University of Nevada, Reno

A Comparison of Effectiveness and Immersion of Different Gait Techniques in Virtual Reality

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science
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by

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Abstract

In the budding world of virtual reality, immersion is one of the greatest aspirations and challenges for developers. Giving a user the most immersion will allow for them to get the full experience of the application they are using. One of the most difficult things when immersing a user is their method of locomotion. There are many ways to move a user through a virtual environment, but this can break the users immersion. Another difficulty could be the amount of effort exerted by the user in order to move through the virtual environment. If a user is using an application for an extended period of time, there should be minimal fatigue from the method of locomotion as locomotion is more than likely the secondary task of an application. User effort should be more focused on the primary tasks within applications rather than the secondaries. The user study performed here showed that there is no statistical correlation to efficiency between the tested methods of movement. Efficiency in this thesis correlates to how quickly a participant completes a test. This study did show there was a significance in motion sickness between two tested methods, gaitless and gait-negation, while partial gait had no correlation to the others. In the case of immersion, the majority of participants claimed that the partial gait method was the best. For effort, participants claimed that the gait-negation method was the most exhausting between the three.

Dedication

I dedicate this thesis to my mother, Barabara Andersen, who unfortunately passed away early this year.

Acknowledgments

I would like to acknowledge my advisor, Dr. Frederic C. Harris, Jr., as well as my committee members Dr. Sergiu Dascalu and Dr. Javaad Sattarvand for their time, energy, and aid with this thesis. I also want to thank everyone who helped me through this process. Those people include: my father Tom Andersen, my brother Brett Andersen, my girlfriend Sarah Johnson and her family, and Connor Scully-Allison. Without any of you I do not believe I would be at this point in my educational career!

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Chapter 1

Introduction

1.1 Brief History of Virtual Reality

Virtual reality is seemingly a new technology and has recently been commercialized for the public; however, virtual reality has been around for about half a century. The concept of virtual reality can be traced all the way back to the Sensorama in 1960 which was designed by Morton Heilig [25]. The Sensorama put the user into a multi-sensory simulator. This ran a pre-recorded colored film for the user. The Sensorama also included sound, scent wind and vibration experiences [25]. From here the first head mounted displays, also known as a binocular omni orientation monitor, was designed by Ivan Sutherland [8]. This design was know as the Sword of Damocles, as shown in Figure 1.1.

Not only did the Sword of Damocles allow the user a steroscopic video display, but it also tracked the position of the users head updating the video display with the head movements. The video was displayed through two mini cathode ray tube displays that sat right infront of the users eyes. Although the tracking on the Sword of Damocles was precise, it was an extremely cumbersome setup and not practical.

Based on Sutherland's design of the Sword of Damocles, cathode ray tube displays continued as the prominent display for virtual reality sets until around the turn of the century [20]. The biggest problem with the cathode ray tube displays, is the static that would generate on the screen. The discharge of this static could damage the users eyes, especially since the eyes were in such close proximity to the displays.

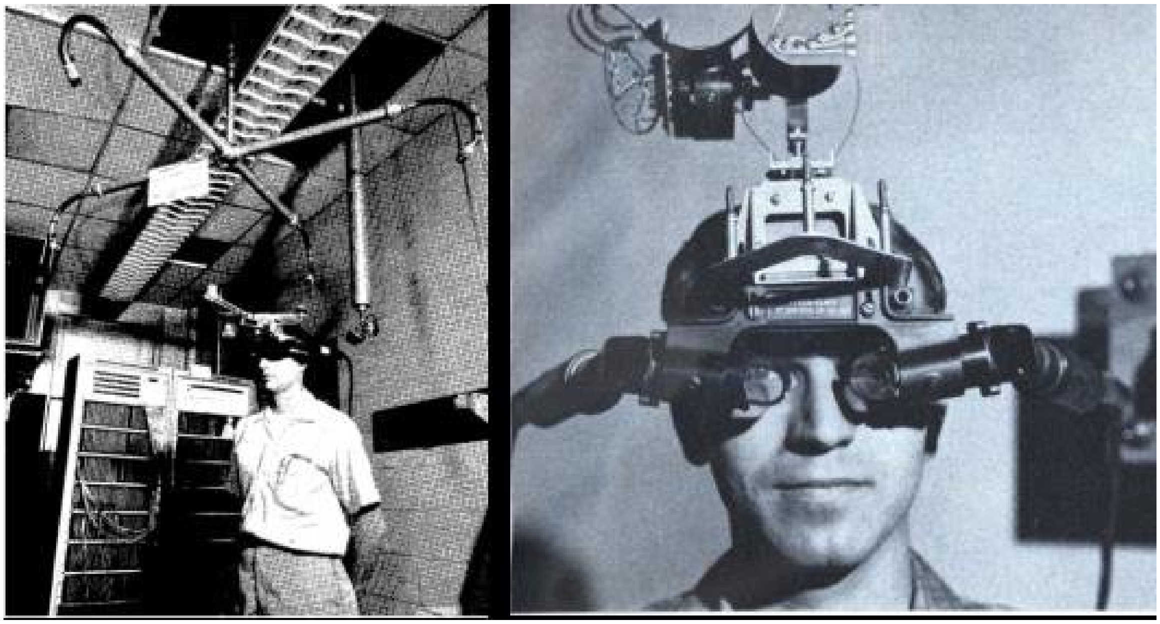

Figure 1.1: The Sword of Damocles worn by Ivan Sutherland [8]. Showing the small cathode ray tube displays on the right, and on the left, the entire setup required for The Sword of Damocles to operate.

This problem was solved using modern technology in the early 2000's by using LED displays.

1.2 Current Status of Virtual Reality

Modern virtual reality has many uses ranging between video games and training simulations. Looking into virtual reality sets, there are two major companies competing for the virtual reality market. These companies are Oculus and HTC. Oculus is known for their Oculus Rift and Oculus Quest, where HTC is known for the HTC Vive and HTC Vive Pro. Both companies headsets provide stereoscopic video. One of the key differences between these companies headsets are how they are tracked in real world space. The Oculus Rift uses an outside-in tracking setup where the headset is tracked via an IR-LED array on the headset that is tracked by a camera. The HTC systems use an inside-out tracking setup via lighthouses. This lighthouse system projects lasers and the devices return the position of where they are at with respect to the lighthouses [20]. Both major headsets use two hand remotes that are each tracked separately from the headset. For this project we decided to use the HTC Vive due to its accessibility at the University of Nevada. In the High Performance Computation and Visualization Lab (HPC-VIS), there are currently two HTC Vive's (Figure 5.1) along with a Virtuix Omni (Figure 5.2), which is an omni-directional treadmill that is usable with the HTC Vive. These are described in more detail later.

Virtual Reality Games: As of July 3, 2019, Valve Corporations online game store, Steam, had over 600 virtual reality titles for users to purchase. These games range anywhere from single and multi-player first person shooters to puzzle games. The most popular titles include rhythm games, first person shooters, and action-adventure role playing games. The most notable game is Beat Saber. This game has over 15,000 reviews where the majority of them are overwhelmingly positive[14]. Steam shows the variety of games in which the public is interested in and love to play. It also shows the versatility of virtual reality sets when it comes to video gaming in general.

Virtual Reality Simulations/Training: VR has been around for decades, but due to high investing costs, slow frame rates and low resolution, HMD's were mostly overlooked in the past. However, due to the introduction of cheaper HMD goggles and vast improvements in performance, several industries have employed VR for training and simulations[21]. One of the industries looking into virtual reality for training is the mining industry. Research about mine accidents has revealed that there is room for improvement of training the workforce in the mining industry as well [35]. The Mining Industry is slowly picking up, however most VR applications in mining have only been developed for research at Universities and have not been commercialized.

Current Research: The University of Queensland, Australia has developed and built a 360 degree cylinder, which one can step into and be surrounded by displays [21]. Different models for safety training, mine modelling etc. can be experienced within the displayed VR environment. Other VR applications refer to simulated virtual worlds that one can interact with on a 2D computer display [29]. HMD applications are constricted to an underground mine drilling training, developed by [48] and an underground mine pilot training from [15] for new miners. The test results of using immersive technology for training workforce showed that the vast majority of test participants preferred the HMD over other training methods (videos, pictures, lectures). Additionally, most felt, that they will memorize the taught material better when learning it in an VR environment [15, 48].

1.3 Locomotion and the Virtual Reality Application

There are many different methods of interacting with computers, and these methods are always evolving to be more accurate, reliable, and easy to use [7]. Locomotion is the act of movement or the ability to be able to move from one place to another. Having an easy to use and efficient method of movement would make the virtual reality experience more pleasing for the user [7]. Generally locomotion is considered to be a secondary task, so we want the user to people to do it without having to think too hard. In virtual reality there are many ways to accomplish the task of locomotion, the ones explored here are a gaitless technique, a partial gait technique, and a gait negation technique. These techniques are initiated via touchpad movement, walking in place, and with the aid of an omni-directional treadmill respectively.

The application being used for this user study is an underground mining evactuaction training simulator. This application was developed by Kurt Andersend and Simone Gaab in the Spring 2019 CS 791 Special Topics: Virtual Reality course at the University of Nevada, Reno. The application was designed to train people who work within underground mines on evacuation procedures. The application was designed and built on the Unity game engine using the SteamVR and Fizzy Steamy Mirror assets.

The application was designed for multiple users and has been adjusted for the user study for a single user. In the original application, one user would be placed within the mine, while the secondary user is placed within a control room. Inside of the control room, the user has an overview of the mine. This overview shows the current location of the user inside of the mine, the available exits from the mine, and where there are hazards within the mine. The user within the mine uses voice communications to talk to and be guided by the user in the control room. The user in the mine uses whatever method of locomotion they choose. For this project, we allow three different methods of locomotion: touchpad movement, walking in place, or using the omni-directional treadmill.

1.4 User Study

A user study in blatant terms is a study of users for information [23]. To elaborate, at least in our case, we have designed a software application that implements different methods of locomotion in virtual reality. These methods of locomotion are considered a user interface. A user interface is how a person interacts with an application [23]. A simple, yet separate example of a user interface is a mouse and keyboard. The user moves the mouse around and clicks to interact with what is appearing on the screen. In the case of our project here, the user implements different ways of moving in order to move through a virtual world. We want to be able to determine which method of locomotion will is the most efficient and immersive. The point of a user study is to compare data between different applied methods to see if the is a statistical significance [23]. In order to determine statistical significance, we use analysis of variance(ANOVA). If the data we are comparing is significant then we will receive a p-value of less than .05. If we are able to achieve a p-value of less than .05 then we will know that we can say there is an statistical difference between the methods of locomotion.

1.5 Purpose

The overall purpose of this study and project is to try and determine what kind of locomotion style in virtual reality feels the most immersive for a user, but also not requiring an immense amount of energy. Immersion can be described as having the feeling of being physically present in a non virtual environment. To create a completely immersive virtual reality environment, the system must generate imagery that occupies the user's entire field of vision [18, 36]. We also do not want to over exert a user in case there needs to be an extended use of an application. Finding a good balance between immersion and energy exertion would allow for others to design simulations where users could have an immersive experience and also be able to spend an extended amount of time if necessary within the application.

The rest of this thesis is structured as follows: In Chapter 2 we will discuss the background and history of virtual reality. We will then continue to examine what Locomotion is including different classifications and tasks for 3D travel, locomotion metaphors, as well as natural and inorganic locomotion. We will then proceed into Chapter 4 where we will discuss the software engineering aspect of the application used in this thesis. We will see a high level overview of the application, its functional and non-functional requirements, use cases for the application, and the overall architecture. Chapter 5 will then discuss the user study that was run. It will go in depth on preparation for the user study, the method used, the participants that took part of the user study, the apparatus used for the user study, the procedure used for each participant, the task each participant had to accomplish, and the design of the whole user study. We then continue into Chapter 6 where we examine the results and do some data analysis. We will look at the data gathered, how we analyzed it, the statistical analysis, and a discussion of the results. Finally we will wrap up with Chapter 7 where we discuss our conclusions as well as some possible future work.

Chapter 2

Background and Related Work

2.1 Virtual Reality

Virtual reality is a simulated environment that immerses a user and allows them to interact with the world in seemingly realistic ways. As mentioned in Chapter 1, virtual reality has been recently commercialized, but the first full set was created and designed by Morton Heilig in 1960 [25]. This set was the Sensorama as seen in Figure 2.1. One application of the Sensorrama was for the user to virtually ride a bike through part of a city and have the bumpy roads bounce your seat and have the wind in your hair. Then when you passed things in the virtual environment, like a bakery, you would also have smells permeate the chamber your head was in. The Seonsorama was then followed by the Sword of Damocles designed by Ivan Sutherland [8] which we saw in Figure 1.1.

As time progressed into the 1970's the GROPE and Videoplace were introduced. The GROPE was developed at the University of North Carolina and was the first prototype force-feedback system [25] which can be seen in Figure 2.2. This was used in applications such as molecular modeling. The Videoplace was designed in 1975 by Myron Krueger which was a conceptual environment with no existence. The Videoplace allowed silhouettes of users grabbed by cameras to be placed onto a large screen. The users were then able to interact with one another via the image processing techniques that tracked each users space on a two dimensional plane [25]. These were important because in modern virtual reality equipment there is haptic feedback

Figure 2.1: The sensorama allowed users to experience simulated senses. Users could experience stereo sound, vibrations, aromas, and wind. They would sit in a seat and immerse themselves within the device. [8]

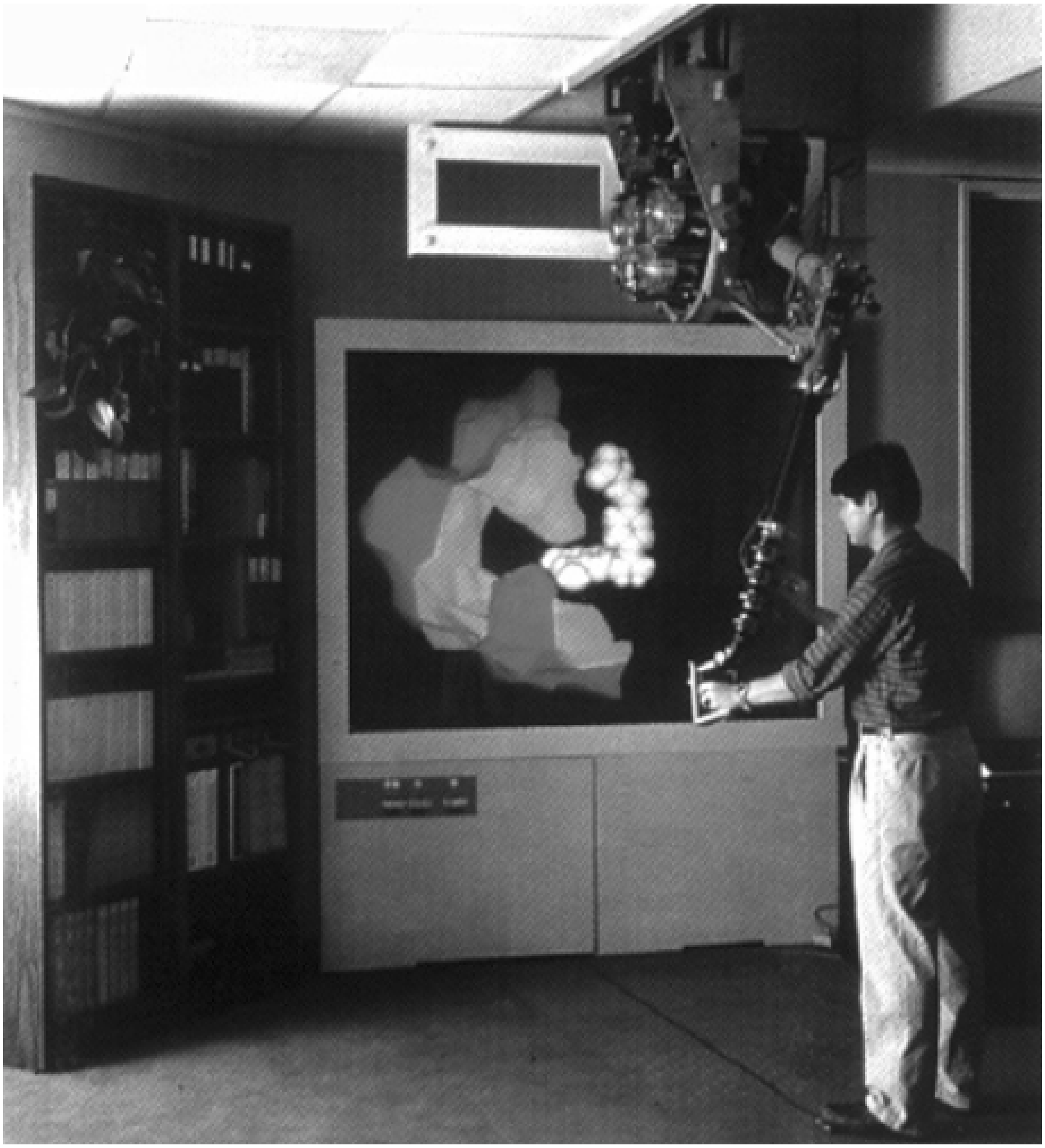

Figure 2.2: A user using the GROPE. The GROPE had a force feedback display. As the users model would collide with other objects in the virtual environment, they would receive haptic feedback signifying the collision [25].

through the hand remotes via vibrations. The same kind of tracking used on the silhouettes led to the tracking in a three dimensional space.

As we move into the 1980's we were introduced to the VCASS which was developed by Thomas Furness in 1982. The VCASS isthe Visually Coupled Airborne Systems Simulator that was used by the United States Air Force. The VCASS was an advanced flight simulator where the fighter pilot wore a head mounted display which augmented the out-the-window view with graphics describing targeting or optimal flight path information [25]. Additionally in the 1980's the VPL company released two products, the DataGlove in 1985, and the Eyephone HMD in 1988. The Dataglove was designed to be used as a new interface device, similar to a mouse but usable in a three dimensional environment and can be seen in Figure 2.3. These were considered the first commercially available virtual reality devices. The last device put

Figure 2.3: The VPL Dataglove used resistive sensors in order to allow a richer interaction than a three dimensional mouse. It allowed the user to use hand gestures that were recognized and translated into proper actions [25].

out in the 1980's was the FakeSpace BOOM (Figure 2.4). The BOOM is a small box that had two cathode ray tube monitors that could be viewed through the eye holes. The user can grab the box and move it around to move their sight perspective in the virtual world. This was tracked by the position of a mechanical arm the measured the position and orientation of the box [25].

Figure 2.4: The FakeSpace BOOM

Finally progressing into the 1990's, prior to modern virtual reality sets, we see the development of the CAVE and an introduction to augmented reality. The CAVE (CAVE Automatic Virtual Environment) is set up with four or six walls that users stand within. Rather than a head mounted display, users within a CAVE will wear LCD shutter glasses [25]. A sample of a user within a cave can be seen in Figure 2.5. This allowed for superior quality and resolution of the viewed images as well as a wider field of view when comparing to a head mounted display system. Augmented reality showed up in the early 1990's as a technology that presents a virtual world that enriches, rather than replacing the real world [25]. One of the first implementations of augmented reality was an overlay for fighter pilots that gave them additional flight information.

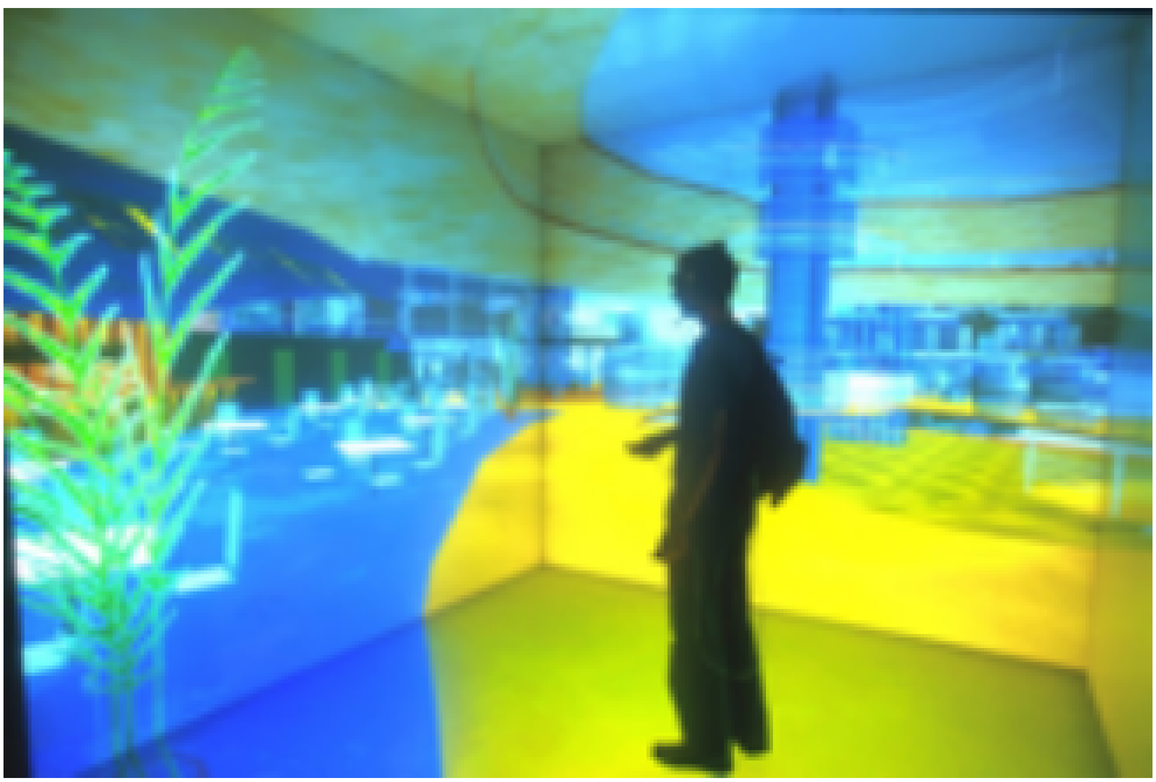

Figure 2.5: A 6-sided CAVE shown here places a users in a virtual environment. Note: the back wall is open for entrance and exit as well as for this photograph. The CAVE places the full body within the environment rather than creating an avatar for the user in the virtual world [8].

2.2 Locomotion

Locomotion is an interface that enables both users to move around within the virtual space and actual reality [45]. There are multiple systems out there that give a user a near real experience, but these systems can cost thousands of dollars. One of the realistic systems is the virtusphere [26]. This device encloses a user within a sphere while strapped to a harness on a stable platform as seen in Figure 2.6. When the user starts to walk, the sphere rotates under them. This allows the user to move in any direction. On the cheaper end of things, there are developments such as redirected walking that alters what the user is seeing, and has them change directions in the real world. The slight warping of the virtual world will reflect into the user walking in an arc shaped pathway. This ensures that the user stays within their boundaries for the virtual reality set [32, 33]. Our goal is to find a form of movement that is inexpensive, natural, efficient, and safe. The user will not have to worry about walking back into a wire connected to their headset.

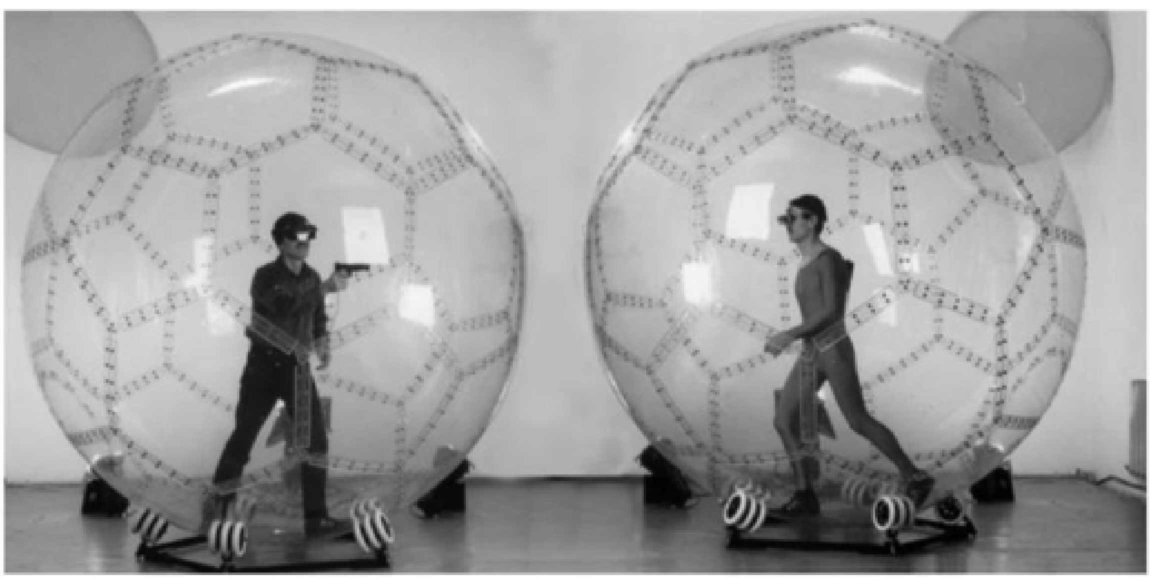

Figure 2.6: The image depicts a person running inside of the virtusphere. This is a clear version of the Virtusphere, retail models are created with a mesh. The user runs or walks where they are, while the ball rotates around them [26].

2.2.1 Tasks and Classification for 3D Travel

When it comes to locomotion, it can be broken down and defined by many things. One of the main things is the tasks of locomotion which can be defined as travel and wayfinding. Travel is described as moving from one location to another target location, or moving in a desired direction [20]. Wayfinding is the process of determining and following a route between an origin and a destination. With the combination of the previously stated definitions of travel and wayfinding, we are able to see the description of the tasks for locomotion. With these definitions in mind, the tasks can be broken down into different travel categories [20].

The first category of tasks is exploration. Exploration is where the is no explicit goal for the user. The user can be placed into an environment and not be given any direction on where they need to go. As the user moves around the environment they are exploring [20]. The next category is search. Searching is tasks that involve travel that require the user to move to a specific goal. Searching can be done in one of two manners. The first is Naive searching, where the user does not know the position of the target, or a known path to the target. The second is Primed searching where the user has been to the target at a previous time and has knowledge about its position [20]. The third category is maneuvering. Maneuvering is specific to small and precise movements within a local area [20].

There are additional characteristics that should not be overlooked when it comes to characterizing 3D travel tasks. These characteristics include the amount of distance to be travelled, the amount of curvature on the path, the number of turns in a path, the visibility of the target from the starting location, the number of degrees of freedom for movement, the required accuracy of the movement, and the primary tasks that will be taking place during movement [20].

When it comes to classification of 3D travel, there are four main technique classifications. The first is active versus passive [20]. In an active environment, the user will directly control movement of their own viewpoint. With passive, the viewpoint is controlled by the system rather than the user. The second classification is physical versus virtual [20]. Physical is when the users body physically translate to create the same kind of manipulation in the virtual environment. Virtual is when the user remains still, but the viewpoint changes in the virtual environment. The third classification is by the use of task decomposition [20]. Task decomposition is when the movement is broken down and executed by the process of target selection, speed control, and the conditions of the input. The final classification is by the use of metaphors [20]. Metaphors are created by creating a similarity in the movement style to something that is already known and familiar to the user [45]. In this study, the use of metaphors was used as the main classification for the users methods of locomotion.

2.2.2 Metaphors

As previously stated, metaphors are created when an action has a similarity to an already known action. Metaphors in the English language are when the words “like” or “as” are used when describing something. An example of a metaphor is, “That pile of trash is as big as a house.” The trash is being described to have the same qualities in mass as that of a house, thus creating a similarity between the two. When we take the description of a metaphor and apply it to locomotion, we are able to use it in different kinds of categories. Some of the primary characterizations of a metaphor for locomotion are gait metaphors, steering metaphors, selection-based travel metaphor, and manipulation-based travel metaphors. Each of these characterizations will be broken down and referred back to the original description of a metaphor. Many of the metaphors will overlap with one another, but they can be classified in different manners.

Gait Metaphors

Gait is essentially the manner in which a person walks or moves. There are many ways to look at and use gait when it comes to virtual reality. In this study we look at partial gait, gait negation, and gaitless techniques. There are however additional gait metaphors that could be used that were not. The metaphor not used is full gait. This technique was not used because of a lack of space in the testing area. Space was taken into consideration when the movement methods were decided upon. All previously mentioned gait metaphors will be explored more thoroughly.

One of the gait metaphors is full gait. Full gait is when you use the entire normal motion of a person's gait. An example of full gait movement is real walking. This is when all the movement in the real world is directly transferred to the virtual world to create the same movement. Something similar to real walking is redirected walking. The advantage with redirected walking is the user has more room to move, but still appear as though they are walking straight [20]. The way redirected walking works, is as the user moves forward, the virtual world slightly shifts which makes the user start to turn in the real world, even though they appear to be moving straight in the virtual environment. The adjustment in the virtual world is minimal enough to where it does not cause motion sickness. A final example of full gait movement is scaled movement [20]. This is similar to real walking, except the movement is scaled in distance. For instance, if the user moved one meter in the real world, they would move five meters in the virtual environment. The scale here would be a one to five. The scale can be changed in any way to create the movement scale desired by the designer. In the case of full gait movement, they are considered metaphors because there is still very mild differences between actual walking. Full gait movement is however the closest to a natural gait method of movement.

Another gait metaphor that is explored is partial gait. Partial gait uses portions of a person's natural gait. It does not require the same movement as full gait metaphors, so it requires less space. A prime example of partial gait is walking in place [20]. This still allows the user to move in a familiar manner, but not have to take up all the space that would be needed for real walking. The walking in place method generally keeps track of where the users feet are in space in the real world. For the study here, a virtual reality tracker is attached to each of the users ankles.

As the user moves their feet up and down as if they were walking, they get propelled forwards in the virtual environment. A participant with the trackers attached to her ankles can be seen in Figure 2.7. Another method of partial gait is the human joystick [20]. The human joystick uses weight distribution from the user. An example of a human joystick would be using a platform that can sense pressure. If the user leans forwards, then more pressure will be on the front of the platform and it will translate to propelling the user forwards in the virtual environment. Partial gait metaphors are great when a designer wants natural feelings movements, but are lacking space. Both

Figure 2.7: This participant has trackers attached to her ankles over her boots which keep track of where her feet are in space. As her feet oscillated, she was propelled forward in the direction she was gazing in the virtual environment.

of the examples previously stated allow the user to stay within their own personal space and not have to move about the real world. Partial gait techniques are excellent examples of metaphors, because the user is moving similarly to natural movement.

The next metaphor that will be explored is gait negation. Gait negation is when there is some sort of apparatus that negates the user's natural gait. Gait negation can be used with an active or passive omni-directional treadmill, a standard treadmill, or low friction surfaces [20]. The most popular methods use either the active or passive omni-directional treadmills. A passive omni-directional treadmill relies on the user's weight and momentum. An example of a passive omni-dirctional treadmill can be see back in Figure 2.6. The Virtusphere is considered passive because it does not start negating the users movement, until they actually move. An active omni-directional treadmill will force the user to move against it. Active omni-dircetional treadmills are like the standard exercise treadmill where the surface will move and the user has to move against it.

The final metaphor to be discussed are gaitless techniques. These methods do not require a user to use their natural gait at all. These methods are best described by using controllers or remotes in order to propel oneself through a virtual environment. For this study, the user uses the touchpad on the HTC Vive's hand remote. The user points the remote in the direction they want to move, then press down on the thumb-pad in order to start moving. The user can execute this method either sitting or standing up. This is still a gait metaphor because it enables a movement in the virtual world that mimics real world movement.

Steering Metaphors

When classifying steering metaphors, it is more focused on how the user adjusts the direction of their locomotion rather than how they initiate propulsion. When classifying an overall metaphor, especially with steering metaphors, methods can be combined. For example, a full gait metaphor can be combined with a spatial steering metaphor. The two main methods of steering metaphors are spatial steering and physical steering props [20]. Many of the methods mentioned from the gait metaphors will have some overlap with steering metaphors.

When looking into the spatial steering metaphor, there are many methods that can control the steering. The first of the methods is gaze directed steering [20]. As the user is being propelled through the environment, the forwards propulsion will always be in the direction they are looking. This can easily be imagined as if there was a line projecting from the users face and always moving in that direction. The next steering method is hand directed steering [20]. This method is used in this study in the gaitless method of movement. As the user presses down on the thumb-pad, they will be propelled in the direction in which the remote is pointing. If the user is looking to the north, but the remote is pointing east, and they press forwards on the remote, they will start moving east. The next method is torso directed steering [20]. This method is best portrayed with the Virtuix Omni. The harness on the virtuix keeps track of the direction of the users torso. As the user runs in place, they will move in the direction their body is facing. This allows the user to look around the environment and still move in the direction the rest of their body is facing. The last method for spatial steering is lean directed steering [20]. This is exemplified by the human joystick movement style. If the user leans forwards, they will move forwards in the virtual environment. If they lean to the right, they will move to their right in the virtual environment.

Physical steering props are fairly self explanatory. The user will use some sort of physical device in the real world in order to maneuver themself throughout the virtual environment. An example of a physical device would be a cockpit for a flight simulator. The user will move the steering device in the cockpit that they are sitting in in order to maneuver the plane in the simulator they are using. These kinds of simulators are also used for military vehicle training. These simulators range from basic four wheeled vehicles to some of the track vehicles, as well as planes that are in use by the military.

Selection-Based Travel Metaphors

Selection-based travel is a unique method of locomotion as in most cases it will instantaneously move the user from one location to another. An example of selection-based travel is fast travelling. Fast travelling is a form of movement that has been implemented in many role playing games such as The Elder Scrolls series or the Fallout series produced by Bethesda Softworks [6]. In these games the user is able to view a map of the areas that they have explored. Specific landmarks and towns will be marked with an icon on the map. If the user has visited the location the can highlight the icon on their map and choose to fast travel to the point. This immediately moves the user to the designated location and passes time in-game as if they had really walked there. The benefit of fast travel is that it allows users to move a great distance in a short amount of time, but still allows in game time to pass to add a layer of immersion to the game.

Another method of selection based travel is teleportation. Teleportation is treated similarly to fast travelling, but it typically tends to be more of a local movement method rather than a global one [9]. Normally the user projects some sort of laser or fires a projectile from their position and can move to the location at which the laser intersects the ground or where the projectile lands. A virtual reality game that takes advantage of teleportation as their primary method of movement is Budget Cuts that was developed by Neat Corporation [12]. In Budget Cuts, the user equips the teleportation gun to one of their hands. They then fire a projectile. Once the projectile lands, the gun transforms into an orb the previews the viewpoint of the location where the projectile landed, as seen in Figure 2.8. If the user likes where the projectile landed, they can pull the orb to their face in order to teleport to the designated location, if they do not like the spot, they can take the teleportation gun back out and fire again at a new location. Teleportation is a quick and efficient method of locomotion, but breaks away from a users immersion because the movement does not feel as natural as something like gait metaphors. Teleportation is generally used when there are great distances for the user to travel, and locomotion is not the main

Figure 2.8: This figure shows that a user recently shot their teleportation gun and have a preview of the area they can move to by moving the orb to their face [12, 41].

focus of the application. The main focus of these applications tends to be something that can be done in the users direct area that they can reach from where they stand.

Manipulation-Based Travel Metaphors

Manipulation-based travel is a unique method of movement, as it requires the user the physically manipulate the environment to move. Generally the world is moving around the user, or the user is directly manipulating their own position in the world [20]. There are a handful of methods in order to accomplish manipulation-based travelling. The first of which is what people call "God Hands." This is when the user can grab the environment and move it around them. For instance, the user can kneel or sit down in order for their hands to reach the ground in the virtual environment. They will then proceed to grab the ground and pull it underneath them. This kind of movement can scale in scale based on how fast the user pulls the ground underneath them. The faster the user moves their hands while grabbing the ground, the faster they move. If the user moves their hands slowly, they will not travel as far.

Another interesting method of manipulation-based travel is know as world in mini. This is similar to the fast travel method, except it allows for more direct manipulation. The user will have a scaled model of the virtual environment in their hand. In this scaled virtual environment, they are able to see where their avatar is at in the world. They can then grasp their avatar and place it in another location in the scaled environment. Once they confirm the moved location of their avatar, they will teleport in the regular virtual world that correlates to where they moved their avatar in the miniature virtual environment [5]. This allows for more precise movement in comparison to fast travelling as the user can directly choose where in the virtual environment they want to move to.

2.2.3 Natural and Inorganic

One of the key aspects of this study is comparing an inorganic method of movement to natural methods of movement. Natural methods are those that mimic something that the human body is already used to [45]. In the case of this study, the two natural methods are the partial gait technique and the gait negation technique, or walking in place and the omni-directional treadmill respectively. Both of these methods mimic the natural movement of a body walking. Natural movement can also be described as something that is not a learned method. With inorganic methods, these are learned methods, meaning that the user can not relate it to something they already know how to do. The touchpad movement, or the gaitless method, will control the users avatar in a way that the body has to learn. Another example of a learned method is a person using a mouse with a computer. When first introduced to a computer, moving the mouse on an x,z plane reflects to the mouse moving on an x,y plane on the computer [45]. One of the main focuses of this study is to determine if natural and inorganic methods correlate to efficiency and immersion in virtual reality.

Chapter 3

Preliminary Work

3.1 Motivation

The idea for this thesis originally started with a course project to design a simple user study that could completed in a short amount of time. The project completed for this study was a comparison between a natural and inorganic method of locomotion. Once the sample study was completed we went back through IRB to get approval to fully run the user study with more users in order to publish the results. This application was put through IRB and approved under IBBNetID: 1487456. This paper for this user study has recently been accepted [2]

3.2 Project Design

In order to increase the overall understanding of the data collected from the study, all participants were asked to fill out a pre-test survey. The survey asked questions about topics such as their current energy level, as well as their experience with VR and video games. A post-test survey was also administered to gather information on how the users felt about the different locomotion methods. The post-test survey questions about feelings of fatigue, sickness, and overall enjoyment. The users experienced both methods. The order of the methods tested were randomized in order to reduce the odds of the data being affected by the ordering.

3.2.1 Participants

The participants used in this study consist of a wide and diverse range of people, both of different backgrounds and genders. There were a total of 20 participants in which 12 were male and 8 were female. They were all at one point enrolled at a university, with fields ranging from marketing to computer science and engineering. We made certain to choose more participants with no background in computer science in order to properly gauge how people outside of the field react to virtual reality. By choosing participants outside of the field of computer science and engineering, it also increased the chances that the subjects never used virtual reality before.

Most of the participants answered in the pre-test survey that they had little to no experience with virtual reality. A higher percentage of males answered that they had little virtual reality experience compared to the females. It is also worth mentioning that two of the female participants were also two out of the three computer science and engineering majors used for the study. Most of the participants, both male and female, also claim to have had experience playing video games with the exception of a few that answered little no experience. There was also about an equal amount of participants that answered in the survey that their energy level was either high or low/moderate.

Most of the participants answered in the pre-test survey that they are not prone to motion sickness; the majority that answered yes were female. In the post-test survey, both male and female participants answered that they felt more motion sickness, as well as fatigue using the natural method. As a result of this, most of the participants in the post-test survey answers suggest that they prefer the inorganic over the natural method of locomotion. In the post-survey, there did not seem to be too much of a disparity between the male and females involving their level of motion sickness and fatigue. A majority of the participants answered that participating in this study increased their interest in virtual reality.

3.2.2 Apparatus

The HTC Vive headset and controller was used for this study (Figure 3.1). These devices were chosen due to familiarity and availability. HTC Vive Trackers were also used to allow tracking of the ankles (Figure 3.2). This was for the implementation of the WIP or natural method.

In order to avoid preventing players from being faster or slower in either method, both the organic and inorganic methods used set speeds. However, the natural methods could have been allowed to have varying speeds if deemed necessary.

We used the Unity Game Engine in order to create the application in which we had participants use (Figure 3.3) [38]. Within Unity, we used the SteamVR asset package as well as the Hand Painted Forest Environment Asset shown in Figure 3.4 [40, 47]. These allowed us to create an aesthetically pleasing environment for the participant to move through, as well as providing us with a library to interface with the HTC Vive headset.

3.2.3 Procedure

The participants were then introduced to the virtual reality system and the space that they were going to be spending the duration of the study in. Then the participants were given the pre-test survey to fill out. Some of the questions asked were about

Figure 3.1: The HTC Vive headset and the two remotes that come with the standard HTC Vive package[17].

Figure 3.2: The HTC Vive Tracker is an additional peripheral for the HTC Vive [16].

their experience with VR, their reason for coming, and what their major is. After completing the survey, the first locomotion method to be tested was explained to them. Once they confirmed they understood the method, they were given the headset and controllers. The participants were told that if they felt sick they could stop the testing at any time. Then they familiarized themselves with the method by exploring the VE before the test was started. The users then completed the course and data was taken.

After completing the first method, the users were given a five minute break. The break was given to reduce the odds of fatigue, along with the possible feeling of motion sickness so that results from the next method were not affected. After the break, they were briefed on the next method. When they verbally confirmed that they understood the method, they were given the headset and feet sensors. They were given time to get used to the method of locomotion, and completed the course again. The data was again recorded. Finally, after obtaining all of the data, the users were then asked to fill out a post-test survey. The survey asked questions about which method was more immersive and enjoyable. The participants were also asked to gauge how sick or tired they felt on a scale of one to ten.

Throughout each run of the course, two separate times were measured. The most important data collected was the overall time from the starting line to the finish. The time it took for the user to move between each checkpoint was also recorded. The data was saved as split times for easier data analysis. The final pieces of data that were collected was from the post survey. These were just a hard value given as an opinion of how motion sick and fatigued the participant felt.

Figure 3.3: A perspective view of what participants would see when the testing application starts

3.2.4 Tasks

As stated previously, after the participants were briefed on the control scheme of each locomotion method, they were allowed one minute of free time in the virtual world to explore using said method of locomotion. Once their exploratory time had expired, the participant was moved to the starting zone of the application. Once they moved through the first checkpoint, the timer was started and they began moving through a predetermined course as fast as possible using the respective locomotion method. There was a single path on the ground for the participant to follow as seen in Figure 3.4. In order to complete the course, the participant needed to navigate through a series of checkpoints. The current checkpoint the participant had to reach was seen as a massive translucent green screen. Once the user reached the end of the course, they were briefed on the other method of locomotion and followed the same steps.

Throughout each run of the course, two separate times were recorded. As mentioned earlier, the most important was the overall time from the starting line to the

Figure 3.4: An overview of the course for each participant to follow.

finish. The time it took each user to move between each checkpoint was also recorded. These values were saved as split times for easier data analysis. The final pieces of data that was collected was from the post survey. These were just a hard value given as an opinion of how motion sick and fatigued the user felt.

3.2.5 Design

In terms of variables for this study, there were not any between-subject variables. Our independent variables were all within-subject. The independent variables were the style of locomotion and how sick and fatigued the participant felt at the end of each course. Each participant performed the two styles of locomotion. The order in which the participants performed them was random. This way, the data was able to be gathered in a more efficient fashion. If each participant did one style first and the second after, then the data could be skewed towards the second movement style being more efficient. This would be because the participant would already know the course. The overall entry for this study was 20 participants, two forms of locomotion, and one course to move through. The course contained sixteen checkpoints, including the time between the last checkpoint to the finish.

3.3 Project Results

Figure 3.5 displays a box and whisker representation of the overall lap times for each participant. We used a One-Way ANOVA calculator to find the p-value. The p-value that resulted from the data was 0.024. Thus, the data between the two populations is statistically significant. The averages between each participant for each reached checkpoint were very close. However, the average times it took for each participant using the inorganic method to reach each checkpoint were faster than the average times it took for each participant using the natural method to reach each checkpoint.

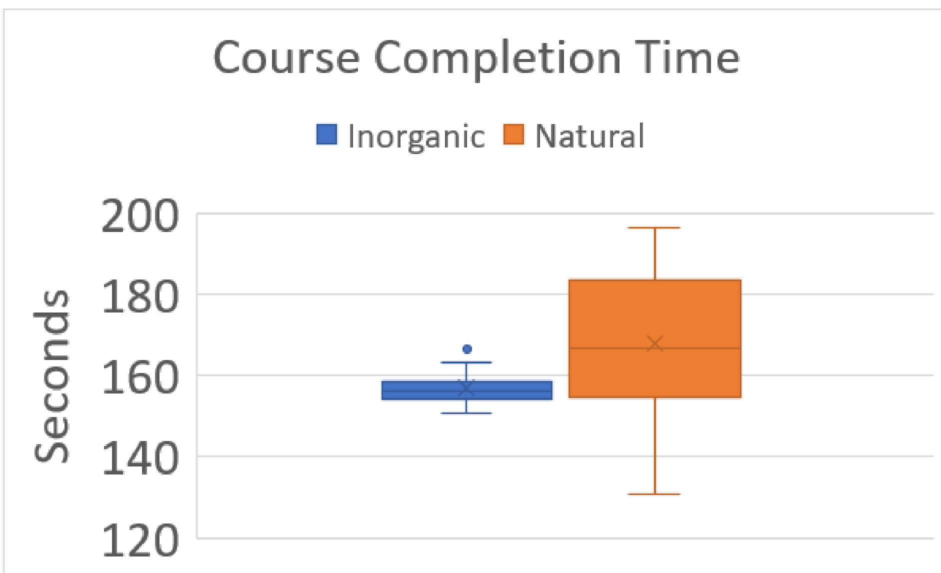

Figure 3.5: Box and Whisker Plot for the course completion times of each participant in seconds. **Inorganic:** Average=156.8, Median=156.2, Outlier=166.6, Maximum=163.4 Minimum=150.7 **Natural:** Average=167.7, Median=166.8, Maximum=196.3, Minimum=130.6

Figure 3.6 shows the Box and Whisker Plot for feelings of motion sickness. We used a Likert scale from 1 to 10 to collect data on feelings of cybersickness. In the

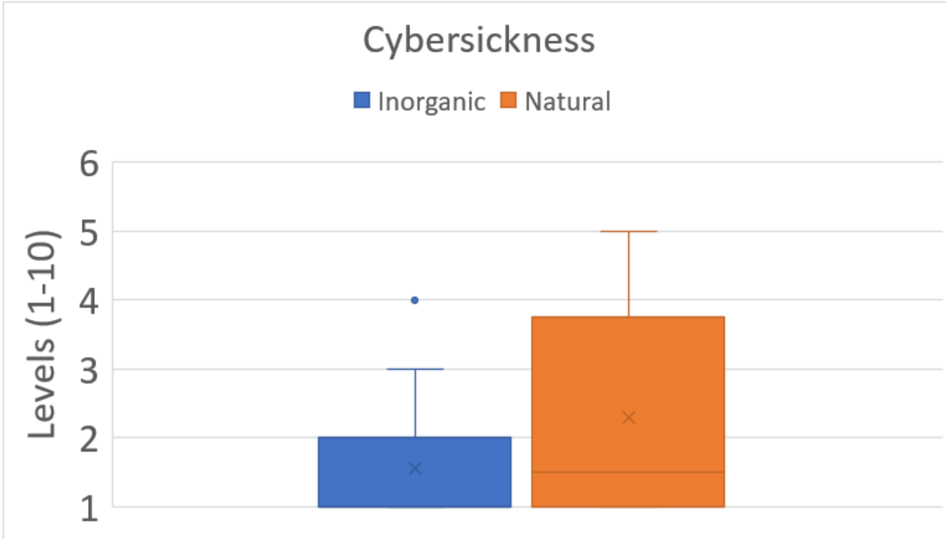

Figure 3.6: Box and Whisker Plot for Cybersickness Responses. **Inorganic:** Average=1.55, Median=1, Outlier=4, Maximum=3 **Natural:** Average=2.3, Median=1.5, Maximum=5

scale, 1 means that the user felt no symptoms of motion sickness, while 10 means they felt extremely sick. After running the data through a one-way ANOVA calculator, the p-value between the two populations resulted in 0.069. If $\alpha = 0.05$ the data between the two populations is not statistically significant. A fair number of participants, one half, felt no sickness whatsoever using both methods. Some felt the inorganic method caused more sickness while some felt the WIP method caused more sickness.

Figure 3.7 shows the Box and Whisker plot for feelings of Fatigue. When we gathered data for fatigue we used a Likert scale from 1 to 10. In this scale, 1 means the participant felt not tired, while 10 means they felt extremely tired. We found the p-values for the data received for fatigue using the same calculator. The p-value is < 0.00001. We had trouble interpreting the responses from ID 16. This is because 16 answered that the inorganic method was more tiring because of walking. We assumed this was a mistake and swapped that participant's values for fatigue.

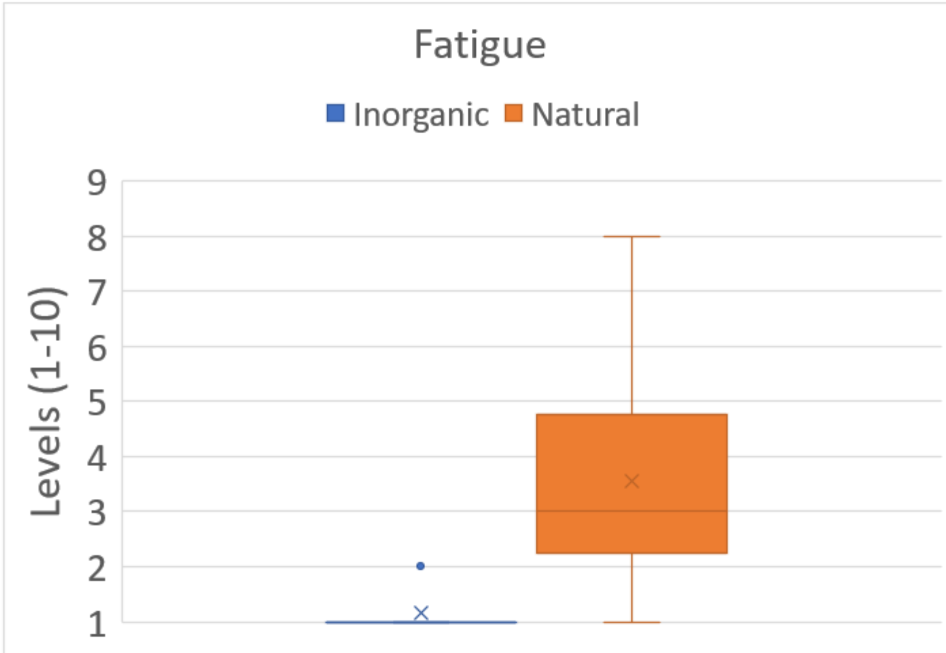

Figure 3.7: Box and Whisker Plot for fatigue responses. **Inorganic:** Average=1.15, Median=1, Outlier=2, Maximum=1 **Natural:** Average=3.55, Median=3, Maximum=8

3.4 Moving Forward

This user study was the basis of this thesis. It was expanded upon by including an additional method of locomotion, as well as altering the environment that the test was run in. Methods of movement were refined and designed to be more responsive in the virtual environment. The passion and interest discovered from this preliminary study led to the conception of this thesis. Although not all future work ideas between the previous projects to this thesis were covered, this thesis still expands upon the basic idea.

Chapter 4

Software Engineering

4.1 High Level Overview

The application used for this user study is a version of a multi-user mining evacuation training simulator that was developed earlier and is under review [3]. This application places one user within the depths of a mine where there are certain hazards throughout it including fires and cave-ins. A second user is placed in a control room where they must communicate with the first user to direct them safely out of the mine. The user in the control knows the location of hazards within the mine and communicates with the other user via a walkie-talkie. For this user study, only the user placed into the mine was present, as they were directed by the investigators for the user study. In the primary application hazards are generated at different locations creating a different escape route for each iteration. For the user study, the same hazard path was used in order to create a similar testing environment for each participant.

4.2 Functional and Non-Functional Requirements

The functional and non-functional requirements for this user study are detailed within this section. The functional requirements are listed in Table 4.1. The non-functional requirements are listed in Table 4.2.

Table 4.1: Functional Requirements

Functional Requirements	
Name	Description
FR1	The system shall allow users to navigate and move through the environment.
FR2	The system shall allow users to communicate with one another.
FR3	The system shall have an environment for the user to interact with.
FR4	The system shall allow users to connect with one another via a network connection.
FR5	The system shall have obstacles for users to navigate around.
FR6	The system shall have a built in timer to allow for data collection.
FR7	The system shall support three methods of locomotion.
FR8	The system shall accommodate users of varying heights.

Table 4.2: Non-Functional Requirements.

Non-Functional Requirements	
Name	Description
NFR1	The system uses Unity, as the entire project was built using this engine.
NFR2	The system shall operate using the HTC Vive.
NFR3	The system shall operate with the SteamVR platform.
NFR4	The system shall operate such that the hardware and software that the user interacts with must be robust and intuitive.
NFR5	The system shall operate such that the user is not physically harmed.
NFR6	The system shall have an intuitive interface to allow the tester to simply change methods of locomotion.
NFR7	The system shall allow users to stop any method at any point in time
NFR8	The system shall be optimized for the best frame rate for the HTC Vive.

4.3 Use Case Modeling

This section breaks down each of the use cases that are part of the Underground Mining Evacuation Training Simulator that was used for this user study. The original design of this application allowed for multiple users to join. Each user that joined would be assigned a specific role and have specific capabilities. In the use case diagram, as seen in Figure 4.1, it is showing the original version of the application with the actors representing their specific roles. The actors represented in this use case diagram are the Participant and the Tester. The participant is the user who would

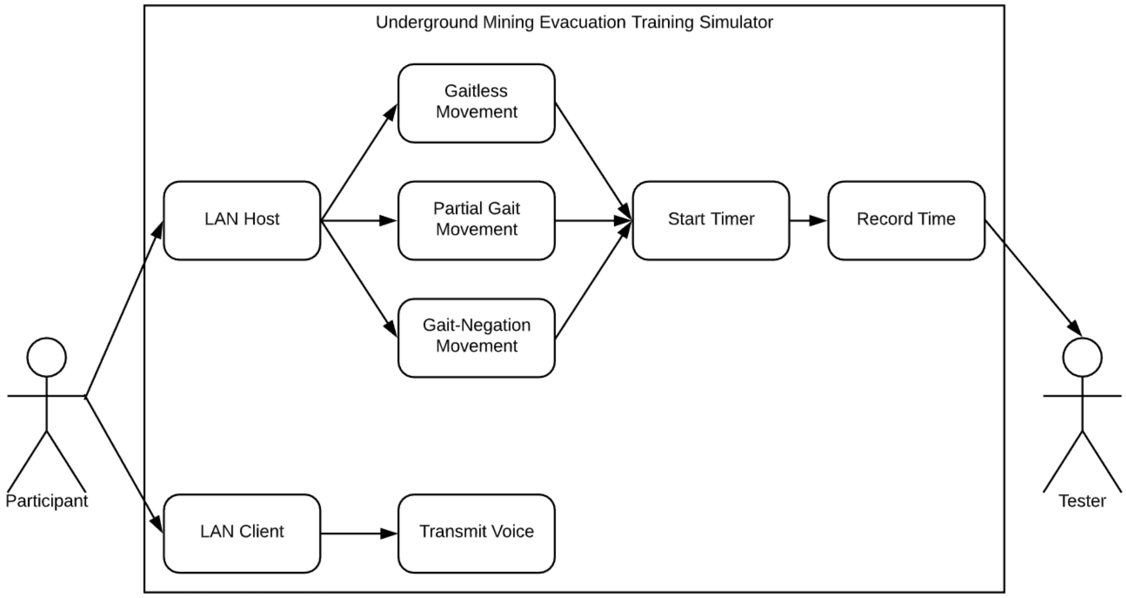

Figure 4.1: The Use Cases for the Underground Mining Evacuation training Simulator that was used for the user study.

choose to host or be a client on a server. As the host of a server, they would be placed within a mine. As the client, the user would be placed inside the control room and guide the host out of the mine. The Tester would record the data to a separate file that was recorded by the application and displayed in the editor. Each of the use cases displayed in Figure 4.1 are described as follows.

LAN Host:

The Participant initializes the application as the host of a server. They are then placed within the mine awaiting instructions to escape.

LAN Client:

The Participant joins an already initialized application and is a client of that server. They are placed within the control room.

Gaitless Movement:

The Participant chooses to use the Gaitless Movement method. This allows movement via the touchpad.

Partial Gait Movement:

The Participant chooses to use the Partial Gait Movement method. This allows movement via sensors attached to the participants ankles in the real world.

Gait-Negation Movement:

The Participant chooses to use the Gait-Negation Movement method. This allows movement via the omni-directional treadmill.

Transmit Voice:

The Participant can use a push to activate command to transmit their voice in the application for others to hear.

Start Timer:

The timer in the application begins, signifying the start of the test iteration.

Record Time:

The participant finishes the test iteration and the time is recorded within the application.

4.4 Architecture

The architecture consists of multiple pieces, most of which correlate to maneuvering the user avatar through the environment. The primary pieces of the architecture is the Hardware Input, the Input Translation, the Input Application, and the Output.

Each part handles its own specific processes, but mainly pass information down a one way pipeline. The high level breakdown is the user applies some sort of input through one of the pieces of input hardware. That input is then sent to its translation software. Once the information is translated it is sent to the C# scripts running in Unity. These scripts have definitions for expected inputs. After every frame is processed by Unity, it is then sent to the display. In this case the display is the HTC Vive headset that is being worn by the user. This is illustrated in Figure 4.2.

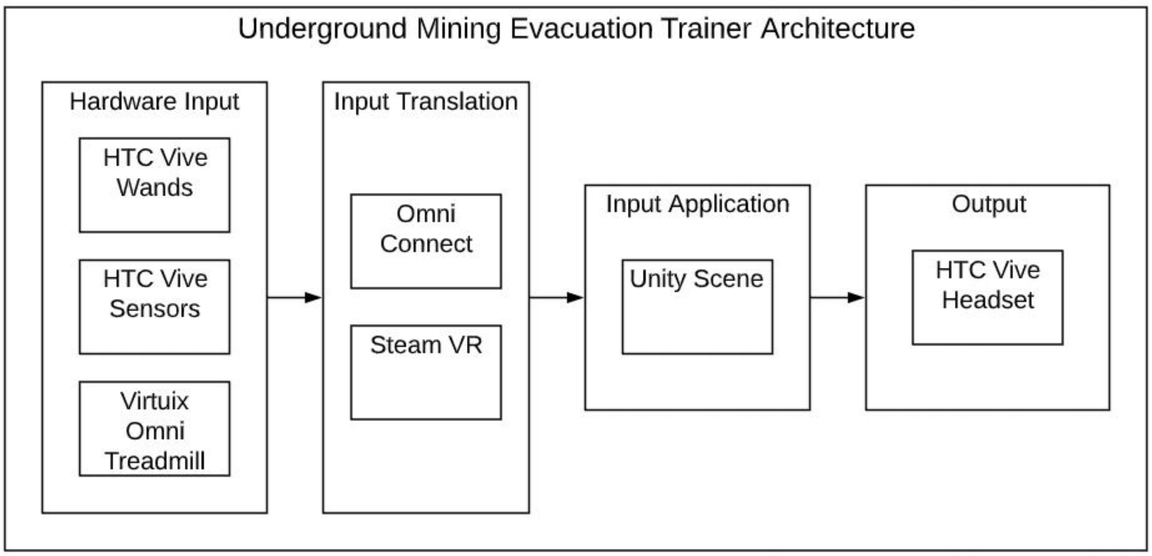

Figure 4.2: The architecture used for the Mining Evacuation Training Simulator showing how data is transferred from the inputs all the way to when it is output to the user.

Hardware Input: The pieces of hardware used for input are the HTC Vive wands, the HTC Vive sensors, and the Virtuix Omni treadmill. Each wand consists of multiple inputs including: position(x, y, z) in space, rotation(α, β, γ), a touchpad that includes a bool value for being pressed and a position vector(x,y) where it is being touched, a grip button, a trigger, and two menu buttons. The HTC Vive sensors only track their position(x, y, z) in space and rotation(α, β, γ). The Omni Virtuix Treadmill keeps track of the pitch of the harness, the yaw of the harness, and the motion of the feet within the limits of the treadmill's tray.

Input Translation: The translation occurs as the input is sent from the hardware to Unity. Unity is running the SteamVR library which will translate any input that is sent in from any of the HTC Vive hardware. The Virtuix Omni will be translated by Omni Connect which is another program that will be running in the background of this application.

Input Application: Once all of the input is translated to something understandable by the scripts written by the designers, it is applied to the Unity scene each frame. If the user is touching forwards on the touchpad of the HTC Vive wand, and the gaitless method of movement is selected, then the avatar in the Unity scene will move in the indicated direction for that frame. The movement will continue as long as the application is still receiving data that that specific input is pressed.

Output: Once the input is processed and applied to the user's avatar in the scene, the visual data is then sent to the HTC Vive headset that is worn by the user. They will have an immersive view of the environment that they are in that is displayed on two displays(one for each eye).

Chapter 5

User Study

5.1 Preparation

In order to perform a user study using human participants, there are many steps that have to be taken before the actual testing can occur. One of the most important things is to have a certification that shows training has been completed about using humans as research subjects. This training is called the Collaborative Institutional Training Initiative(CITI) [31]. CITI training not only handles how human subjects should be treated during testing, but it also teaches you about the rights and safety for any person who participates within a study. For this project, we had to complete the "Group 1 Social Behavioral Research Inverstigators and Key Personnel Group" training [31].

Once CITI training was completed, the next step in the process of getting approved for a human based user study is getting Institutional Review Board(IRB) approval [22]. In order to receive IRB approval, you must create a package on IRBNet and attach all the appropriate documentation. For this project, we had to complete the cover sheet for our institution, for this project it is the University of Nevada, Reno - Part 1, Cover Sheet as shown in Appenxdix A [22]. We also had to complete the application form stating that this research falls under the Exempt IRBFlex Minimum

Risk category as shown in Appendix B. The other mandatory form for any human based research is a consent form, in this case we use the Consent Information Script, which is read to all participants and we receive verbal consent for their participation as shown in Appendix C. Another consent form that was required to be completed was a video/photo release form as seen in Appexdix D. For this project we also had to include the pre and post study surveys that each participant will fill out shown in Appendix E and Appendix F, as well as the advertisement form that will be used to get the attention of students on the university's campus shown in Appendix G. Once the package is submitted, it will be reviewed by a board and approved or you will be provided a list of required changes. This review typically takes approximately one to two weeks.

5.2 Method

In order to understand and identify the appropriate locomotion movement style that is most suitable within a virtual reality environment as well as maintaining a high level of immersion, all the participants completed two quick surveys for gathering data including the participant's virtual reality experience level, how immersed they felt throughout the process, and their motion sickness level after the experiment. This experiment used within subject testing due to the possibility of data disturbance where all participants would perform the same order movement method. The three methods of locomotion that are tested in this experiment include a gaitless technique, a partial gait technique, and a gait negation technique. Data analysis is performed upon the completion time of the course, the level of reported immersion, and the level of reported motion sickness each participant stated.

5.3 Participants

The participants used within this study are mostly University of Nevada, Reno students, while the others range from a software engineer to sales associates. Each of the participants ranged between the ages of eighteen and thirty. This group of participants was easily obtained as most of them are students at the university. The other participants were brought in by their friends who attend the university. In order for students to participate they just had to take an extra hour of time while they were already on campus. We found these participants by posting fliers around the University of Nevada, Reno's campus. Each person emailed for more information and scheduled a time in order to participate. We attempted to maintain a balance of gender as well as experience with virtual reality. By keeping wide range of experience with virtual reality it allowed us to get less skewed results.

5.4 Apparatus

For this study we decided to use the HTC Vive. We chose to use this device as we had two headsets in the High Performance Computation and Data Visualization Lab (HPC-VIS). Along with the headset we used to hand remotes, the tracking lighthouses and two additional trackers. All of which can be seen, except the second extra tracker, in Figure 5.1. The HTC Vive tracks the position of the headset, remotes, and trackers by producing an laser light pulse from the lighthouses [11]. The peripherals then are calculated where they are in the space.

For the gaitless movement, movement will be produced from the hand remotes. The participant points in the direction they want to move then press forwards on the hand remote. This will propel the user forwards in the direction they are pointing. For the partial gait movement method, we are using walking in place as the movement metaphor. The participant will have one of the extra trackers strapped to each of

Figure 5.1: The HTC head mounted display along with the two lighthouse trackers, two hand remotes, and a single extra tracker(two of which are used in this experiment) [11].

their ankles. As the participant syncopates their feet, or walk in place, they will be propelled forwards. The participant will steer in this method using their gaze. Whichever direction they are facing, they will be propelled forwards in that direction. The gait negation technique will be using the Virtuix Omni. This is a passive omni-directional treadmill that provides extra sensors for the feet to track steps, as well as a harness that provides body tilt and hip orientation [43]. The platform for the Virtuix Omni can be seen in Figure 5.2. The participant will walk or run on the treadmill to propel themselves forward, and they will steer based off of the direction of their hips.

All of the in application movement speed has been normalized to where one method is movement is not inherently faster than another. To accomplish the same speeds, we spent time testing each method on the same route to ensure times were within a small margin of one another.

Figure 5.2: The Virtuix Omni, which is a passive omni-directional treadmill. Users wear a harness and special shoes with trackers in order to track hip orientation and foot position. The bowl in which the users feet go is extremely slippery to allow for walking or running motions [43].

5.5 Procedure

When a participant arrived at the study site, they sat down at the conference table and the entire process was described to them. The participant was able to leave at any time they felt uncomfortable with any of the testing. The participant was then familiarized with the virtual reality set being used and the space they would be operating in. Once the process was explained, the participant was given a pre-test survey. This survey gathered information based on their prior experience with virtual reality.

Once the pre-test survey was completed the first method of movement would be explained and demonstrated to the current participant. The participant was given time to learn the method of movement for themselves. Once two minutes elapsed or the participant said they were comfortable with the method, they were be placed into the underground mine evacuation training simulator. The participant was then guided on the correct path to exit the mine. The overall map of the mine can be seen in Figure 5.3.

Figure 5.3: The overall map of the mine as seen from the users perspective in the control room. The white disc on the map represents the user inside of the mine. The orange lights represent hazards within the mine, in this case, fires.

Throughout the mine, the participant encountered hazards that block paths. The hazards used in this simulator are fires and can be seen in Figure 5.4. Once the participant began moving within the mine a timer will start. Once the participant exits the mine, the timer will stop. The overall time will be collected and stored on a spreadsheet that only the PI and researchers will be able to access. Personal data was not stored. All participants were assigned a number. The number in no way correlates to personal information. The only data stored will be participant number, gender, completion time for each of the locomotion methods. Once the participant completes the first method of locomotion, they will be given a five minute break to

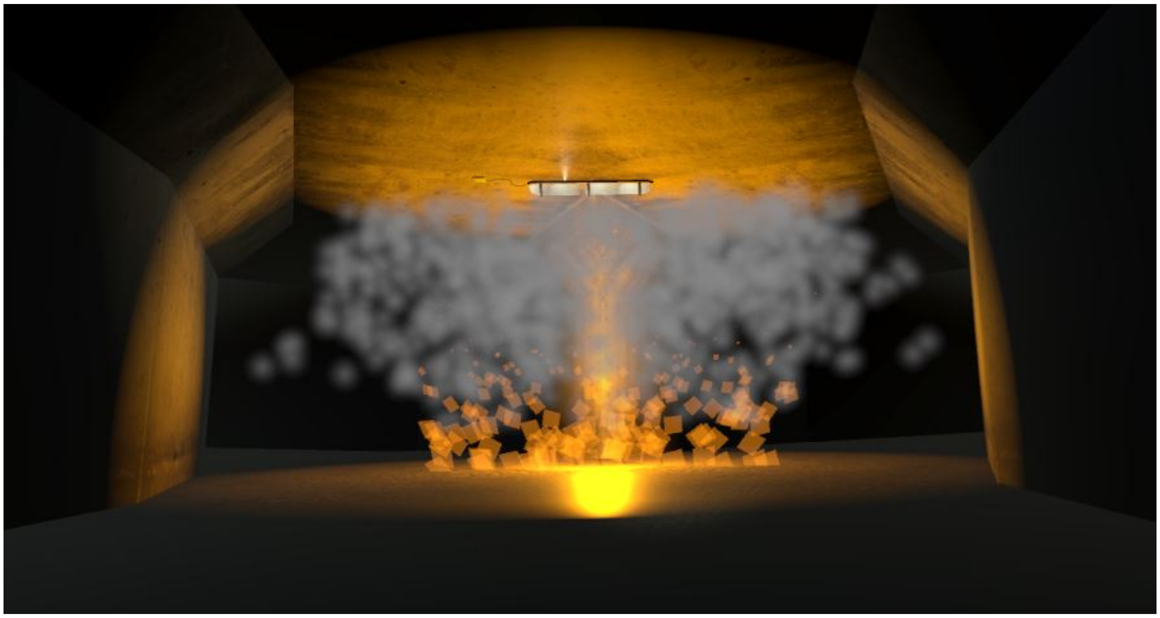

Figure 5.4: Fires are created using a two tier particle system. The first system emits the flame portions, where each of those particles have their own emitter which releases the smoke particles. The smoke effects have collision detection on them in order to have smoke fill the drifts.

regain any exerted energy.

This process was repeated until the participant completed all three methods of locomotion. Once the participant finished with all three methods, they completed a post-test survey. The main information being gathered from the post-test survey is a personal rating of virtual reality sickness. This data was also placed upon the aforementioned spreadsheet.

When the participant was done with the post-test survey they were given up to an additional hour of time to play video games on the virtual reality set. They were also be given a chance to play virtual reality games using the omni-directional treadmill that is at the test location.

5.6 Tasks

As previously mentioned, the main task for the participant was to escape the mine by following directions given. From our perspective, we are able to see where the participant was at all time within the mine. We are also able to see where all of the hazards were within the mine. For the test, we kept the hazards in the same location so we could get an accurate time comparison between each of the different methods of locomotion.

Prior to starting a test, the participant was placed into the mine at a random location. They were then allotted two minutes to familiarize them self with the current method being tested. They could walk through the drifts and explore parts of the mine. Once they felt comfortable with the movement style, or the two minutes had elapsed, they were placed at the start position for their evacuation. The participants perspective view can be seen in Figure 5.5.

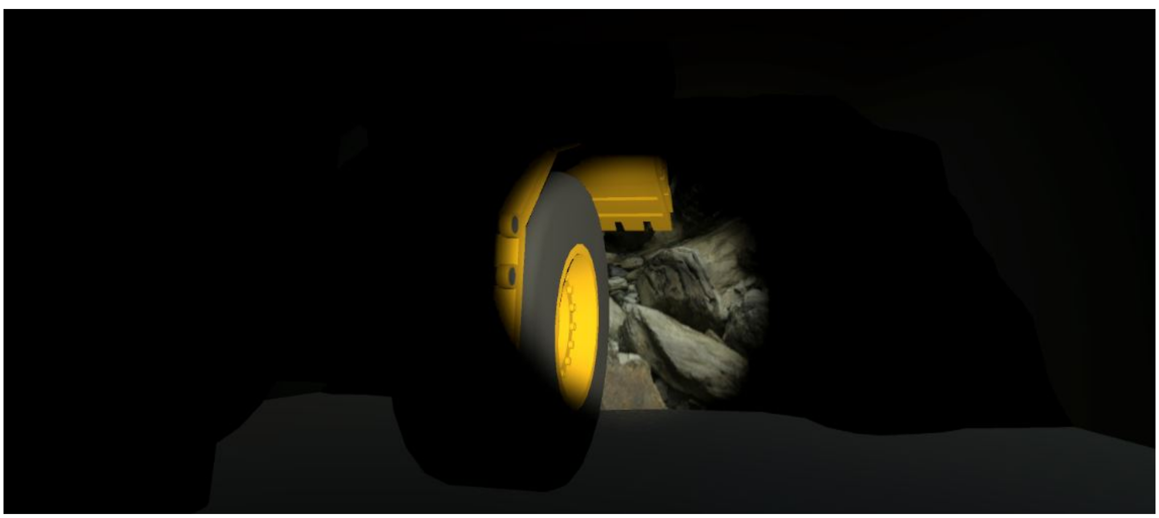

Figure 5.5: Once the test begins, the participant is placed at the end of a drift. The lighting inside the mine reflects what an underground mine would look like. The participant is equipped with a headlamp. The headlamp points where ever the participant is looking to illuminate their field of view.

Once the participants completed the first method of movement, they were introduced to the next method. They were then allotted another two minutes to familiarize themselves with the new method of movement. The test would then begin again from the same location on the same course. Once they completed the second test they would repeat this process again for the final method of movement. After the participant completed each of the methods all the data was recorded for analysis.

5.7 Design

For this user study, there are no between variables. All of the independent variables in this study are within subject. This means that every participant performed all of the tasks in order to gather data. In order to maintain data integrity, test order was randomized for each participant. This was done to ensure there was no skewing towards the final test. Since the participants were running the same course with all three methods of movement, we had to ensure the results were as balanced as possible. The order of the tests can be seen in Table 5.1. The data that was gathered in this user study is as follows: the overall time of completion(in seconds) for each of the different methods of movement, each participants level of virtual reality sickness(scale 1-10) for each method of movement, and each participants reported level of immersion(scale 1-10) for each method of movement.

Table 5.1: The different testing orders for the participants. Test A is representative of touchpad movement, Test B is walking in place, and Test C is the omni-directional treadmill.

Permutation for Test Order		
First Test	Second Test	Third Test
A	B	C
A	C	B
B	A	C
B	C	A
C	A	B
C	B	A

Chapter 6

Results and Data Analysis

6.1 Data Gathered

The participants for this study all ranged between the ages of 18 to 30 years of age except one participant who was 50 years of age. The majority of the participants were students at the University of Nevada, Reno. The participants that are students ranged in majors including computer science and engineering, theatre, dance, musical theatre, physics, psychology, and kineseology. Some of the other participants are working careers such as a software engineer, dog trainer, and retail worker. Having a broad range of backgrounds for participants helps ensure data will not be skewed in one direction based off of similar experiences and backgrounds [45]. Along with each of the participants backgrounds, their experience with virtual reality in general was investigated. Eight of the fifteen participants had no experience with virtual reality in their life, while the other half ranged between having minimal exposure, such as playing a game once or twice, to owning their own headset and playing games regularly on their headset. This study had a great distribution with the participants when it comes to backgrounds and prior virtual reality experience.

As described in Chapter 5, each of the participants did all three of the tests. The order in which they did the test was one of the six combinations as mentioned before.

This ensured that the data for the latter methods tested for each person would not be skewed. If the same order was run for each participant, then they would all be familiar with the course they would be maneuvering, making it much easier for them to complete the course on their final test in comparison to their first test. The data collected for the participants overall times can be seen in Table 6.1. The table shows each of the participants times for each of the tests as well as the overall average for each of the tests.

Table 6.1: The overall time in seconds it took each of the participants to complete the course.

Overall Times By Participant For Each Test			
Participant Number	Gaitless	Partial Gait	Gait Negation
1	114.52	119.23	98.38
2	110.22	108.98	100.48
3	117.18	103.21	99.54
4	108.04	103.42	132.90
5	111.93	126.85	91.05
6	96.47	102.05	155.82
7	111.37	104.85	93.52
8	104.84	104.77	157.89
9	114.55	106.12	107.85
10	116.22	98.94	103.81
11	119.67	126.25	108.57
12	103.59	107.90	88.73
13	105.98	114.80	82.29
14	109.33	100.24	123.55
15	131.11	122.71	152.00
Average	111.67	110.02	113.09

Alongside investigating backgrounds and prior experience, each participant was asked how prone to motion sickness they are. These responses ranged between not being prone to motion sickness at all to mild responses from winding car roads and sea sickness. Although rating ones level of motion sickness is purely subjective to each participant, it still enables a look into what kind of motions and methods can cause sickness. Each of the participants rating of how motion sick they felt during each of the tests can be seen in Table 6.2. The table shows each of the participants rating of how sick they felt for each of the tests as well as the overall average of how sick all of the participants felt. The participants were given a scale of 1 to 10 to rate their sickness, where 1 is not feeling sick at all, while 10 is feeling the urgency to want to barf.

Table 6.2: The recorded motion sickness level of each of the participants to complete the course on a scale from 1 to 10.

Overall Motion Sickeness By Participant For Each Test			
Participant Number	Gaitless	Partial Gait	Gait Negation
1	3	5	4
2	1	1	4
3	1	1	1
4	4	2	7
5	2	1	1
6	1	1	2
7	2	5	6
8	1	1	4
9	1	1	3
10	3	1	1
11	1	1	4
12	1	1	2
13	3	4	5
14	1	1	1
15	2	1	1
Average	1.8	1.8	3.07

All of the data for sickness was collected after the testing. Each of the participants commented on what made them feel uncomfortable or sick during each of the tests. For the gaitless motion, one participant commented, “I did not have to move around, but I was still being moved in the virtual world which felt really weird.” Another participant commented on the partial gait method saying, “The sensation of moving while being nearly stationary after taking the goggles off got me a little dizzy.” For the gait negation technique, one participant stated, “While walking on the treadmill, I sure felt like I was sliding and spinning while walking.” Responses from each participant varied and gave a great insight into what specifically about each of the methods made them uncomfortable or sick. These responses will be more thoroughly discussed in the Data Analysis section.

6.2 Data Analysis

Once all the data was collected, it was organized by participant and placed into a box plot as seen in Figure 6.1. Just at first glance, you can see that the gaitless method had the least general variance. There was however one outlier, but aside from that, the gaitless method had the most consistenet time. The median of the group was similar to the average as well. The partial gait method had a similar distribution as the gaitless method. With the partial gait, there were no extreme outliers. Looking at the gait negation method, you can see it had an enormous range between its max and minimum time, especially in comparison to the other two methods.

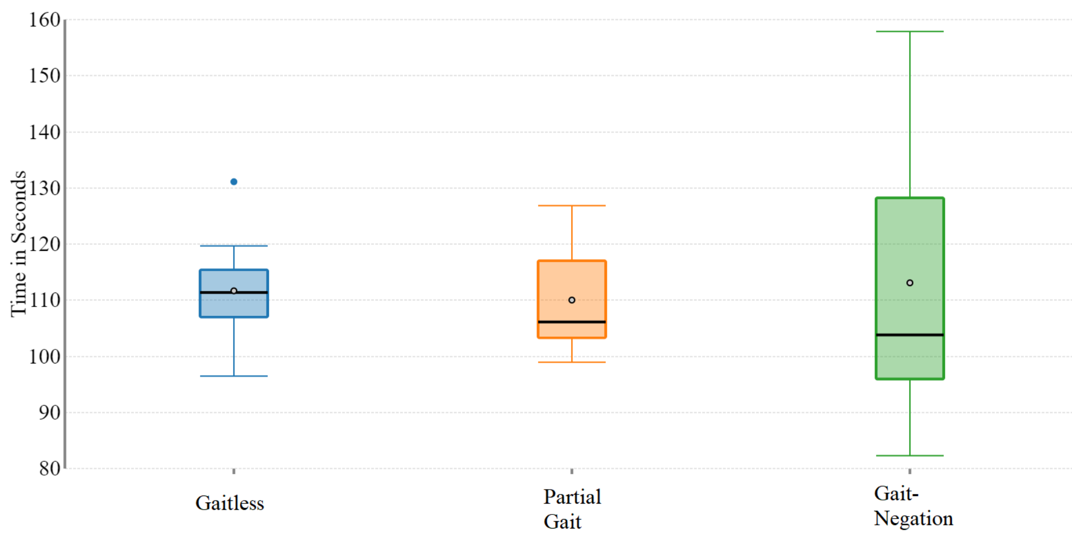

Figure 6.1: The distribution of the overall times for each of the tests. The uncolored dot represents the mean of each data set, and the colored in dot is an extreme outlier.

Prior to doing any statistical analysis, we can see that the gaitless method had the least variance, aside from the one major outlier telling us that this may have been the easiest method to pick up. Although it was not a natural method, it was easy for the majority of participants to pick up. One participant stated, “I play a lot of video games, so using the touchpad to move around felt just as if I was playing a video game." This method also did not create a deep level of immersion in comparison to the other methods. Many participants talked about, "It felt strange just sliding along the ground." This method was the least talked about in the post test survey, as most of the comments were towards the partial gait method and the gait-negation method. This method was praised for its similarity to video game controls, but that does not have the same simplicity to each person due to not everyone enjoying or playing video games.

The partial gait method seemed to be the most liked through the participants. There was a lot of praise about this method of movement due to it feeling more natural and immersive. One participant stated, "This method felt the most realistic because I could feel my head bobbing as I walked in real life as well as in the virtual world." Many of the participants also praised the partial gait method on the steering style. It was easy for them to pick up and navigate. Prior to running each method for time, as mentioned before, participants were given time to familiarize themselves to the method of movement. Not a single participant used the full time to familiarize themselves with the partial gait method of movement. The only complaint about the partial gait method was, "I could not see myself doing this for a long period of time, especially if I am playing a game. I just feel like I would get really tired after a short amount of time."

The gait-negation method was the least well received. Many participants thought it was an interesting concept prior to using the hardware, but after their experience with it they did not feel it was as good as it could have been. Participants stated, "I didn't like how you had to lean and move your legs to walk, it felt really weird." Other participants expressed their disdain about how it felt like they were just sliding around everywhere. In the virtual environment, participants talked about how difficult it was to steer because they could not turn very easily due to slipping. The gait-negation method did have the fastest overall time for the course, but it also had the slowest overall time. This method had the biggest variance between all of the participants. Many of the participants also noted, “This seemed like it would be the easiest to pick up, but it was actually the hardest one.”

6.3 Statistical Analysis

In order to see if the data that was collected had any sort of significance statistically, it was analyzed using one way ANOVA (Analysis of Variance) statistical analysis. When using ANOVA, we mainly focus on the p-value (calculated probability) to determine if we can or can not reject the null hypothesis. When observing our p-value, we need it to be less than .05 in order to reject the null hypothesis. To put the null hypothesis simply, when we reject it, we are saying that there is a significant difference between our specified data [45]. If we are to accept the null hypothesis, then we are accepting that there is no statistical significance between our data. For this user study, we made six different ANOVA analyses on our sets of data. These comparisons are: gaitless compared to partial gait, gaitless compared to gait-negation, and partial gait compared to gait-negation. The three listed comparisons were done for both overall completion times (3 comparison) as well as recorded levels of motion sickness (3 comparisons). This section aims to state statistical significance and deeper analysis will occur in the following section.

When observing the overall completion time for the gaitless method to the partial gait method, we get a p-value of 0.6123. This value is obviously much greater than 0.05, so in the case of completion time for these two methods, we can state that there is no significant statistical difference. As for overall recorded motion sickness between these two methods we obtained a p-value of 1. This means there is absolutely no statistical significance between these two methods when it comes to motion sickness. In both cases where ANOVA was applied to these two methods, they both proved to be statistically insignificant.

Moving onto the comparison of overall completion times between the gaitless method and the gait-negation method, we obtain a p-value of 0.8376. This again is obviously much greater than 0.05, so in the case of completion time between the gaitless method and the gait-negation method, we can state there is no statistic significance. When observing the overall motion sickness level between the two methods, we obtain a p-value of 0.0359. Since our p-value is less than 0.05 we can state that there is a statistical significance between the rated levels of motion sickness between these two methods. In the case of the gaitless method compared to the gait-negation method, we have no statistical significance for completion, but we do have statistical significance when comparing recorded levels of motion sickness.

For the last comparison of overall completion times between the partial gait method and the gait-negation method, we obtain a p-value of 0.6638. This p-value is greater than 0.05 so we can not state there is statistical significance between these two methods in terms of completion times. As for the recorded levels of motion sickness between the partial gait and gait-negation method we obtain a p-value of .0595. This p-value again is not greater than .05 so we do not have statistical significance for the recorded level of motion sickness between these two methods. There is no statistical significance when comparing completion times as well as recorded levels of motion sickness between the partial gait method and the gait-negation method.

From all six comparison we only found statistical significance between the recorded levels of motion sickness between the gaitless method and the gait-negation method of movement. As for the other recorded levels of motion sickness and the overall completion times, there was no statistical significance. Although there is no statistical significance between the majority of the tests ran, it does not mean we can not draw any conclusions from our testing.

6.4 Discussion

As mentioned in the previous section there was almost no statistical significance between any of the data collected. The only statistical significance was the recorded level of motion sickness between the gaitless method and the gait-negation method of movement. This is due to the level of sickness recorded for the gaitless method having a low average. On top of having a low average, there were no extreme values. This maintained a consistent set of data. As for the gait-negation there was a large range of levels of discomfort, but it averaged out at a higher value. Given this data and its statistical significance, we can say that there is a correlation between people getting motion sick between the two methods.

As for the other comparisons we were not able to determine any statistical significance. Even though not having statistical significance sounds like it can be a bad thing, it does however open other avenues of analysis. For instance, when looking at all the different methods for their overall completion time, we can state that given ample time to learn a method of movement and apply it to a pre-determined path, users should be able to complete the task in a similar amount of time. We can see this as it is reflected in the data collected and shown in Figure 6.1 or it can be seen numerically in Table 6.1. Since the method of movement does not affect how quickly one can accomplish the task of moving from one location to another, we can look at efficiency in terms of energy consumption. During the test many participants stated feeling mildly exhausted after using the gait-negation method. This could be due to inexperience with the hardware itself, or it could be that the gait-negation method is not efficient in terms of energy. This is something that could be explored more thoroughly in a future study.

In terms of motion sickness, we were able to determine that there is no statistical significance between the gaitless and partial gait methods as well as between the partial gait and gait-negation methods. Participants responded on average similar levels between the gaitless and partial gait tests. The interesting thing, even though the average between these two methods was the same, the partial gait method had more variance in its responses. There were fewer recorded values near the mean of the partial gait. Most of the recorded values were either above or below. As for the partial gait, most of the values were near the mean. The difficult one to measure and make statements about is obviously the gait-negation method. The responses seemed a lot more sporadic and had a much greater variance per response. This can be due to how prone a participant can be to motion sickness, their inexperience with virtual reality, or a combination of both. The responses the body has to the different methods of movement was interesting to read about from each of the participants responses. Some participants who stated they are not very prone to motion sickness still felt dizzy or uncomfortable after some of the tests.

Chapter 7

Conclusions and Future Work

7.1 Conclusions

The results from the user study were not what was expected prior to running the test. There were assumptions that the gait-negation method of movement would be more efficient than of the other two methods. There were also premonitions that the gait-negation method of movement would prove to be more immersive than the gaitless and the partial gait method. Overall it turned out that there was no correlation in efficiency, or how fast a participant completed a course, between each of the separate methods of movement. What we were able to gather however, is that one can apply any of the methods and still achieve the same kind of efficiency. If the design is to be for more sustained movement, then the designer should steer away from the gait-negation method, at least the one used here, because many of the tests participants claimed to feel exhausted after the test. Even though the test only lasted 82 seconds up to 157 seconds, the amount of effort that was put fourth caused exhaustion in the participants. Participants stated that the partial gait method did feel more immersive than the gait-negation method. This could be due to the natural feeling of the method. Even though the gait-negation method uses a users full gait, the way that it is used feels quite unnatural. Including the users regular gait, you must lean into the direction you want to be moving as well. With the partial gait method, the user just reduced their step so they could stay in place, while getting their natural head bobbing with more of a natural motion.

As for the results that showed statistical significance, we are able to see that there is correlation between feeling motion sickness between the gaitless method and the gait-negation method. The gaitless method had a less common occurrence with motion sickness, while the gait-negation had a large range and more commonly had participants feeling sick. To our surprise, we believed that the partial-gait would have been the method with the most consistent non-sick feelings due to the naturalness of the movement. the style of movement for the touchpad would be more consistent between participants, because the only thing that will change their head position, is their head itself. With the partial gait movement, their head was moving a lot more so even though the head movement was natural it can still feel strange because everything you are seeing is the virtual environment moving not the real world.

The most important take-away from this study is that there is no method that is more efficient than another. Some methods may be easier to pick up, but the overall efficiency, or at least time to move from one point to another on a predetermined path, is similar between all methods. When it comes to the level of motion sickness, it was a purely subjective statistic from each of the participants. There are tests out there that require the participants to pay a lot more attention to what is going on with their body during the testing. If this test were to be run again, it could emphasize the motion sickness level of participants over how efficient movement can be.

7.2 Future Work

The work done in this study can be taken in a multitude of directions. As previously mentioned, more in depth analysis of motion sickness could be done. Using these more in depth tests should result in a less subjective statistic from the participants. Having the less subjective results should yield more accurately depicted statistics. Another way to redo the test could be having each of the participants perform some sort of task aside from moving from one point to another. Generally locomotion is a secondary task, so if the participants had some sort primary task to accomplish, then efficiency could be re-examined.

The application that was used for this, as mentioned before was an underground mining evacuation training simulator. The application was stripped down to its most basic form in order to allow participants to focus on the task of locomotion. This application still has a lot of room for improvement to increase how immersive it can be for the participants. Emphasizing the level of immersion for each of the methods could be an additional test that could be studied.

With virtual reality still being a fairly new field, there is a lot that still needs to be explored to determine what will give users the best experience. One of the biggest obstacles to overcome when it comes to virtual reality is how people are affected by motion sickness. Just in this test, we were able to see how differently each of the methods affect different people. There probably is not one method of locomotion that is superior to others, but there are different methods that suit different users better.

If this study were to be redone the amount of participants would be greatly adjusted. By having 6 different combinations with the permutation of the test orders, multiple things could be done to adjust how the project is conducted. One work around could be having a multiple of six for the amount of participants. This would ensure that each of the test combinations would have the same amount of participants ensuring better balance. Another possibility could be to get fifteen participants for each of the categories. This would mean a total of forty-five participants. This would ensure participants not knowing the course for each iteration of the test since they would only be doing one test. This would also prevent sickness carrying over from previous tests, influencing how sick a participant felt on the latter tests.

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Appendix A

UNR IRB Application

University of Nevada, Reno
Institutional Review Board
Part I, Cover Sheet

Last edited by: Kurt Andersen
Last edited on: July 24, 2019
[click for checklist]

[1455409-2] METS: Underground Mining Evacuation Training Simulator

Answer all questions on this form completely, include attachments and obtain signatures of Principal Investigator and the Responsible official prior to final submission on IRBNet.

I. Principal Investigator

Name: Sergiu Dascalu
Institution:
Department: College of Engineering
Telephone: 7757844613 **Email:** dascalus@cse.unr.edu
Address: Department of Computer Science and Engineering University of Nevada, Reno Reno, NV 89557

II. Contact Person N/A ☐

Name: Kurt Andersen
Telephone: 7752253252 **Email:** kurt.t.andersen@gmail.com

III. Co-Investigator(s) Including Student Investigator(s) N/A ☐

Name: Kurt Andersen,
Institution:
Telephone: 7752253252 **Email:** kurt.t.andersen@gmail.com

IV. Research Assistant(s)/Coordinator(s) N/A ☐

Name: Kurt Andersen
Telephone: 7752253252 **Email:** kurt.t.andersen@gmail.com

V. Responsible Official

Name: Eelke Folmer
Title: Professor and Chair
Institution:
Department: College of Engineering

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Telephone: 7757847592 **Email:** efolmer@unr.edu

VI. Project Information

Research Type:

- [ ] Biomedical
- [x] Social Behavioral/Educational

Research Location:

- [ ] VA Sierra Nevada Healthcare System
- [ ] Saint Mary's Regional Medical Center
- [ ] Renown Health
- [x] UNR Campus
- [ ] Other -

Renown Health Research Locations:

- [ ] Renown Regional
- [ ] Renown South Meadows
- [ ] Renown Pregnancy Center
- [ ] Renown Outpatient Clinic
- [ ] Renown Urgent Care
- [ ] Renown Imaging
- [ ] Renown Lab
- [ ] Renown Pharmacy
- [ ] Renown Emergency Room
- [ ] Renown Skilled Nursing
- [ ] Renown Hospice Care
- [ ] Renown Home Health
- [ ] Renown Rehabilitation

Requested Review Path:

- [ ] Requesting a determination about whether a project is human subject research
  Complete Request for Human Research Determination
- [ ] Requesting authorization to use an external IRB
  Complete Request to Use an External IRB
- [ ] Reporting emergency use of an FDA-regulated drug or device
  Complete Emergency Use of a Test Article
- [ ] Minimal risk exempt research involving contact with participants
  Complete Exempt Core Application Research with Participants
- [ ] Minimal risk exempt research involving existing records or specimens
  Complete Exempt Core Application Review of Existing Records or Specimens
- [x] Exempt, IRB Flex: Minimal Risk, Non Federally Funded Research
  Complete Exempt, IRB Flex: Minimal Risk, Non Federally Funded Research
- [ ] Exempt, IRB Flex: Ethnographic and Naturalistic Field Research
  Complete Exempt, IRB Flex: Ethnographic and Naturalistic Field Research
- [ ] Expedited IRB Review
  Complete Part II for Social/Educational Research or Part II for Biomedical Research
- [ ] Full Board Review
  Complete Part II for Social/Educational Research or Part II for Biomedical Research

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Risk Level:

- [x] Minimal risk
- [ ] Greater than minimal risk (requires full board review)
- [ ] No known risk

Involvement of Vulnerable Populations:

- [x] N/A, research will not involve vulnerable populations
- [ ] Pregnant women and fetuses
  Complete Population: Pregnant Women and Fetuses
- [ ] Prisoners
  Complete Population: Prisoners
- [ ] Children (persons under 18 years of age)
  Complete Population: Children
- [ ] Adults with impaired decision-making capacity
  Complete Population: Impaired Decision-Making Capacity
- [ ] Persons Living in a Foreign Country
  Complete International Research

VII. Funding Information N/A [x]

Sponsor Type:

- [ ] Federal Government
- [ ] Other Government (State/Local)
- [ ] Industry Sponsor
- [ ] Other Private Funds
- [ ] Departmental
- [ ] Subcontract
- [ ] Other:

Sponsor Name:

Grant/Contract Title and Number:

VIII. Researcher Conflict of Interest

Significant Financial Interests Related to this Research:

- [ ] Yes
- [x] No

Significant Financial Interest or Performance Commitment:

- [ ] Yes
- [x] No

IX. Federal Agencies with Additional Requirements to Protect Human Participants

- [ ] DoD
  Complete Research Involving Department of Defense
- [ ] DoE
  Complete Research Involving Department of Energy

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- [ ] DoEd
  Complete Educational Records and Classroom Survey Research (FERPA and PPRA)
- [ ] DoJ or NIJ
  Complete Research Involving Department of Justice or National Institute of Justice
- [ ] EPA
  Complete Research Involving the Environmental Protection Agency
- [ ] NSF
  Additional training requirement only; no supplemental form. See our website for training details.
- [ ] VA
  Complete forms with "VA" in the title.
- [x] N/A

X. FDA-Regulated Research (Clinical Trials Involving Investigational Drugs or Devices)

- [x] N/A, research does not involve drugs or devices
- [ ] Drug research

Trade Name	Generic Name

- [ ] Device research

Name of Device	Device Manufacturer

XI. External Committee Approvals

- [x] Thesis Committee
- [ ] Radiation Safety Committee
- [ ] Biosafety Committee
- [ ] Other:
- [ ] N/A

INSTRUCTIONS TO RESEARCHERS

[top]

You have completed Part I of the application process. **Preview** Part I and correct if needed. Print the last page so you have the list of the researcher forms required for this research. Click **Save and Exit.** Log-in to IRBNet, go to My Projects, select the new project, and **Add** the remaining required documents (listed below or referenced in the researcher forms/applications), and electronically **Sign** and **Submit** the project.
If you have any questions, refer to the IRBNet pages of the RI website.

Additional required researcher forms:

- Complete *Exempt, IRB Flex: Minimal Risk, Non Federally Funded Research*

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Appendix B

UNR IRB Exempt Application

University of Nevada, Reno

Research Integrity
218 Ross Hall / 331, Reno, Nevada 89557
775.327.2368 / 775.327.2369 fax
www.unr.edu/research-integrity

Exempt, IRB-Flex: Minimal Risk Research with No Federal Funding/Support

A University of Nevada, Reno Part I, Cover Sheet is required for each project submitted in IRBNet.	
Study Purpose and Narrative	
1. Describe the study background, significance, and purpose/hypothesis/research questions.	Methods of interacting with virtual reality is always evolving to be more accurate, reliable and easy to use. Having an easy to use and efficient method of movement would make a virtual reality experience more pleasing to the user. This will also ensure the user experiences a greater level of immersion. Aside from touching and interacting with objects, one of the primary objectives in virtual reality is navigating through the space. Locomotion is an interface that enables both the user to move around the virtual space as well as reality. Related work and research can be seen in the following: Ian Bishop and Muhammad Rizwan Abid. Survey of locomotion systemsin virtual reality. InProceedings of the 2Nd International Conference onInformation System and Data Mining, ICISDM ’18, pages 151–154, NewYork, NY, USA, 2018. ACM Philip Kortum.HCI beyond the GUI: Design for haptic, speech, olfactory,and other nontraditional interfaces, pages 107–137. Elsevier, 2008
2. Provide a detailed narrative, non-technical description of the project and of the planned activity for the participants and/or data collection.	When a participant arrives at the study site, they will sit down at the conference table and the entire process will be described to them. The participant may leave at any time they feel uncomfortable with any of the testing. The participant will then be familiarized with the virtual reality set being used and the space they will be operating in. Once the process is explained, the participant will be given a pre-test survey. This survey will gather information based on their prior experience with virtual reality. Once the pre-test survey is complete the first method of movement will be explained and demonstrated to the current participant. The participant will be given time to learn the method of movement for themselves. Once two minutes elapses or the participant says they are comfortable

	with the method, they will be placed into the underground mine evacuation training simulator. The participant will then be guided on the correct path to exit the mine. Once the participant begins moving within the mine a timer will start. Once the participant exits the mine, the timer will stop. The overall time will be collected and stored on a spreadsheet that only the PI and researchers will be able to access. Personal data will not be stored. All participants will be assigned number. The number in no way will correlate to personal information. The only data being stored will be participant number, gender, completion time for each of the locomotion methods. Once the participant completes the first method of locomotion, they will be given a five minute break to regain any exerted energy. This process will repeat until the participant completes all three methods of locomotion. Once the participant is done with all three methods, they will complete a post-test survey. The main information being gathered from the post-test survey is a personal rating of virtual reality sickness. This data will also be placed upon the aforementioned spreadsheet. When the participant is done with the post-test survey they will be given up to an additional hour of time to play video games on the virtual reality set. They will also be given a chance to play virtual reality games using the omni-directional treadmill that is at the test location.
Study Sites	
3. List or describe the study sites.	__ N/A, Internet or telephone survey Study sites: High Performance Computation and Data Visualization lab at University of Nevada, Reno. The lab consists of 13 computers capable of high performance computation. The lab is capable of sitting approximately 20 people. There are areas left open in order to use virtual reality headsets. There is also a space with an omni-directional treadmill.
4. Is approval from an external entity required for this research (e.g., TMCC, school district, oversight committee or board)?	_x_ No __ Yes, specify:

Add documentation of approval, or submit via subsequent amendment package if site requires IRB approval. IRB program staff will coordinate WCSD Accountability Office approval.	
Study Populations	
5. How many participants or records will the project involve?	20 participants, each will complete a pre and post survey. Totaling 40 records.
6. Describe the study populations or the sources of the records for this project.	University students between the ages of 18 and 40.
7. Will any participants be younger than 18 years old?	_X_ No __ Yes, explain why it's necessary to include children:
8. Will this project involve pregnant women, fetuses, or neonates?	_x_ No __ Yes, explain why it's necessary to include pregnant women/fetuses:
Recruitment and Informed Consent	
9. Will prospective participants be invited to consider participation in the research? Add recruitment scripts/flyers.	__ N/A, recruitment combined with consent __ N/A, records review or covert observation only __ No, explain why not: __ Yes, describe the invitation process:
10. Will potential participants be told about the research and be given the opportunity to agree to participate? Add information scripts, sheets, or letters.	__ N/A, records review or covert observation only __ No, explain why not: _x_ Yes, describe when, where, and how: Participants will be personally solicited by the Researcher as well as flyers posted on the university campus. Example flyer will be attached. Prior to testing, the test will be described to the participant. At that time they can choose whether to continue participating or leave. Additionally the participant will be given a modified Consent Form Template, 1 Information Sheet which will be attached to this packet.
11. Will incentives be provided to enhance enrollment?	__ No _x_ Yes, specify the incentives (include dollar value and odds of winning): Allow participants an additional hour of virtual reality video game time.
12. When, how, and by whom will incentives be distributed?	__ N/A, no incentives __ N/A, using SONA; standard procedures apply Explanation: Post testing, participants will be offered time to play a selection of video games.
Research Activities/Study Procedures	
13. Indicate the types of research activities that will be used.	Select all that apply: __ Tests (cognitive, diagnostic, aptitude) _x_ Survey, paper/pencil (including via mail)

	__ Survey, telephone __ Survey, Internet __ Interviews, including focus group interviews _x_ Assessment of participant performance of simple tasks _x_ Computer simulations __ Training simulations __ Non-invasive physical assessments (e.g., eye tracking, body fat assessment using calipers, obtaining blood via heel or finger stick, cheek swab, assessment of physical activity) ___ Review of existing records NOTE: another exempt category may apply __ Review of records to be obtained prospectively __ Other, describe:
14. What is the date range for selecting records for this project (e.g., month/year of first and last records obtained)?	_x_ N/A, project does not involve existing records Explanation:
15. How will the researchers obtain information from existing records?	_x_ N/A, information will not be obtained from existing records Description:
16. Describe in detail and in chronological order what participants will be asked to do:	__ N/A, records review only Description:
17. Will participants be video-recorded or photographed? Add the video/photo release form participants will sign.	_x_ No __ Yes, explain why videos or photos are necessary for the research:
18. How much time will a participant spend in the study and how long will her/his participation last?	__ N/A, records review only __ N/A, single contact ___1___ Number of contacts ___1 hour___ Time spent participating in minutes/hours ___N/A___ Length of time/duration in weeks/months
19. List all study materials/research instruments (e.g., surveys, questionnaires, interview guides, data collection logs) and equipment. Add study materials and equipment manuals.	HTC Vive Virtuix Omni Pre Test Survey – See attached files Post Test Survey – See attached files
20. List the data that will be collected for this study:	Pre and Post Test Survey Time of completion for each test case
21. How will the data be analyzed?	Anova test Common statistical transformations and methods

Participant Privacy and Data Confidentiality	
22. Will participants' Protected Personally Identifiable Information (PPII) (see Policy Manual Definitions) be recorded?	_x_ No __ Yes, list the PPII that will be recorded and explain why it's necessary to record PPII:
23. How will participants' privacy rights be protected?	None will be collected
24. How will research records be handled and stored to ensure confidentiality?	Each participant will be assigned a randomized ID where there will be no correlation to any identifiable information. All data collected will be stored under said ID number and saved on a computer that requires specific login information within a lab that requires a keycode entry.
25. If a master list will be used to link participant research IDs with PPII, when will the code list be destroyed?	_x_ N/A, PPII not recorded or not linked Specify:
HIPAA Requirements	
26. Will Protected Health Information (PHI) (see Policy Manual Definitions) be obtained or recorded for this research?	_x_ No, SKIP remaining questions __ Yes, Requires signed HIPAA authorization from participant or IRB approval of waiver of HIPAA authorization (HIPAA templates are in researcher library in IRBNet)
27. Will the PHI be provided as a Limited Data Set (i.e., data that excludes direct identifiers of the individuals and her/his relatives, employers, and household members)?	__ No __ Yes, Requires Data Use Agreement between the covered entity and the researcher (Add fully-executed Agreement to project in IRBNet)

28. What PHI will be obtained/recorded for this project? (Select all that apply.)

__ Names	__ Certificate/license numbers	__ Vehicle ID, serial, and license plate numbers
__ Biometric identifiers including finger/voice print	__ Device identifiers/serial numbers	__ Dates relevant to an individual or any age over 89, specify:
__ Full face photographic or comparable images	__ Telephone numbers	__ Geographic subdivision smaller than a state, specify:
__ Social security numbers	__ Fax numbers	__ Other unique identifying number, characteristic, or code, specify:
__ Medical record numbers	__ Account numbers	
__ Health plan beneficiary numbers	__ Email addresses	
	__ IP addresses	
	__ Internet URLs	

29. How do the researchers have permission to access medical records for this project?	__ N/A, researchers will not access medical records Explanation:

1. Obtain electronic signature of the Principal Investigator. A signature of the Responsible Official is not required for exempt research.
2. Confirm application is complete and submit for exempt review.

Principal Investigator Assurance

My electronic signature certifies that I have read and agree to comply with the PI responsibilities in the IRB Policy Manual.

Appendix C

UNR IRB Consent Information Sheet

Consent Information Script or Sheet Template

We are conducting a research study to learn what the most efficient and immersive method of movement in virtual reality is.

If you volunteer to be in this study, you will be asked to learn three different methods of movement with a virtual reality set. You will then be asked to use the three different methods of movement to complete a test course as quickly as possible. No personal information will be recorded. Video recording may occur. Videos will only be used for academic purposes and personal information will not be made public.

Your participation should take approximately 30 minutes to 1 hour.

This study is considered to be minimal risk of harm. This means the risks of your participation in the research are similar in type or intensity to what you encounter during your daily activities. You may experience motion sickness. If at any point in time you begin to feel sick, please remove the virtual reality headset. We can continue testing or stop altogether.

Benefits of doing research are not definite; but we hope to learn what the most efficient method of movement in virtual reality is that maintains a strong level of immersion. There are no direct benefits to you in this study activity.

The researchers and the University of Nevada, Reno will treat your identity and the information collected about you with professional standards of confidentiality and protect it to the extent allowed by law. You will not be personally identified in any reports or publications that may result from this study. The US Department of Health and Human Services, the University of Nevada, Reno Research Integrity Office, and the Institutional Review Board may look at your study records.

Required Language

You may ask questions of the researcher at any time by calling Kurt Andersen at (775)225-3252 or by sending an email to kurt.t.andersen@gmail.com.

Your participation in this study is completely voluntary. You may stop at any time. Declining to participate or stopping your participation will not have any negative effects on you nor the overall study.

You may ask about your rights as a research participant. If you have questions, concerns, or complaints about this research, you may report them (anonymously if you so choose) by calling the University of Nevada, Reno Research Integrity Office at 775.327.2368.

Thank you for your participation in this study!

Appendix D

UNR IRB Video-Photo Consent Release Form

University of Nevada, Reno
Photo/Video Release Form for Research

Title of Study:	**METS: Underground Mining Evacuation Training Simulator**
Principal Investigator:	**Sergiu Dascalu**
Co-Investigators:	**Kurt Andersen**
IRB Number:	**1445409**
Sponsor:	**N/A**

Photographs may be taken, or video-recordings may be made of you during your participation in this research project. Please indicate below how we may use your images. Agreeing to allow your images to be used for research is completely voluntary and up to you. In any use of your images, your name will not be disclosed.

For all uses to which you agree, please initial in the spaces provided in the following table:

Initials	**Uses**
	1. The images may be studied by the research team for this research project.
	2. The images may be used for scientific publications.
	3. The images may be used at meetings of scientists interested in the study of Computer Science and Engineering.
	4. The images may be used in classrooms to teach students about Virtual Reality.
	5. The images may be used in public presentations to non-scientific groups.
	6. The audio recording may be used on television and radio.

You have the right to request that the recording be stopped or erased at any time.

By signing below, you are agreeing that you have read the above description and give your consent for the uses of your images as indicated by your initials.

____
Participant's Name Printed

____________________________________ ____________________
Signature of Participant Date

____________________________________ ____________________
Signature of Person Obtaining Consent Date

Appendix E

UNR IRB Pre-Test Survey

Participant ID:________________

Do you have any experience with virtual reality? If so, please describe your experience(s).

What is your major at the university? / What is your profession?

Are you prone to motion sickness, if yes please describe a previous experience?

What interests you within the field of virtual reality?

What interested you in participating in today's testing?

Appendix F

UNR IRB Post-Test Survey

Participant ID:_________________
Which method of movement did you find to be the most efficient and why?

Which method of movement felt the most realistic/immersive and why?

Please rate on a scale of 1 to 10 how motion sick you felt for each method, 1 being not at all, 10 being extremely sick. Please give a brief explanation for each rating.

Gaitless:

Partial Gait:

Gait Negation:

Did participating in this study increase your interest in virtual reality?

Appendix G

UNR IRB User Study Flyer

Virtual Reality User Study!

Comparison of different movement styles in virtual reality
Ansari Business Building Room 632
Email Kurt at: **kurt.t.andersen@gmail.com**
then sign up on the online schedule that will be sent to you!

Come experience the Virtuix Omni, an omni-directional treadmill!

All participants will be given an hour of free time to play any of the virtual reality games that we have as well as using the Virtuix-Omni.