( )	( )	( )	( )

Simulator sickness post test

Do these questions after you have completed the VR test.

11. **Questions** *

Mark only one oval per row.

	None	Slight	Moderate	Severe
General Discomfort	◯	◯	◯	◯
Fatigue	◯	◯	◯	◯
Headache	◯	◯	◯	◯
Eye strain	◯	◯	◯	◯
Difficulty focusing	◯	◯	◯	◯
Salivation increasing	◯	◯	◯	◯
Sweating	◯	◯	◯	◯
Nausea	◯	◯	◯	◯
Difficulty concentrating	◯	◯	◯	◯
« Fullness of the Head »	◯	◯	◯	◯
Blurred vision	◯	◯	◯	◯
Dizziness with eyes open	◯	◯	◯	◯
Dizziness with eyes closed	◯	◯	◯	◯
Vertigo	◯	◯	◯	◯
Stomach awareness	◯	◯	◯	◯
Burping	◯	◯	◯	◯

B Instructions

This appendix chapter contain the written instructions used in the tutorial of the experiment.

Tutorial

B.1 Before starting the Experiment

- Please fill the following Simulator Sickness Questionnaire, leave the Post-test section untouched until later in the experiment.

B.2 During the Experiment

- Welcome to the Speed of Completion experiment. Please step on the Wii Balance Board.
- Place your feet in the center of each block to assess the center of balance.
- (Proceeds to place the HMD on the user) If you feel any discomfort or nausea, please notify me and if you wish to stop the experiment it can be stopped at anytime.
- In the virtual world you will see several targets, each target will appear after you reached the previous target.
- As you can see, there is a GameObject below you that represents the Wii Balance Board. If there is any changes in the position of it in contrast to your position please notify me.
- Lean forward to advance.
- Lean backwards to go back.
- Lean to the right to rotate the GameObject to the right side.
- Lean to the left to rotate the GameObject to the left side.
- Please allow yourself to try freely as a practice session.
- Try to reach each target as indicated in the Virtual World.
- If you wish to try again it can be possible, however the experiment will start from the first target.

After the explanation and trial period, the user engages in the experiment. The experiment is timed by the experimenter who is observing the development of it from the computer screen.

B.3 After the Experiment

- Please fill the last part of the Simulator Sickness Questionnaire. If you felt any discomfort, nausea or disorientation please fill the desired options.
- Lastly, any feedback you could give us from the experiment? Your opinion is valuable and will remain anonymous.

C Experiment Raw Data

The appendix contains additional data from the experiments that was considered too long for the results chapter.

C.1 Participants

C.1.1 Demographical Data

The individual results from the questionnaire for Demographical data A. The answers to the multiple choice questions are written as numbers 1-4 instead of the answer from the questionnaire to save space. Meaning 1 is the first option and 4 is the last. The last "Completed" column was added to specify if the user completed the experiment completely or not (Table 1).

C.1.2 SSQ Questionnaire

The individual results from the questionnaire for Simulation Sickness Questionnaire A. The answers to the multiple choice questions are written as numbers 0-3 instead of the answer from the questionnaire to save space. Meaning 0 is the NONE and 4 is SEVERE. The following results are from the Pre-Experiment testing (Table **??**) and the next one is for Post-Experiment testing (Table **??**).

C.2 Speed of Completion Experiment

C.2.1 Speed Of Completion First Round

The individual results from the Speed of Completion experiment can be found here. The results are translated in Seconds and targets reached. The following results can be found in Table 2.

C.2.2 Speed Of Completion Second Round

The individual results from the Speed of Completion experiment can be found here. The results are translated in Seconds and targets reached. The following results can be found in Table 3

C.3 Speed of Completion Experiment T-TEST

UserID	Gender	Vision Correction	Lenses	Game Exp	VR Exp	Completed
A01	M	FALSE	FALSE	4	4	TRUE
A02	F	TRUE	FALSE	2	2	TRUE
A03	M	FALSE	FALSE	4	4	TRUE
A04	M	FALSE	FALSE	4	4	TRUE
A05	M	FALSE	FALSE	4	4	TRUE
A06	M	FALSE	FALSE	4	4	TRUE
A07	M	FALSE	FALSE	4	4	TRUE
A08	F	TRUE	TRUE	2	2	TRUE
A09	M	FALSE	FALSE	4	4	TRUE
A10	F	FALSE	FALSE	3	2	TRUE
A11	M	FALSE	FALSE	4	4	TRUE
A12	M	FALSE	FALSE	4	4	TRUE
A13	M	FALSE	FALSE	4	4	TRUE
A14	M	FALSE	FALSE	4	4	TRUE
A15	M	FALSE	FALSE	4	4	TRUE
A16	F	FALSE	FALSE	2	2	TRUE
A18	M	FALSE	FALSE	4	4	TRUE
A19	M	FALSE	FALSE	4	4	TRUE
A20	M	FALSE	FALSE	4	4	TRUE

Table 1: User testing Demographic data

UserID	Seconds	Targets Reached
A01	118	8
A02	183	8
A03	121	8
A04	81	8
A05	141	8
A06	92	8
A07	160	8
A08	181	8
A09	85	8
A10	118	8
A11	155	8
A12	178	8
A13	93	8
A14	117	8
A15	142	8
A16	87	8
A17	167	8
A18	179	8
A19	100	8
A20	90	8
Average	129.4	8

Table 2: Speed of Completion Experiment: First Round

UserID	Seconds	Targets Reached
A01	100	8
A02	160	8
A03	121	8
A04	75	8
A05	136	8
A06	99	8
A07	145	8
A08	183	8
A09	74	8
A10	103	8
A11	161	8
A12	155	8
A13	91	8
A14	114	8
A15	120	8
A16	95	8
A17	160	8
A18	184	8
A19	91	8
A20	97	8
Average	123.2	8

Table 3: Speed of Completion Experiment: Second Round

ID	Seconds	Normal distribution
A01	81	0.0045427066977942
A02	85	0.00521947606818302
A03	87	0.0055697187958258
A04	90	0.00610528049189733
A05	92	0.00646639752050546
A06	93	0.00664742354730577
A07	100	0.00789752827038403
A08	117	0.0103026461264635
A09	118	0.0103947915271781
A10	118	0.0103947915271781
A11	121	0.0106283791248371
A12	141	0.010376917889286
A13	142	0.0102833919192666
A14	155	0.00853983156583844
A15	160	0.00768763401205357
A16	167	0.00643021085021561
A17	178	0.00450985526454415
A18	179	0.00434717540682752
A19	181	0.00403015184886701
A20	183	0.00372508188110689

Table 4: Normal distribution: First round

ID	Seconds	Normal distribution
A01	74	0.00346144502978158
A02	75	0.00360659715553157
A03	91	0.00628559636979872
A04	91	0.00628559636979872
A05	95	0.00700906973381362
A06	97	0.00736830472494345
A07	99	0.00772280276890681
A08	100	0.00789752827038403
A09	103	0.00840795110896461
A10	114	0.00998614878736915
A11	120	0.0105578359880635
A12	121	0.0106283791248371
A13	136	0.010736283512115
A14	145	0.00996301220953268
A15	155	0.00853983156583844
A16	160	0.00768763401205357
A17	160	0.00768763401205357
A18	161	0.0075108053041952
A19	183	0.00372508188110689
A20	184	0.00357730189938551

Table 5: Normal distribution: Second round

D Replication

This appendix chapter contains an overview of features that are needed for replication but were not considered important enough to mention in the implementation section.

D.1 Tools

For the implementation of this project a wide variety of tools were used. This section contains an overview of the different tool and describes why they were used, how they were used and what possible alternatives there were.

D.1.1 Git

Git [] was used as the version control system when developing using the UNITY engine. Again the reason that git was used was because the Author had more experience with it compared to other version control systems.. When working with the UNITY engine it is generally best practice to use source control system to maintain a controlled progress and improve scalability.

When committing, pulling and pushing new changes the GIT bash and GUI were generally used. However, the GitHub desktop application [] was also used as when developing on a certain PC the authentication notification would not appear when using Git Bash and GUI.

D.1.2 GitHub

As the hosting service for the unreal engine project GitHub [] was used. Asides from experience in the doftware it is more common to host open source project on GitHub.

D.1.3 Google Forms

As mentioned in Chapter 4 the questionnaire used was given on paper format. Originally, the questionnaire was meant to be answered through Google Forms site as this was a quick and more efficient way to create and host a questionnaire. However, because of issues regarding NSD and their rules regarding using 3D parties and the storage of personal information the questionnaire was done on paper instead. The Questionnaire was however still made in Google Forms before being printed. Alternative options were contemplated (like hosting the questionnaire form on the university server), however it was finally decided that the questionnaire be done in Google Forms due to time constraints.