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Benchmarking Virtual Reality Control Methods

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Abstract

This project aimed to create a benchmark test that can be used to evaluate and compare virtual reality control methods using dexterity as a measurement. The results were recorded by asking a participant to perform a variation of a 9-hole peg test in both the real world and in virtual reality for each control method. The time taken to perform the task was recorded and used as a means to compare the control methods to each other and to the real world results. This project has been a success in proving that dexterity can be used to compare virtual reality control methods however more research is required in order to create a true benchmark test that evaluates all aspects of a control method.

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1 Introduction

This study aims to find a benchmark test that can be performed in order to assess and compare virtual reality (VR) control methods. VR control methods describe the way in which a VR user can manipulate and control objects in a virtual environment. For the majority of commercial VR systems, such as the HTC Vive and the Oculus Rift, these come in the form of real world physical controllers which the user holds and moves around in a predefined area where the controllers movements are tracked and translated into the virtual environment.

VR is a growing industry and with constant advancements in its technologies it is important to understand what is required for the "perfect" control method. It is most likely that the best possible and most versatile control method would be similar to our own hands as possible, however, it is yet to be decided as to how we can accurately compare the performance of our hands in the real world to the performance of a control method in a virtual world.

For this to be determined a test is required in which real world results can be recorded and compared to results recorded from an identical test environment that has been built in VR. The real world results can be considered a gold standard that all VR control methods can aspire to reach in order to be as realistic and natural as possible.

In this study it is proposed that *dexterity* would be a suitable measurement for analysing and comparing VR control methods to real world results. Dexterity is used in medicine to assess and evaluate a variety of conditions that affect a patients hands such as Parkinson's disease and arthritis. This usually consists of a patient performing a medical dexterity peg test. These tests involve a patient placing a number of pegs into a number of holes in a board. Once a patient has successfully completed a task, their time

is recorded and used to compare against their previous attempts and the times recorded from other patients. Once the validity of these tests had been confirmed they seemed to be an ideal way to compare a user's performance in the real world and in VR. Due to the simple design of the tests they could be translated well into a virtual environment and the test could be recorded in the same way for both the real and virtual worlds.

It was decided that the 9-hole peg test (9HPT) would be the most appropriate for this task due to its simplicity and effective results. Some modifications are proposed to the design of the 9HPT in order for it to translate into VR such as quadrupling the size of the test board and pegs in order to allow participants to be able to perform the experiment without the need to practise prior to the testing. The physical dexterity test was used as a control test as it is believed that the perfect and most versatile control method would offer the same experience as our hands in the real world. A control method that provided this level of control could potentially be used in any application that is based on a real world scenario as a user could pick up and use virtual tools as if they were physical tools in the real world. With the testing strategy decided upon, the test environments were built using a variety of software programs and techniques.

The real world tests were built to exact dimensions and the virtual environment was built to be an almost exact replica using 3D modelling software and the same dimensions. The environment was built in unity where the VR control methods were implemented. For this experiment two types of VR control methods were used, the HTC Vive controllers and the Leap Motion controller. It was decided to use these two styles of control method primarily due to availability as these were the two styles of control methods that could be obtained during the course of this experiment. Besides this these two control methods show two very different styles of hand and finger tracking. The Vive uses the joystick style of controller which as mentioned previously is the current industry standard and therefore shows how current VR systems can perform this experiment. The Leap motion on the other hand uses a camera tracking method that completely tracks the hands and fingers of a user, this is closer to a glove style of control method which is described in the goggles 'n' gloves definition of a VR system. These two styles of control method offer vastly different user experiences whilst performing the same task.

The Vive controllers are the standard style of controllers used with VR hardware at the time of writing this paper and for the purposes of this research paper are dubbed a 'joystick'-style controller. As mentioned previously joystick controllers are held by the user and tracked in a pre-mapped real world location. They utilise buttons and triggers in order to allow a user to control and manipulate the objects they can see in the virtual world. These controllers are primarily targeted towards the gaming industry and therefore are designed to be used by this target demographic. The Leap motion on the other hand uses a 3D camera tracking system, similar to the XBOX Kinect, in order to track a user's hand and finger positions and orientations. This allows a user to see a 3D hand model in VR that mimics the movements they make in the real world. The Leap motion does not need to use buttons and triggers as it allows users to interact directly with objects in the virtual space using their hands.

These two styles of controllers implement two fundamentally different types of control methods. The pre-tests provided some insight into how participants were likely to interact with the control methods and predictions were made about the performance of each. The following is the final list of hypotheses, finalised after the pretests were conducted:

- **Hypothesis 1**: There will be a significant difference in time between the first and second tests performed using a control method in the virtual environment
- **Hypothesis 2**: Real world test times will be the fastest
- **Hypothesis 3**:VR users will return the fastest times
- **Hypothesis 4**: Participants will record faster times using the Leap Motion due to its more realistic and natural interface.
- **Hypothesis 5**: Participants will find the Vive controllers to be clunky and awkward to use for the task they must perform in this experiment
- **Hypothesis 6**: The order in which a participant performs the virtual tests will affect their times, for example, if a participant uses the Vive controllers first than their Leap Motion time will be faster as a result of becoming more adapted to the virtual test environment.
- **Hypothesis 7**: Participants will figure out a technique for performing the task and this will result in the faster times for the later tests in the experiment

- **Hypothesis 8**: Real world tests will be the fastest, Leap Motion tests will be the second fastest and Vive controllers will be the slowest.

The experimentation was performed and results were recorded from twenty-seven participants who each performed a real world, Vive controller and Leap motion controller test twice. The analysis of participants task times shows the difference between control methods performance and the learning effect between control methods.

2 Literature Review

2.1 VR Control Methods

2.1.1 What is a VR control method?

In order to correctly evaluate and compare VR control methods they must first be defined. VR itself has been defined in a variety of ways, Bamodu and Ye, 2013 accurately describes VR as "a medium composed of interactive computer simulations... giving the feeling of being immersed..." whereas Steuer, 1992 gave a more detailed definition as "a high end Human-Machine interface, that combine technologies such as computer graphics, image processing, pattern recognition, artificial intelligence, networking, sound systems and others to produce computer simulation and interaction, which gives the feeling of being present through multiple synthetic feedback sent to sensorial channels like virtual, aural, haptic and others".

As these definitions suggest, being "immersed" or feeling "present" in a virtual environment is arguably the most important factor of VR. Certain hardware is required for a user to experience VR, (Steuer, 1992) analyses a variety of VR definitions and states that the most popular required components for a VR system are "a computer capable of real-time animation, controlled by a set of wired gloves and a position tracker, and using a head-mounted stereoscopic display for visual output" (Steuer, 1992). This style of system is later dubbed a "goggles 'n' gloves" system (Steuer, 1992). The "goggles 'n' gloves" description is accurate for the most part, with the vast majority of VR systems including a powerful computer and a head-mounted stereoscopic display. The "gloves" aspect, however, of this definition is where it falls short. Sony's PlayStation VR, HTC's Vive and Facebook's Oculus rift consisted of over 50% of all VR device shipments from 2017-2019 (statista,

2019) , none of which use a glove based controller to track the users hand movements. They instead adopt a more traditional "joystick" style controller with buttons, triggers, etc. The question is why the common definition of VR is a "goggles 'n' gloves" system, yet that the current popular VR hardware manufacturers use a "joystick" style over gloves is apparent. To answer this question, we must first gain an understanding on how the different styles of VR control methods provide different benefits.

2.1.2 How are control methods tracked?

As VR is a 3D medium, for a user to interact with and manipulate virtual objects it is essential that they have the ability to move in 3D space. As VR aims for immersion, his usually requires a form of 3D body tracking. Generally body tracking can be split into two categories Outside-In and Inside-Out (Gourlay and Held, 2017).

Outside-in: This is when a user's movements are observed and tracked from a distance (Gourlay and Held, 2017). An example of this would be the XBOX Kinect. Outside-in tracking is a form of optical tracking that looks for an object in a scene and tracks its coordinates as it moves (Ribo, Pinz, and Fuhrmann, 2001). This can be done using a variety of technologies but most commonly depth cameras or infrared trackers. Infrared tracking requires the tracked object to be equipped with a number of tracking markers that reflect the infrared light so the tracking stations can detect them. Camera tracking generally requires the tracked object to be a recognisable to the system, for body tracking a system would use machine vision to detect the shape of the human body (head, torso, two arms and two legs) and once found the cameras would track the body's location. Outside-in tracking is very accurate and is commonly used by a variety of VR systems, however, it often requires a large open space and will need to be set up and calibrated for each location it is used in (Niehorster, Li, and Lappe, 2017).

Inside-out: This form of tracking allows a user's movements to be tracked from their point of view, meaning no external devices are needed to see the user (Busam et al., 2018). Inside-out tracking often uses a variety of sensors including IMU's, gyroscopes and accelerometers but can still also

use camera tracking as well. Optical sensors can be attached to the user's headset to allow for more accurate tracking of the control methods. Using cameras like this helps negate the effect of drift which commonly occurs when tracking an object using only internal sensors (Busam et al., 2018).

2.1.3 Types of control methods

As mentioned previously the top three VR system providers all use similarly designed controllers, as well as the style. All of these controllers, however, use an outside-in tracking system (statista, 2019), for the HTC Vive it can be argued that their Lighthouse tracking system uses a combination of inside-out and outside-in (Niehorster, Li, and Lappe, 2017). This style of controller seems to be inspired by 'regular' gaming controllers, such as an Xbox or PlayStation controllers. Basing the design of VR controllers on console controllers makes sense for these companies as they would be familiar to their target audience. PlayStation, Oculus and HTC are all aiming their products primarily towards the gaming market (Gregory, 2016). Designing their controllers for the average consumer in this market is advantageous. As VR's popularity grows, however, more uses outside of gaming are being explored such as Riva, 2019, which suggests uses for VR in cultural heritage. However, more research is required to find a universal control method that can be used for all VR applications. The need for this can be seen from Rhienmora et al., 2010 who have designed a new VR controller to teach dentists how to operate with the specific tools used in surgery. The joystick style of controller would not provide the necessary likeness to the real world situation to be effective at training in surgery. The solution to this would seem to be a system that allows a user to use their hands in the virtual world as they would if in the real world. A "goggles 'n' gloves" system could potentially offer this level of performance, however, glove based controllers are often expensive and directed towards the gaming market. The Leap Motion controller allows for a full hand and finger tracking using cameras and depth sensors. This style of tracking could be efficient enough for most systems, however, the lack of haptic feedback provided with camera solutions could hinder a user. An assessment into the usefulness of a controller's design is required to find out what would make

the perfect controller and what makes a controller sufficient.

2.2 Current Research

2.2.1 Related research

From conducting research on VR Control methods it has been noted that the primary focus in VR research is on Head-Mounted Display's (HMD). Research that has been performed around the control methods themselves focus mainly on the creation of specialist controllers designed to perform certain tasks, such as the dentist surgery controller previously mentioned (Rhienmora et al., 2010). This has been the focus as a HMD is arguably the most important aspect of a VR system. Without a HMD VR wouldn't exist, whereas controllers are a desired accessory to VR. The concept of VR has been discussed outside of fiction since as early as the 1960's with (Sutherland, 1968) describing the creation of a HMD in 1968. However, exploration into how we can control computers has been a focus since the creation of the first computers. Sutherland, 1964 details the creation of a sketchpad that allows a user to draw on a sketch pad and see the drawing displayed on a computer. This exploration into control methods for PC's has been ongoing with constant advancements in mice, from ball to laser or nipple to trackpad. The same can be seen in VR with the standard joystick style of controller being slowly replaced by knuckles, seen in (Essa, 2019). However, this paper aims to find what is needed in a VR controller as the effectiveness of different controllers is not being explored.

2.2.2 Adding to current research

Based on research conducted into the performance and comparison of different control methods it was evident that a "gold-standard" of VR control methods was required. With this research it will be possible to see where controllers fall short of our real world capabilities and which shortcomings need to addressed. In doing so more questions will be made

apparent further opening up the research field. This research aims to find the characteristics of the "ideal" control method but also find out what a control needs in order to be "good enough" for general use. To find out what these characteristics are, a way of evaluating and comparing the control methods is required.

A controller that is good enough would be a controller that can perform a set task but is not designed to be used for all tasks, for example an XBOX controller can be used to play any game designed on an XBOX system however would most likely not be suitable for virtual surgery training. An idea controller on the other hand would be a controller that is capable of performing any task to a certain level.

A perfect controller in the context of this experiment could be considered a controller that is able to perform any given task to the same speed and ability as a person performing the same task in the real world. A controller that is sufficient, on the other hand, would be a controller that can perform a given task to an ability that is comparable to the results of those found in the real world.

2.3 Dexterity

Figure 2.1: Minnesota dexterity test

Figure 2.2: Purdue pegboard

Figure 2.3: Nine-hole peg test

2.3.1 Dexterity use in the real world

Dexterity is commonly used in physio therapy as a way to assess patients with medical conditions that affect motor function (Feys et al., 2017). The tests used to evaluate a patient's dexterity vary, but the majority tend to be based on what is known as a peg test. Peg tests require a user to perform a task which involves placing pegs, long thin cylinders, into holes in a board. Where the style of peg tests vary is in how the pegs are placed into the holes or on the size/number of holes and pegs used.

The Minnesota dexterity test (Figure 2.1) for example uses a high number of large pegs and holes to assess the patient whereas the Purdue pegboard (Figure 2.2) uses a high number of small pegs and holes and also requires the patient to place washers onto the pegs after they have been placed in the holes. The main metric for the vast majority of peg tests is the time taken for the user to complete the task.

One variation of a Peg test is the 9-hole peg test (9-HPT)(Figure 2.3), this is the design that has been used in this experiment. The 9-HPT uses a relatively simple design of nine evenly spaced holes in a small board in which the user is required to place nine pegs in a certain order as fast as possible. This test was chosen for this experiment as it is quick to perform and easily understood by participants. Another reason this test was chosen was that its simplicity does not negatively affect its accuracy at assessing dexterity. In Wang et al., 2011, the authors compare two tools to see which should be included in the National Institutes of Health (NIH) Toolbox for Assessment of Neurological and Behavioural Function and conclude "the 9-HPT was recommended for inclusion in the motor battery of the NIH Toolbox". The effectiveness of the 9-HPT is also supported by Grice et al., 2003, who state that "the Nine Hole Peg Test is commonly used by occupational therapists as a simple, quick assessment for finger dexterity" (Grice et al., 2003) suggesting that the 9-HPT is regularly used to assess dexterity.

2.3.2 Dexterity use in VR

When assessing the ability of the VR control methods in the context of this study it was important to find a metric that translates from the real world to the virtual world. Little research on tests that measure VR dexterity has been performed. This research aims, in part, to find out whether or not dexterity can be used in this medium and to assess if dexterity is a correct way to measure and compare a VR control method. In Broeren, Rydmark, and Sunnerhagen, 2004 discuss the use of VR as a training method for movement rehabilitation on stroke patients and state that after the VR training had been performed "improvements were found in fine manual dexterity" (Broeren, Rydmark, and Sunnerhagen, 2004). Furthermore, Colt, Crawford, and Galbraith III, 2001 detail the creation of a VR Bronchoscopy simulation, the author states that after using the simulation, "novices significantly improved their dexterity and accuracy", suggesting that VR can be used to improve dexterity. Based on this research, a hypothesis that 'if dexterity can be improved by VR then it can be measured in VR' was used for this research. In order to assess this hypothesis, the 9-HPT was created in a virtual environment to provide adequate data to put this and the other hypotheses to scrutiny (see Section 1).

2.3.3 Dexterity used to compare real world and VR

With evidence that dexterity can be an effective measure for the real world and can also be measured in VR, research was required to find if these data sets could be compared to one another. As previously mentioned VR can be used for training (Broeren, Rydmark, and Sunnerhagen, 2004) (Colt, Crawford, and Galbraith III, 2001) and this training can lead to an improvement of real world dexterity. This suggests that a person's dexterity in VR can affect their dexterity in the real world, based on this causality it is assumed that VR and real world dexterity are effected and measured in a similar fashion and from this it was hypothesized that dexterity can be compared from VR to the real world. Based on this hypothesis, this research uses a real world 9-HPT to assess a user's real world dexterity and a VR 9-HPT that is the same size and dimensions as the real world counterpart

to assess a user's VR dexterity. The times taken to perform the task both in the real world and in VR are recorded and can be compared.

2.4 Current Control Method Evaluations

As mentioned this project has focused on using dexterity as a means to measure a control method. The task that will be performed by the participants has been designed to be the same environment for each participant. Other studies, however, have taken a different approach to evaluating control methods.

For example, Farella et al., 2008 mention a variety of cases studies for a glove control method that the researches had designed. One of the case studies used involved asking participants to use the glove in the video game Quake 3 to modify 3D meshes in game (Farella et al., 2008). They have also used the glove to control a robotic hand (Farella et al., 2008). These case studies were used to assess the gloves proximity-awareness and its use as an interactive device (Farella et al., 2008). This style of assessing a control method is potentially more accurate to their designed purposes. Gaming is one of the most well known uses for VR and therefore VR systems are often marketed towards gamers. The HTC Vive for example is designed for use in video games but can be used for other applications. It could make sense to assess a users performance in a video game in order to evaluate the control methods effectiveness as this is what the control method is designed to do. The reason why this wasn't used as a way to assess control methods in the project described in this paper is due to the unpredictability of this scenario. Commercial video games are designed to be entertaining and therefore are not constantly the same, putting reliability of the experiment at risk. This being said an argument can be made that the environment used in this project is also somewhat of a video game as a user is put in a virtual environment and is given a clear task to complete the results of which are recorded and effectively considered to be a score.

In another study, researchers aim to see how objects can be used to create a narrative in an environment using an Augmented Reality (AR) glove control method (Tanenbaum et al., 2011). Whilst VR and AR are different

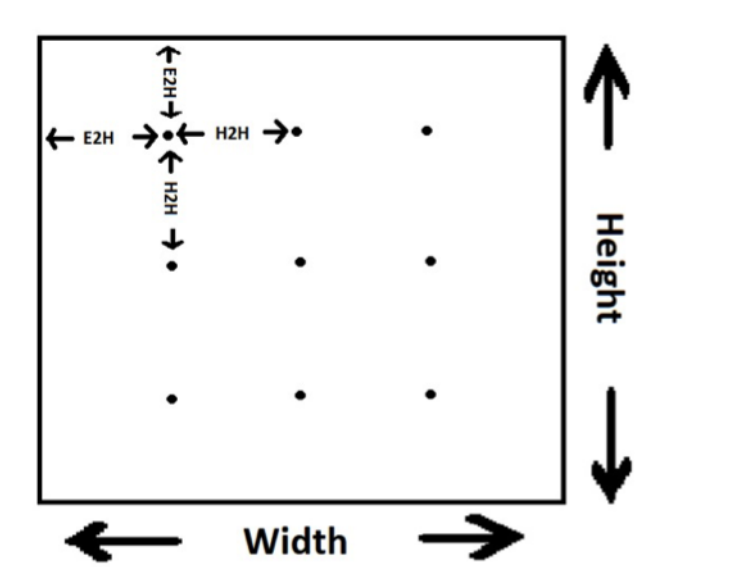
systems they can use similar technologies that are applied in different ways and therefore can be seen as comparable. The study does not necessarily assess the functionality of a glove designed in terms of being an accurate and precise control methods, however, it does show that the glove control method used can aid in creating a more compelling narrative for a user, suggested by a quote from one of the participants involved in the study "Participant 1 said 'It's easier to relate to the main protagonist, in a way, when you have the objects at hand and you can... feel what he's going into in some ways'" (Tanenbaum et al., 2011). This quote not only suggests that the interaction with an object aids a narrative but also suggests that the object itself can add to a users experience. This is worthy of note as in the project described in this paper all objects are intentionally designed to discourage distraction. For the dexterity task involved in this project any distractions could affect a participants time and therefore could have been detrimental to the results.

3 Implementation

3.1 Materials

3.1.1 Real World Test Design

As mentioned previously the test environment used for this research is based on a medical dexterity test. Commercially these tests are made from either plastic or wood and can be bought from various medical supply stores. The boards are 13.8cm squares with 6mm holes spaced 3.6cm apart and 6mm pegs that slot into the holes. However, for the purpose of this experiment some modifications were made to the original design of the tests. In order to ensure that the control methods could perform the task in VR the dimensions of the original board were scaled up by x2 and x4. This allowed there to essentially be three difficulty levels; the original size, twice the original size and quadruple the original size. The dimensions used for each board are as follows:



	Small	Medium	Big
Height	13.8 cm	27.6 cm	55.2 cm
Width	13.8 cm	27.6 cm	55.2 cm
E2H	3.3 cm	6.6 cm	13.2 cm
H2H	3.6 cm	7.2 cm	14.4 cm
Hole Diameter	0.6 cm	1.2 cm	2.4 cm
Hole Depth	1.5 cm	1.5 cm	1.5 cm
Peg Diameter	0.6 cm	1.2 cm	2.4 cm
Peg Height	3 cm	3 cm	3 cm

E2H = The edge of the board to the centre of a hole

H2H = The centre of one hole to the centre of the next hole

Figure 3.1: Dimensions of dexterity test boards

These dimensions where sent to a carpenter who created the boards out of plywood and used different thicknesses of dowel to make the pegs. The dimensions had to be followed accurately while creating these boards as they all have to be proportional to each other. If, for example, the largest board was slightly out of proportion then the validity of the experiment could be at risk.

The pre-tests of this experiment show that when translated into VR the smaller sized boards where too difficult for a first time user to perform. Only once a participant had experience with the smaller boards where they able

to achieve a time that was somewhat comparable with the real world boards. For this reason the smaller boards where not used in the final experiment and instead users where only tested using the largest board.

3.2 VR test materials

The VR boards are digital replicas of the real-world boards and required a variety of computer programs to ensure that they were designed correctly.

3.2.1 Blender

To design and create the 3D board and peg objects a 3D modelling software called *Blender* was used. Blender is a free 3D modelling software commonly used for creating virtual objects for video games, and is a commonly used program for designing assets for Unity applications. As Unity is the game engine used for this experiment Blender was adequate for creating the 3D objects required. Blender can use a variety of measurement types for creating objects including centimetres, this allowed the objects to be created at the exact same size as their real-world counter parts (Blender, 2019).

3.2.2 Pegs

The *pegs* required for the virtual boards simply needed to be cylinders that where the same size as their real world counterparts. Once the pegs where made it was noted that in order for the real world and VR tests to be completely comparable every aspect of the pegs had to be as similar to the real world tests as possible. Due to this a wood texture was applied to the pegs to ensure that they closely resembled the real world pegs.

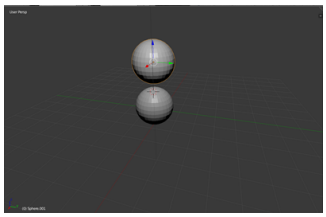


Figure 3.2: Two spheres

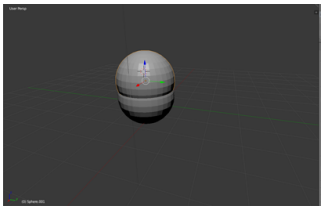


Figure 3.3: Intersecting

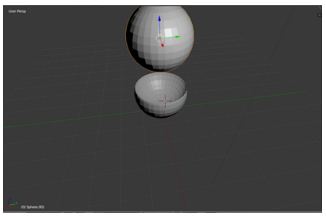


Figure 3.4: Bowl shape

3.2.3 Boards

The *board* design was more complicated then the pegs due to the holes that the pegs where to be placed into. The board itself is a simple cuboid shape sized to the same dimensions as the real-world boards. In order to create the holes in the board that the pegs were placed into the Boolean modifier was used. The Boolean modifier allows objects to be added and subtracted from each other, for example, if two spheres where made (Figure 3.2) and one was placed halfway inside the other (Figure 3.3) using the subtract method would create a bowl shape (Figure 3.4). To create the holes in the board the previously created pegs where subtracted from the board in the exact location of the holes, creating the right sized holes in the correct locations. This also created the mesh within the holes of the board that prevented the pegs passing through the inside of the holes.

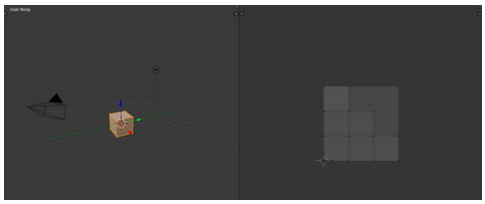


Figure 3.5: Cube Mesh

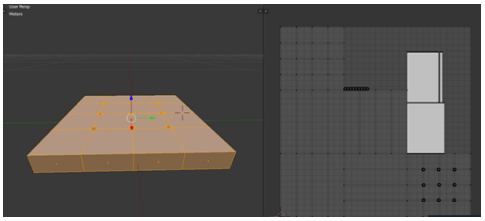


Figure 3.6: Board Mesh

When creating 3D objects which will be manipulated and controlled by a user it is important to ensure that the mesh of the object is correct. The mesh describes the faces of each object, for example, a cube object's mesh would simply be six squares one for each face (Figure 3.5). The mesh for the boards can be seen in (Figure 3.6) it had to include the holes as otherwise they

would not be recognised by Unity. As well as the meshes, the normals of the faces had to be correct. Normals are the directional data for a face, they store

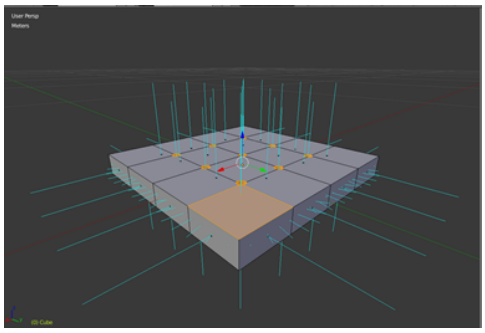


Figure 3.7: Board Normals

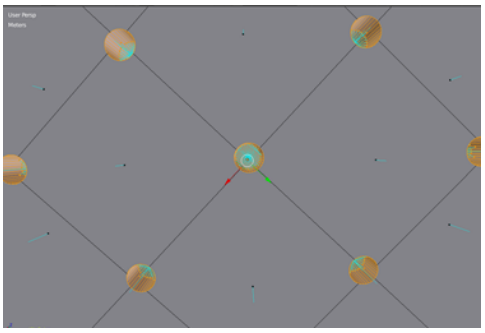


Figure 3.8: Holes Normals

the information about whether a face is pointing inwards or outwards shown by the light blue line in (Figure 3.7). Normals are important when objects require collisions, if a normal is pointing in in the wrong directions then a collision will not be detected. For the holes in the board the normals had to be flipped due to how the Boolean modifier subtracts objects (Figure 3.8). as With the pegs the boards were also given a wooden texture as to match the real world boards. Once the 3D objects where created to the correct specifications they were converted to an FBX file, a 3D object file format that Unity can read, and moved into a scene in Unity

3.2.4 Unity

Unity is a game engine which is extremely popular with both independent and mainstream game developers. Unity is a suitable game engine for this project due to its VR integration and due to the experience of the researches involved in this project (Unity, 2019).

3.2.5 Test environment design

The virtual test environment had to be created to be as similar to the real world test environment as possible and therefore had to be arranged in the same way as the real world test environment. A rectangular cuboid was used to resemble the desk used in the real world due to the simplicity of this object it was created using Unity's built in 3D modelling functionality and was arranged to appear at a similar height to the real world desk. As the users would be seated at a desk using a generic desk chair for both the real world and VR experiment they were able adjust their height and position as desired. With the desk serving as a canvas for the test environment the imported 3D objects where then added to the scene and were organised to match positions of their real world counterparts.

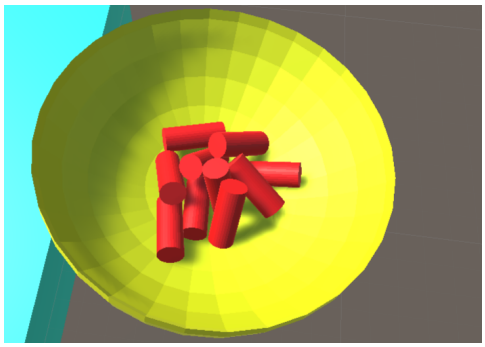


Figure 3.9: Pegs spawned in a bowl

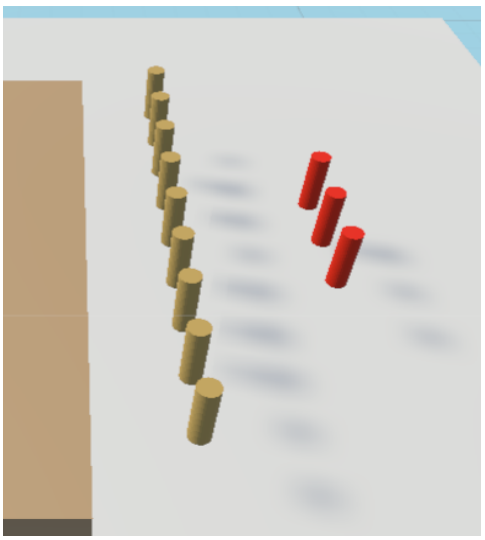


Figure 3.10: Pegs lined up

Originally the pegs were then spawned into a bowl as they would be in a real medical dexterity test (Figure 3.9), however, it was noted that this method adds a level of randomisation to each test which cannot be controlled as the pegs would fall into the bowl without consistency. It was then decided to line the pegs up alongside the board based on the dominate hand of the user (Figure 3.10) removing any inconsistency and allowing the test environment to be as consist-ant as possible for each participant.

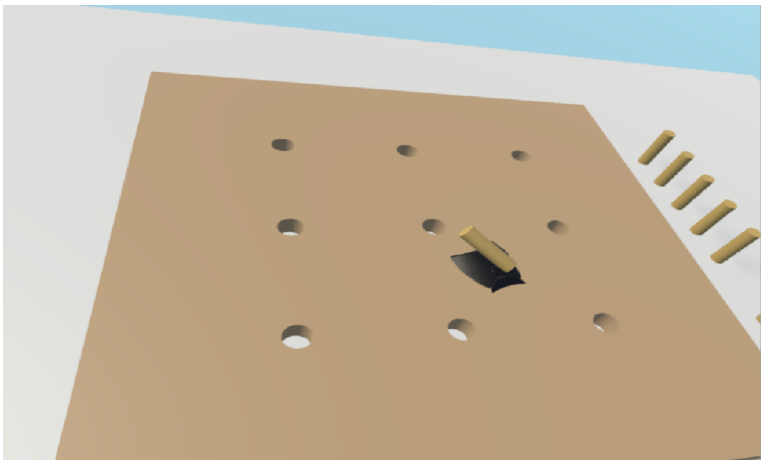


Figure 3.11: Pegs colliding

At this point it was noted that the major difference between VR and the real-world is the way in which their respective physics behave. In the real-world physics is uncontrollable and a user is restricted to complying to these rules, VR on the other hand allows for almost complete flexibility in the way in which a user can interact with the virtual world. This is one of the appealing features of VR when it comes to entertainment as it allows a developer to create an exciting and unique experience for their user's. However, in applications such as the test environment used for this research where the VR world needs to interact in way that is as close as possible to the real world it is vital that the virtual physics are grounded and realistic. For example, in the real-world it would be physically impossible for a user to pass their hand through a physical object. Where in the virtual world, without the use of advanced haptic feedback, it would be almost impossible to prevent a user passing their hand through a virtual object if they wanted to. In order to prevent participant's data being effected by situations such as this the test environment was designed so that objects in the environment interacted with each other in a realistic way instead of trying to limit the participants use of each control method. In essence a user can still pass their hand through the virtual board and table in front of them, however, if they were holding a peg whilst doing so it would collide with the board/table and not pass through, seen in (Figure 3.11).

3.2.6 Script overview and pseudo code

For this environment a variety of different scripts were used. Firstly a collider was added to each object. This includes a script which prevents objects from passing through one another. The pseudo code for this is as follows:

Listing 3.1: Collision pseudo code

```
If (This_Object collides with That_Object) then {
        This_Object position = This_Object previous.position
        This_Object rotation = This_Object previous.rotation
}
```

This is a very useful basic tool that unity provides and is required for all forms of the virtual environment. The pegs in the virtual world are instances of a prefab, this essentially means that an original object is created, the peg, known as a prefab and any instances of this prefab are clones of the original object (Unity, 2018). Doing this allows an instance of a prefab to be edited and manipulated in any such way without effecting the original object. As well as colliders and prefabs the pegs also utilised tags. Tags are marker values that allow an object to be identified in the unity project (Unity, 2019). The original peg prefab was given a tag named “Interaction” and therefore all instances of the peg had the “Interaction” tag. The pegs also used the fixed joint script provided by unity, fixed joints restrict an objects movement to be dependent on another (Unity, 2019), in essence allowing one object to be stuck to another and therefore move/behave as the other object does.

The peg prefab created and utilising the tools unity provides an interaction script allows the control methods to pick up and drop individual pegs. This script finds the closest peg to the control method and if it is within a certain range picks it when triggered and drops it when triggered. The pseudo code is as follows:

Listing 3.2: Interaction pseudo code

```
If (interact) then {
        Int x;
        gameObject closest;
        For each(object in x range){
```

```
                If(closest = null){
                Closest = object;
        } else if (object..distance < closest.distance) {
                closest = object;
        }
    }
    closest.fixedJoint attached to this.fixedjoint
}
```

Alongside the code that allowed pegs to be picked up and dropped another script was created which allowed the position and rotation of the peg to be tracked for each frame that the peg has been picked up. This allows for concrete data that shows the transformation for each peg from the time that the peg was picked up to the time the peg was placed. Using this data more information can be gathered such as the average time taken to pickup and place a peg, which peg takes the longest to place, and if any of the participants drop a peg it can be seen how long it took the user to pick it up again. The code used to track the pegs was also altered to track the position of the users hand while they were performing the experiment. Tracking the users hand shows any techniques that they used to perform the test.

Pseudo code:

Listing 3.3: Record pseudo code

```
List positionList;
List rotationList;
If (pegPickedUp = true) then{
    string pickUpTime = currentTime;
    record = true;
}else (pegPickedUp = false) then{
    String placeTime = currentTime;
    record = false;
}
if(record = true){
    foreach(frame){
        positionList.add(this.position);
        rotationList.add(this.rotation);
    }
```

```
}
```

Adding the leap motion allowed the performance of the Vive controllers to be compared to another control method. The Leap motion uses a 3D camera to track the hand and finger positions of a user, this data is then copied and translated on to a virtual hand object in unity which can be used to manipulate virtual objects. The main difference in this style of controller compared to the Vive controllers is the finger tracking. It is predicted that the user being able to see their hand in VR will give them a better sense of control as it should feel more natural. In order to implement the Leap Motion unity package had to be added to the project, this is a third party plugin created by leap motion and provides the majority of the leap motions functionality straight into unity. When it came to implementing the leap motion to use the test environment in the same manner as the Vive controllers it was important to make sure that the interaction scripts used works with the standard leap motion interaction script. If any extra code was scripted in order to perfect the leap motion integration then it would most likely affect the results of the leap motion as the tests would be testing the edited version of the leap motions control not the interaction scripts that are made for the Leap Motion.

4 Methodology

4.1 Participants

4.1.1 How participants were selected

Twenty-Seven people were selected as participants for this project. Each participant selected for this experiment has volunteered to partake via an email application or face to face. All participants have been required to read an instruction sheet which explains the experimentation process and details how their data will be used and stored (Figure 10.3). As well as the information sheet each participant has signed a consent form allowing their test data and any video/audio recordings to be used in support of this research. Participants have been selected based on their willingness to partake in the experiment with no intentional bias towards any personal characteristics. This said it is important to note that a with the participant pool being twenty-seven the results may not accurately reflect the possible results gained by the entire population.

4.1.2 Participant requirements

In order to protect the safety of the participants and the validity of the test results participants had to meet certain criteria in order to be accepted for the study. One potentially adverse effect that a participant could have experienced was virtual reality sickness (LaViola Jr, 2000). VR sickness is a form of motion sickness that is triggered when a user has a visual representation of movement but can feel that their body is still (Johnson, 2005). Symptoms include general discomfort, headaches, stomach awareness,

nausea, vomiting, pallor, sweating, fatigue, drowsiness, disorientation, and apathy (Kolasinski, 1995). In order to mitigate this risk users were asked in their consent form if they have ever experienced motion sickness before, if so they were not selected to take part in the experiment. As well as this, users were advised to use and familiarise themselves with the VR system prior to the experiment in order to adjust to the feeling of VR and had been instructed to remove the headset at any time during the experiment and rest if they feel any of the symptoms of VR sickness. Another potential risk was is a participant with a health condition that affects their dexterity, e.g. Parkinson's disease and arthritis, performed the experiment. As the experiment's task was based on a medical dexterity test, used in physio therapy to monitor conditions that affect dexterity, but the data from this experiment is not to be used in this way it was important to not allow these individuals to participate in the experiment. For the participant it was important that they did not become discouraged by or were given a false sense of hope based on their results, For the experiment it was important that an individual's uncontrollable characteristics did not skew their data. To prevent this, participants will be asked prior to the experiment to confirm that they do not have any health conditions that could affect dexterity in their consent form.

4.2 Experiment design

In order to understand how this experiment was performed it is important to understand which variables are measured and how.

4.2.1 Dependant

The dependant variable for this experiment is dexterity, this is the variable that is measured and compared for each stage of the experiment. This is the only common variable for each type of test and will be determined by the speed at which the user was able to complete the dexterity test, the faster the user was the more dexterous the control method.

4.2.2 Independent

For this experiment the independent variable is the control methods as this is the variable that is directly changed by the researchers for each stage of the experiment. This variable has to be different for the experiments as it allows the dexterity to prove predictions made about the control methods. In order to counter act any learning effects made during the experiments the order in which participants perform the types of experiments will be altered at random. Randomising the order that the tests are performed reduces the possibility of the results being skewed by an internal learning effect. Meaning that if all tests were performed in the same order than the final test could produce better results due to the participant having a better understanding of the task. Randomising the test order for each participant evens this effect out as if the Vive test was performed last with 50 percent of the participants and the Leap Motion test was performed last for the other 50 percent of participants, than the averages of each would account for any learning effect that could of occurred.

4.2.3 Controlled

The variables that are controlled would be all objects in both the real world and VR test environments. It was vital that these tests were as close to identical as possible for all variations of the test. This meant that the VR tests are all identical copies of each other with only the control methods altering and the VR test environment has been carefully created to be as close as possible to the real world test environment.

As well as the variables that are involved in this experiment it is important to understand that this experiment was performed using a within groups style of extermination. Within groups means that the all participants are required to complete each style of the test opposed to asking a participant to perform one test and then bringing in a new participant to perform the next test. Within groups allows for a high level of accuracy with a lower number of participants than other testing styles and as such it is believed that within groups has provided adequate results for this project.

4.3 Experiment procedure

4.3.1 Participants

In order for the participants to understand how they were to complete the experiment correctly the where given and information sheet explaining how they were to complete the experiment. the information sheet contained the following information:

The test consists of a participant being seated in front of a wooden board with nine evenly spaced holes in a grid pattern. nine pegs will be lined up next to the board on either the left or right hand side based on the dominant hand of the participant. The goal of the participant is to place all nine pegs into the nine holes in the board. This task must be completed with the participant's dominant hand and must be performed in the following order:

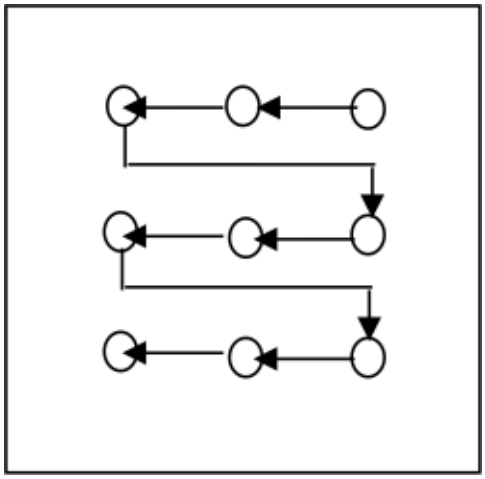


Figure 4.1: Left Handed

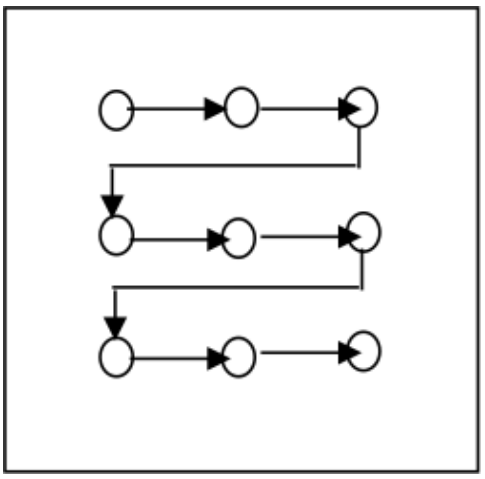


Figure 4.2: Right Handed

This test has also been recreated in VR and participants will be asked to perform the same test in the virtual world with a variety of control methods. On average the real-world test takes no longer than 20 seconds and the virtual test no longer than 60 seconds. However, participants will be given five minutes to complete the task for each of the tests, the total for all

experiments taking no longer than 30 minutes. The time taken to complete each test will be recorded anonymously as only the controllers are being assessed not individual's times. Participants are advised to take breaks in-between tests as to prevent VR sickness, a form of motion sickness, these breaks will not be timed. The VR tests will also be performed in a random order as to account for a learning effect.

4.3.2 Researcher

In order for the experiment to be run correctly a researcher must monitor the experiments and record relevant information. This process requires at least one researcher who must give the exact same directions to each participant for each type and run of the tests involved.

Real World

To prepare for the real world tests the researcher would first find out the dominant hand of the participant and set up the real world board and pegs in the correct format. Once the test equipment was set up the research would explain to the participant what they are expected to do and how they are expected to do so. In the case of a right handed participant the researcher would organise the board with all pegs lined up on the right hand side of the board and would then explain to the participant that they must use their right hand to place all pegs in the board starting with the peg closest to them placing it in the top left hole in the board followed by the second peg into the top middle hole then the third into the top right hole and so on. The procedure is the same for a left handed participant just reversed. Once this had been explained and the participant understood what they were supposed to do the researcher would ask the participant if they are ready and if so would count down from three to one as to signal to the participant when to start but also to ensure the participant starts at the same time as the stopwatch is triggered. The researcher would then observe the user to see if any steps were performed incorrectly and stop the stop watch when the final peg was placed into the board. The time taken for the test was recorded and the test re-set and performed again. With the time

recorded the researcher would ask the participant to reset the experiment and perform it once more.

VR

The VR tests are performed in a similar set up to the real world test and began with the researcher explaining how the virtual environment will look and be set up for the user so that they could arrange themselves correctly. The order in which the tests for the VR control methods were randomized for each participant to account for a learning curve. For example, some participants would perform the Leap Motion test first and others would start with the Vive controllers. Each participant would perform both the Vive controller and Leap Motion tests twice and the times were recorded for both. All participants would perform the real world test first as to aid in the explanation of the task they would perform in VR. As the real world experiment was recorded using a stop watch both VR tests were recorded using a virtual stop watch that was triggered by the researcher pressing the space bar on the computer running the test environment. As with the real world tests the stop watch would be started on the count of three and would be stopped once the final peg has been placed into the board. As well as the overall time for each test the time taken for each peg has also been recorded as well as the positional data for each peg and the users hand as mentioned previously. The researcher would move all data recorded into the correct location as to be associated with the test participant and ensure that it is stored safely. During pre-testing it was found that if a participant was told to use a control method with no explanation on how they operate then they would often ask for directions during the experiment. In order to ensure that all participants were given the exact same treatment it was decided that prior to testing on both the Vive controllers and the Leap motion the researcher would explain to the participant how to use each control method and would allow the participant to practice using both. The scripts used to explain each control method are as follows:

Vive controllers

"The Vive controller will be passed to your dominate hand once the test environment has loaded and you are happy that the headset is on correctly. The controller will appear in the virtual world and will follow the hand movements you make in the real world. In order to pick up a peg you must bring your hand towards a peg and pull the trigger on the back of the controller. The peg will attach to the top of the controller and remain there whilst you are holding the trigger down, the peg will be released once you let go of the trigger. You will be given time to practice with the controller before the test is recorded, once you are happy with how the controller interacts with the pegs the test environment will be loaded and your time to complete the task will be recorded. At the end of the test the environment will be reloaded and you will be asked to perform the test a second time. Do you have any questions before we begin?"

Leap motion

"Once the test environment has loaded place your hands straight out in front of you with an open palm allowing the Leap Motion to see and start tracking your hands. You will see a 3D model of a grey hand that will mimic your hand and finger movements in the virtual environment. In order to pick up a peg you will move your hand over to the desired peg and pinch with your index finger and thumb along the vertical length of the peg. Once you are ready to release the peg you will un-pinch your index finger and thumb. The peg will follow the orientation of your hand whilst it is picked up. You will be given time to practice with the Leap Motion before the test is recorded, once you are happy with how the Leap Motion interacts with the pegs the test environment will be loaded and your time to complete the task will be recorded. At the end of the test the environment will be reloaded and you will be asked to perform the test a second time Do you have any questions before we begin?"

Once a participant has completed a test it is the researcher's responsibility to ensure that all data is stored correctly. This involves moving the recorded positional data into the correct location and making note of the times

taken to complete each test. The participant will then be asked to fill in a questionnaire that consists of a variety of open ended questions asking for the participant's opinion on the different control methods used. The questionnaire is designed to gather any comments that are worth noting and as it is based on the participant's opinion it will not return concrete facts. The questionnaire used can be seen at Figure 10.1.

5 Pre-Testing

Pre-tests have been performed throughout the development of this project in order to better shape and define the final experiment procedure. From these pre-tests predictions on how the final results might look where drawn. These predictions where made around how the user will interact with different control methods and how their times will be effected based on various variables controlled in the experiment. Four participants were used for the pre-testing of this experiment all of which had experience in computer science and limited knowledge of the project and its technologies.

Before the pre-tests, the experiment design was different to the final design used. The original design had participants performing the same task using three different sized boards. The board sizes where based on a medical dexterity test with the smallest board being the same size and dimensions as a real medical dexterity test, the medium board was twice this size and the largest board was twice the size of the medium board. However, during pre-testing it was found that the smallest board was too difficult for untrained participants to use efficiently and would result in times that where far to different from the real world tests to be comparable. From the results recorded from the four participants who took place in the pre-testing it was found that there was not a significant difference in time between preforming the task on the largest board and on the smallest board. This is most likely due to Fitts' Law which states that the time required for a person to move a pointer to a target area is based on the distance to the target divided by the size of the target. As the boards are scaled replicates of each other the ratio of target size and distance is the same for each board and therefore the time taken should be similar. Due to these discoveries it was decided to only use the largest board for the real world and virtual tests and each participant would have to perform each test twice. It was

also decided The following Hypothesis's were made based on this stage of pre-testing:

- **Hypothesis 1**: There will be a significant difference in time between the first and second tests performed using a control method in the virtual environment
- **Hypothesis 2**: Real world test times will be the fastest
- **Hypothesis 3**: VR users will return the fastest times

With the experimentation design changed, more pre-tests were run in order to see if the new design was effective. These tests where run as if it was the final experiment and finalised the experimentation design. From these pre-tests it was discovered that participants struggled to use the various control methods without any instructions on how they operate. Because of this the scripts mentioned in the methodology section of this paper where written. it was also decided that participants should be given time to practice with each control method prior to their times being recorded. This practice time was not monitored and was solely to allow the participants to become more familiar with the test environment and the control methods. It was also decided at this stage to randomise the order in which participant will use the control methods as to counteract a learning effect that could have given the later control methods to result in faster times. From this stage of pre-testing further hypothesis's were made:

- **Hypothesis 4**: Participants will record faster times using the Leap Motion due to its more realistic and natural interface.
- **Hypothesis 5**: Participants will find the Vive controllers to be clunky and awkward to use for the task they must perform in this experiment
- **Hypothesis 6**: The order in which a participant performs the virtual tests will affect their times, for example, if a participant uses the Vive controllers first than their Leap Motion time will be faster as a result of becoming more adapted to the virtual test environment.
- **Hypothesis 7**: Participants will figure out a technique for performing the task and this will result in the faster times for the later tests in the experiment
- **Hypothesis 8**: Real world tests will be the fastest, Leap Motion tests will be the second fastest and Vive controllers will be the slowest.

5 Pre-Testing

With the pre-testing completed and the experimentation design and process finalised the project was ready to move onto the next stage of experimentation. Before the experiments could begin participants had to be gathered, twenty-seven participants were used in order to gather the data. The majority of participants were gathered from around the Oxford Brookes Wheatley campus, consisting mostly of admin and HR staff, others were brought in from outside of the university. An effort was made to ensure that the majority of participants were not from the computer science department of Oxford Brookes as this could have an effect on the results as well as not accurately depicting the general public. Potential participants were given an information sheet describing the experiment (Figure 10.3) and were asked if they would be interested in taking part, if so they could book a time slot either face to face or via email.

The twenty-seven participants used for this experiment were shown the experiment set up and were briefed on the experimentation process before being asked to complete a consent form (Figure 10.5) if they were happy to take part in the experiment. All participants performed the experiment separately in the same environment with the same researcher monitoring them as to avoid any uncontrollable influences on their performance. All participants were assured anonymity during this experiment so the order of the experiment data has been randomised and categorised by number.

In hind sight it would have been advantageous to repeat the experiment multiple times for each participant as a learning effect could have been better evaluated. However, due to the time constraints of the project this would not have been viable as the testing phase of the project was already running behind.

6 Results

Table 6.1 Shows all recorded data for the experiments performed. The data is split by participant and the type of test performed; Real world, Vive and leap. All times are recorded to three decimal places and in a case where a user did not finish a test correctly their time has been noted with 'DNF'.

Table 6.2 Shows the significance for the A-B comparison of each type of tests recorded using a pared T-Test and a Sign test.

Table6.3 Shows the average times recorded for the Vive controllers and Leap motion depending on the order a participant performed the tests.

	Real World				Vive				Leap			
#	A	B	AV	Diff	A	B	AV	Diff	A	B	AV	Diff
1	12.66	12.03	12.345	0.63	21.21	17.13	19.17	4.08	26.37	22.94	24.655	3.43
2	10.66	10.13	10.395	0.53	16.68	15.32	16	1.36	35.86	26.29	31.075	9.57
3	9.31	8.9	9.105	0.41	22.92	15.88	19.4	7.04	26.53	29.8	28.165	-3.27
4	13.08	12.37	12.725	0.71	195.31	42.1	118.705	153.21	38.51	44.65	41.58	-6.14
5	13.69	13.6	13.645	0.09	29.01	31.87	30.44	-2.86	54.6	31.5	43.05	23.1
6	16.31	14.65	15.48	1.66	25.09	29.31	27.2	-4.22	49.06	39.88	44.47	9.18
7	13.47	12.74	13.105	0.73	93.91	37.05	65.48	56.86	47.27	35.41	41.34	11.86
8	11.91	11.45	11.68	0.46	31.39	29.19	30.29	2.2	144.89	132.33	138.61	12.56
9	11.33	10.66	10.995	0.67	27.4	24.33	25.865	3.07	42.53	18.78	30.655	23.75
10	11.43	10.41	10.92	1.02	27.94	18.49	23.215	9.45	53.77	83.02	68.395	-29.25
11	14.89	13.03	13.96	1.86	59.78	29.02	44.4	30.76	37.88	32.77	35.325	5.11
12	10.03	11.18	10.605	-1.15	24.97	18.19	21.58	6.78	25.08	24.18	24.63	0.9
13	11.3	10.36	10.83	0.94	43.07	31.22	37.145	11.85	56.4	46.06	51.23	10.34
14	12.89	11.06	11.975	1.83	21.91	15.5	18.705	6.41	72.41	DNF	72.41	
15	16.06	15.81	15.935	0.25	25.59	23.81	24.7	1.78	27.65	59.45	43.55	-31.8
16	14.52	13.07	13.795	1.45	25.14	19.88	22.51	5.26	45.47	73.35	59.41	-27.88
17	12.57	12.57	12.57	0	22.21	18.28	20.245	3.93	66.58	35.82	51.2	30.76
18	14.87	13.5	14.185	1.37	18.28	22.85	20.565	-4.57	47.91	34.18	41.045	13.73
19	11.78	11.25	11.515	0.53	25.89	17.59	21.74	8.3	45.81	44.41	45.11	1.4
20	12.07	10.72	11.395	1.35	16.63	20.7	18.665	-4.07	27.46	18.92	23.19	8.54
21	12.76	11.98	12.37	0.78	31.07	29.33	30.2	1.74	106.64	44.41	75.525	62.23
22	13	11.53	12.265	1.47	31.43	18.27	24.85	13.16	62.06	102.02	82.04	-39.96
23	23.41	16.22	19.815	7.19	43.24	44.36	43.8	-1.12	131.29	66.41	98.85	64.88
24	13.22	13.3	13.26	-0.08	30.71	29.48	30.095	1.23	44.4	40.81	42.605	3.59
25	11.86	11	11.43	0.86	31.54	36.6	34.07	-5.06	37.93	34.9	36.415	3.03
26	10.66	9.93	10.295	0.73	20.34	21.07	20.705	-0.73	41.61	16.66	29.135	24.95
27	13.4	13.14	13.27	0.26	26.39	22.53	24.46	3.86	36.96	32.16	34.56	4.8
ø	13.08	12.10	12.59	0.98	36.63	25.16	30.90	11.47	53.07	45.04	49.56	7.28

Table 6.1: Raw Data

	A-B Significance		
	Real World	**Vive**	**Leap**
T-Test T-Stat (P-Number)	3.64 (0.00118)	1.92 (0.0651)	1.53 (0.13665)
Sign Test	2.80E-06	0.00958	0.00468

Table 6.2: A-B Significance

	Vive 1st vs Leap 1st	
	Vive	**Leap**
Vive 1st	26.68	42.968
Leap 1st	23.365	48.961

Table 6.3: Vive 1st vs Leap 1st

7 Analysis

Figure 7.1 shows the average test times of the A and B tests for both virtual experiments and the real world experiments. As hypothesized, the table shows that out of all of the tests the real world proved to have the fastest times. This was to be expected as regardless of how much experience a participant has with VR technologies they will have more experience with their hands especially for performing intricate tasks such as the one used for this experiment. Contrary to the predictions made prior to the testing, the Vive controllers recorded much faster average times than those from the leap motion controller. This was an interesting but unexpected development, it is assumed that due to the participants used for the pre-tests having knowledge of the project and knowing the technologies better than most that their times recorded were faster with the Leap motion than the average found in this experiment. From the times recorded it was clear that participants recorded faster times on their second test than on their first. Both a T-test and a sign test were run on each test type to see if there was a significant difference between the means averages of tests A and B that could be due to a learning effect. On the graph the results of the T-test

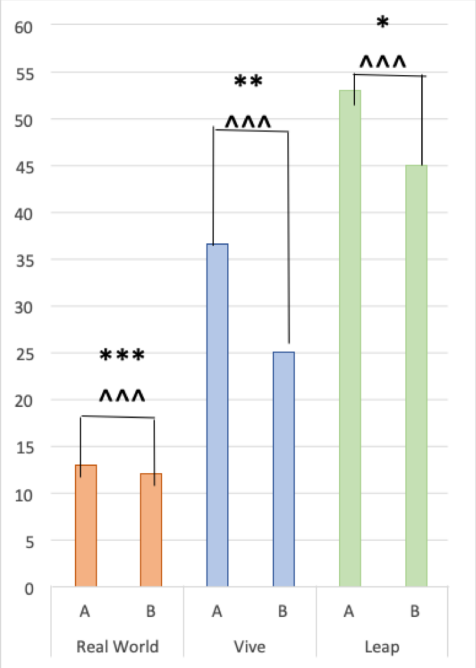


Figure 7.1: Average Results

are dictated by a number of ”*” symbols, with three being significant and ”*” one being insignificant. The results of the sign test results are shown by the number of ‘ˆ symbols with three being significant and one being insignificant.

The Sign test was chosen for this experiment due to it being non parametric meaning that it does not assume a particular distribution of the data. This test works by using two data sets and counting the number of times a null hypothesis is either true or false, this data is then inputted into a binomial calculator which returns a P-Number based on the probability, number of data points and the number of times the null hypothesis is true. For example, Hypothesis 4 states that the leap motion test would be performed faster than the Vive tests, the sign test can be used to assess this hypothesis. From the results gathered this hypothesis was true 3 times and false 24 times while this seems to show that the hypothesis is wrong the sign test can be used to see if it is significant. Using a probability of 0.5, the number of data points being 27 and the number of times this hypothesis was true being 3 a binomial calculator results a P-Number of 2.46E-05 which is lower than the Alpha level of 0.05 meaning that the null hypothesis can be rejected and that there is a significant difference.

The T-test shows the significance based on the averages including the variance of the results meaning that the lower the variance of the results the more likely the averages are to be significant whereas the sign test will show the significance regardless of the variance of the results. As seen by (Figure) both the T-test and the sign test have shown that there is a significant difference between the A and B test for the real world tests suggesting that there is a learning affect occurring.

For both the Vive and Leap motion controllers results the sign test suggests that there is a significant difference between the A and B tests. The T-test, however, suggests that the Vive controller cannot be considered a significant difference but is considered a trend meaning that it is likely that the results are correlated however more tests would have to be performed in order to say indefinitely that the results from test B are affected by the results from test A.

As for the Leap motion tests the T-test suggests that there is not a significant difference between the leap motions A and B test and therefore it cannot

be claimed that the learning effect has occurred for the leap motion. This is due to the variance in the times recorded for the Leap motion making it harder to compare the Leap motions times.

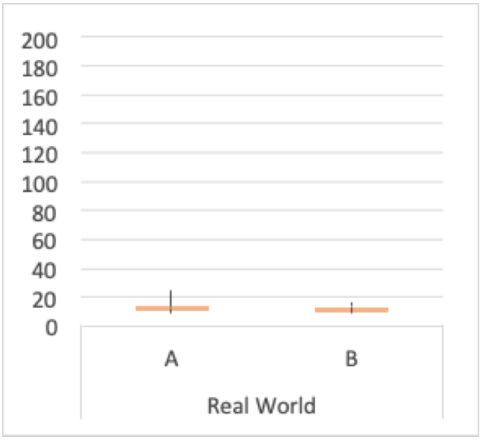


Figure 7.2: Real World

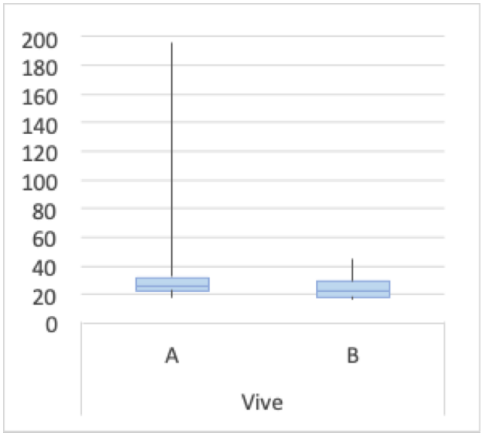


Figure 7.3: Vive Controllers

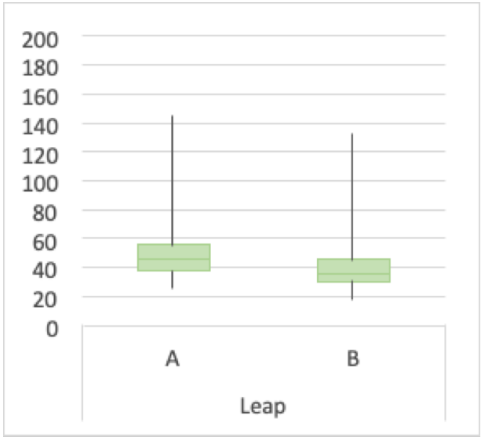


Figure 7.4: Leap Motion

(Figure 7.2), (Figure 7.3) and (Figure 7.4) are box plots of the real world, Vive controllers and the Leap motion controller tests results for tests A and B. The box plots show the highest recorded time and the lowest recorded time shown by the peak and base of the lines for each bar. The box section of the bars shows the middle two quartiles of the data recorded with the horizontal line inside the box dictating the median value of the results. The

wider the range of the results found in the box, the wider the variance of the results found for that data set.

As can be seen in Figure 7.2 the variance for the real world experiment is extremely small with all results, including the maximum and minimum falling between zero seconds and twenty-five seconds. This would be a factor into the significance of the comparison between the A and B tests. As the results are very consistent no further testing is required to determine that the averages are correct. For the Vive controller results seen in Figure 7.3 the range inside the boxes for both test A and test B is small, suggesting that the average would be correct. However, due to the high maximum result in the Vive controller A test data set the average would be skewed. This could be why the T-test results show the averages as a trend opposed to being significant. More testing would be required to confirm that this high time recorded is an anomaly. In the case of the Leap motions recorded times the variance is much greater. This can be seen by the size of the range for the boxes on Figure 7.4, these ranges are much larger than those of the Vive controllers and the real world. As well as this the range from the maximum and the minimum is much greater than those of the other two tests and therefore there is much more variety in times recorded for the Leap motion times. This variety causes uncertainty and suggests that the mean average that is drawn from this data is likely to have been skewed. The sign test however is non-parametric meaning that it doesn't assume a data sets distribution, this allows the sign test to ignore the distribution of the data and suggests that the results from test A do in fact impact the results from test B for all three types of test.

Though the Leap motion recorded by far the slowest times for each stage of the test it is interesting to note that on the questionnaire users were asked to fill in post the experiment fourteen of the participants said that they preferred the leap motion controller whereas thirteen said that they preferred the Vive controllers. From the twenty-seven participants a split of fourteen to thirteen cannot be considered a high enough majority to claim that on average people will prefer the Leap motion to the Vive. However, the fact that the scores were an almost 50/50 split and considering the significantly slower times recorded from the Leap motion it is fair to say that the speed of learning how to use a technology is not the only factor into how a person perceives it. Participants were also asked to give a brief

explanation as to why they preferred a control method, listed below are some comments that participants made about the control methods when asked "Which VR control method did you prefer and why?":

"It was cool having a responsive hand in VR however the Vive controllers were more responsive and less buggy" – Participant 1

"Leap Motion. It was realistic but also a challenge to use" – Participant 6

"Vive controllers, but I wanted to become better with the Leap motion as I preferred to use my fingers" – Participant 12

"Probably seeing my hands (a reference to the leap motion) although I was slower, I think, it felt closer to reality I feel I would get quicker" – Participant 13

These comment have been singled out as they all show a conflict of opinions about the control methods. Although these participants could tell they performed better with the Vive controllers they felt as if their time would improve if given more time to practice. Participant 13's comment is noteworthy in particular as by referring to Table 6.1 in the results section of this chapter, this participants average time on the Leap motion, 51.23 seconds, is higher than the average of 49.56 seconds. This participant recognised that they were slower in this test but still decided that they preferred the Leap motion over the Vive controllers. This could prove that the speed in which a VR user performs a task is not the only factor into what makes a control method preferable. Realism and immersion is a vital part of VR in the entertainment industry. Regardless of the outlandishness of a virtual setting important that a user feels somewhat present in their virtual setting. Without a sense of immersion VR entertainment would be dull and uninteresting.

For example, the virtual environment used for this experiment is designed to be as realistic as possible to dexterity test placed on an average desk you would find in any class room or office. This evidently is not the most interesting setting, as is by design, for this environment is built in order to serve a purpose not for entertainment. Despite the dullness of this environment users still feel immersed within it due to its realism, this is only heightened when a user is able to see their hands in the environment as well. While possibly distracting and difficult to use when performing a dexterous task, being able to see your own hands in a virtual world makes

it feel more realistic and involved which in turn might be the reason for the increase in appeal to the Leap motion.

7.1 VR users vs Non-VR users

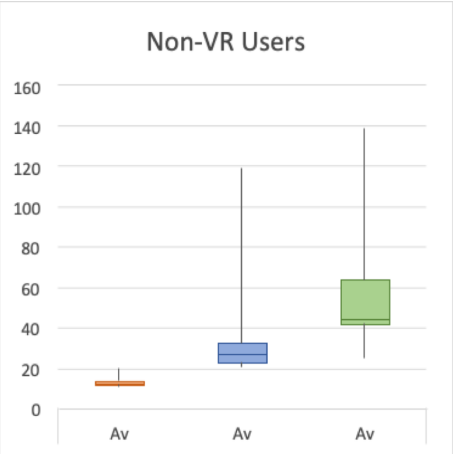


Figure 7.5: Non-VR Users

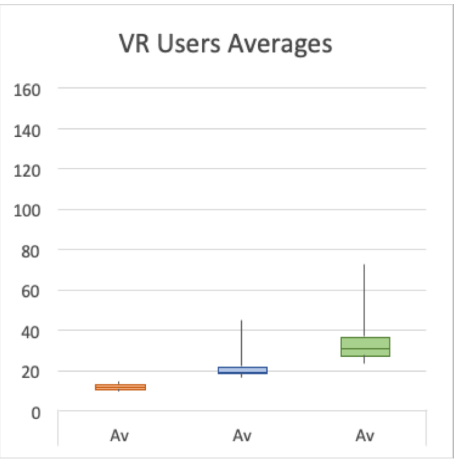


Figure 7.6: VR Users

The results from participants who have regularly used VR and Participants who have either never used VR or have experienced it a few times in demonstration were split. Figure 7.5 and Figure 7.6 show that there is a significant difference between in times recorded for participants who are familiar with VR. Not only did these participants record faster times than those from who are not considered VR users, the VR users were also more consistent.

The data recorded for the real world test was much the same for both categories which is to be expected. It is also clear that VR users performed better with the Vive controllers which again is to be expected as even if these participants use a different VR system, such as the Oculus Rift, the controller style would be much the same as the Vive.

This is because the joystick style of controllers are common place for the major VR hardware companies and exploration into different styles of

controllers are starting to be explored with the introduction of knuckle controllers. Interestingly the results for the Leap motion were also, on average, much faster for VR users. It is theorised that this could be due a sort of sensory overload that could be present when using VR and a Leap motion without much experience. VR can be quite disorientating especially when the user is not familiar with it, introducing the Leap Motion adds another level of technology that could further impact a user's attitude towards the virtual environment. This is backed up by looking at the variance for the leap motions times on the Non-VR users. There is a lot of inconsistency for this test much more than the VR users counterpart, this would support that not being used to virtual environments could affect the results of separate technologies. Another theory as to why this is the case is that VR is a relatively new mainstream technology and therefore its users would be more open and used to more "advanced" technologies which in turn could have affected their test times. It is to be noted that out of all of the twenty-seven participants used for this experiment only eight where considered to be VR users so the results will not be accurate enough to represent all VR users.

From all of the participants used in this experiment only one, participant 14, has had experience with both the Vive controllers and the leap motion. This participant was also the only participant to not finish one of the tests, this can be seen in from the table in the results section. The DNF (did not finish) was recorded on the participants second leap motion test and was due to the participant dropping more than three pegs in a way in which they could not be retrieved. This meant that the participant was unable to complete the test as they had no pegs to fill in the final holes. It was decided during the pre-testing phase of that if a user was to lose more than three pegs than that test would count as a DNF. As mentioned previously this participant was the only participant to have experience with the leap motion prior to the experiment. Discussions with the participant about their Leap motion use revealed that they had used the Leap motion for desktop applications. The Leap motion was originally designed to be used with a desktop computer where the Leap itself would be mounted on a desk in between the user and the computer screen similar to a keyboard. Once set up the user can manipulate and control objects on the screen with their hands hovering over the Leap motion. In 2016 Leap motion released software which allowed the

hardware to be used in a VR format. As this participant has had experience with the Leap motion in its desktop form it is possible that the switch to VR could have confused the user due to the subtle differences in the Leap motions tracking ability. When using the Leap motion in desktop mode it is designed to track the users while having full view of their hands from the underneath of the palm, when it used for VR however, it tracks the users hands whilst being mounted on the users head.

From the underneath of a user's hands the Leap motion can have a much clearer view of the where each finger it and how it is moving with little disruption, seen in the first image of Figure 7.7. whilst being attached to the users HMD (head mounted display) and tracking from behind the hands there is a much greater chance that the view of the users hands can be obstructed by themselves. the second image in Figure 7.7 shows a view that would be similar to what the leap motion can see if a user has their hands angled upwards, it is clear where the hand and each finger is. the third image in Figure 7.7, however, shows an image that would be similar to the Leap motions view when a user's hands were flat and the fourth image in Figure 7.7 shows when the users hands are angled downwards. From these images it is clear to see that the fingers are obstructed and only the thumb is clearly visible. This would make it harder for the Leap motion to be able to see what the user is trying to do especially when compared to the view of the desktop version. Due to this, when using the Leap motion for VR a user must make their movements very obvious ensuring that their hands are always visible to the Leap motion.

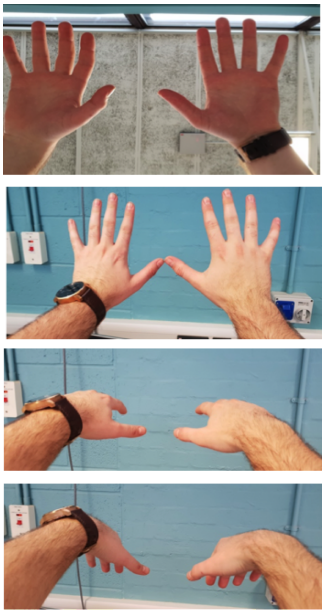


Figure 7.7: Leap motions view

7.2 Test Order

All participants performed the real world test first and then were asked to do the VR tests. This was due to the nature of the explanation of the task and it was believed that participants would have a better understanding of the task if they were to perform it in the real world first. The order in which the participants performed the VR tests was randomised however. The average results for both the VR tests depending on the order in which they were performed can be seen in 6.3. The results show that participants record, on average, faster times with their second control method. For participants who performed the Vive test first they performed the Leap Motion test, on average, 6.0 seconds faster than those who performed the Leap motion test first. For participants who performed the Leap motion test first they, on average, performed the Vive test 3.315 seconds faster than those who used the Vive test first. This could show that the more familiar a participant is with the test environment the faster their times. However, it could also show that a participant can be better with one control method once they have had experience with another regardless of the differing two technologies.

7.3 Limitations

There are a variety of limitations to this project. The participants characteristics were not being recorded. This project is designed to assess control methods as a whole an not how individuals perform with them. Due to this it was decided to not ask participants for their personal data such as age, gender or sex. In hindsight, it could have been interesting to see how this data could have affected a participants performance. As well as this, the data would have shown the clear limitations of this project, for example all participants were selected from the in and around the Oxford area of the UK with the majority being selected from the Oxford Brookes Wheatley campus.

As this is a very small area it does not completely represent the results of the general public and without vigorous testing there would be a possible argument that where a participant is from could have an impact on their

results in the experiment. This could be especially true for the university staff and students as even though the majority of them were not considered VR users some of them said they have seen and tried VR before in demonstrations performed around the university on open days and similar events. This small amount of experience with VR could have effected the users results but more testing would be required to find out if this true.

The area that the participants were selected from can also suggest the average age of the participants. Most students start university after 18 years old due to how the schooling systems work and according to (theguardian, 2019) 70.9 percent of Brookes university students are 24 years old or younger. based on this it is fair to suggest that the majority of students who participated in this experiment would have been between 18 and 24. Brooke's staff on the other hand is most likely to be much more varied due to the different job roles and average ages associated with them. The main limitation for this is that with 65 being the normal pension age, according to (University, 2017). It would be fair to assume that it would be rare for participants to be over 65 years old. This would suggest that from the area that participants where gathered they would most likely fall between 18 and 65 years of age. This is a large range however it ignores the upper and lower limits of the general public's age.

Gender would also have been and interesting characteristic to measure and has been used before when assessing the real world medical dexterity tests that are used for medicinal purposes. (sralab, 2017) shows the results recorded when assessing the dexterity of a variety of participants using a Functional Dexterity Test (FDT) which is a style of peg test but is different to the 9HPT used in this experiment. The results show that in some cases a female participant could be on average 5.2 seconds faster than a male participant (sralab, 2017). As a participants sex was not recorded in this experiment, it can not be said if difference in time can be seen on VR control methods.

7.4 Hypothesis Summary

This section re-evaluates the hypotheses shown in the introduction chapter of this report, which are numbered from one to eight, to see if they were accepted.

All T-Tests performed in this study where conducted using the T-Test function provided by Microsoft Excel using a probability of 0.5 and an alpha value of 0.005 to determine whether or not the results were significant or not.

Hypothesis: 1

"There will be a significant difference in time between the first and second tests performed using a control method in the virtual environment"

Partially accepted.

The results of a two tailed T-test have shown that there is a definite significant correlation between tests A and B for the real world test, however, with the VR tests this is more ambiguous. For the Vive controllers there is a trend and potentially a significant correlation where for the Leap Motion there is a potential correlation but the variation is too vast to determine that it is significant.

Hypothesis: 2

"Real world test times will be the fastest"

Accepted

The Real World tests were the fastest times with an average of 12.56 seconds and the difference between the A-B tests for each participant were similar being on average 0.98 seconds. Both the sign test and a one-tailed T-test have shown that this hypothesis is not only true but can be considered significant.

Hypothesis: 3

"VR users will return the fastest times"

Partially accepted.

Regular VR users did record faster times with their average time being 22.846 seconds on the Vive controllers and 35.815 seconds on the Leap Motion. for comparison non-VR users recorded an average time of 34.285 seconds on the Vive controllers and 55.352 seconds on the Leap motion. However, as mentioned previously the only participant to have used the Leap Motion before the experiment was the only participant to record a DNF on the Leap Motion. As well as this there was not enough non-VR user data for either the sign test or the one-tailed T-Test for this to be significant.

Hypothesis: 4

"Participants will record faster times using the Leap Motion due to its more realistic and natural interface."

Rejected.

As shown in (6.1) participants performed worse on average when using the Leap Motion compared to the Vive controllers. This is also shown to be significant by both the sign test and the one-tailed paired T-Test.

Hypothesis: 5

"Participants will find the Vive controllers to be clunky and awkward to use for the task they must perform in this experiment "

Rejected.

None of the participants mentioned that they felt the Vive controllers clunky or awkward to use for this task.

Hypothesis: 6

"The order in which a participant performs the virtual tests will affect their times, for example, if a participant uses the Vive controllers first than their Leap Motion time will be faster as a result of becoming more adapted to the virtual test environment."

Partially accepted.

For participants who used the Vive controllers first they recorded an average time for the B tests on the Vive controllers of 26.68 seconds and 42.9 seconds on the Leap Motion. Participants who used the Leap motion first recorded a time of 48.9 seconds on the leap motion and 23.3 seconds on the Vive Controllers. In both cases the participants performed a faster time with there second control method when compared to participants who used that control method first. However, both the one-tailed T-Test and the Sign test results show that this is not significant, this is most likely due to the data set being too small for this type of assessment. This data can be seen in 6.3.

Hypothesis: 7

"Participants will figure out a technique for performing the task and this will result in the faster times for the later tests in the experiment"

Partially accepted.

Some participants were observed using a tactic in order to place the pegs in the holes as fast as possible which could have resulted in a faster B test, however, this was not recorded in a way which makes it measurable.

Hypothesis: 8

"Real world tests will be the fastest, Leap Motion tests will be the second fastest and Vive controllers will be the slowest."

Rejected.

The real world time was the fastest on average then the Vive controllers followed by the Leap Motion, this can be seen in (6.1)

Hypothesis	Test	Accepted	T-Test Tails	T-Test Result	Sign test result	Alpha	Significant
1	RW 1st vs 2nd	Y	2	0.001184482	2.82377E-06	0.05	Y
2	RW vs Vive	Y	1	3.43579E-05	7.45058E-09	0.05	Y
	RW vs Leap	Y	1	2.55202E-08	7.45058E-09	0.05	Y
3	VR vs Non-VR Vive	P	1	0.064215134	0.36328125	0.05	N
4	Leap vs Vive	N	1	0.00296471	2.46167E-05	0.05	Y
5	N/A	N				0.05	
6	Leap 1st	P		0.164014772	0.855	0.05	N
	Vive 1st	P		0.064875551	0.96484375	0.05	N
7	N/A	P					
8	N/A	N					

The table above shows the significance tests performed on each hypothesis and there results

8 Future Work

From the research performed in this study a variety of different possibilities for future work have been discovered. These range from improving the test itself to creating a control method designed specifically to completing this task.

The main task that would be beneficial for improving upon this study would be to expand the results. Performing the same experiment but on a larger scale and with a larger variety of control methods would provide more conclusive results. From these results it would be clearer as to whether or not dexterity can be used as a definite measurement of a control methods ability. More data would provide more realistic averages for each test and using a larger variety of control methods would allow for a clearer idea of what style of control method is considered the current best for the style of task seen in this experiment.

If this test was to be repeated again with a larger variety of control methods it could be possible to use the best performing control methods in another study in which the participants are to use the dexterity test which dimensions are the same as the medical dexterity test. For the control methods used in this experiment this was not possible as they were not accurate enough however it is certainly possible that there are a number of control methods available that are capable of performing the true medical dexterity test in a feasible time.

Another opportunity for future work would be to ask a similar pool of participants to perform the same experiment multiple time in order to better understand and measure the learning effect seen in this study. This study could be performed in a variety of different ways in order to see how a learning effect changes depending on the order the tests in the experiment are performed. On way to measure the learning affect would be to ask

a third of the participants to perform one style of test multiple times a day for a number of days and analyse the difference in learning curves associated with each. Another style of learning effect that could be measured would be to ask participants to perform the virtual test a number of times a day for a number of days half of which with the Vive controllers and the other half of the participants to use the Leap motion then ask them to perform the real world experiment and see if their times are faster than average. This test could also be performed in the opposite way to see if participants can perform better in VR once they are more familiar with the real world environment. How participant learn can open up for almost endless possibilities in research each worthy of their own study.

It would be interesting to see a the results of a control method that was specifically designed to perform the task used in this experiment. a control method such as this could debunk the theory of dexterity being used for measuring control methods ability. Questions could be asked as to how much dexterous aid can be given to control method before it is no longer a challenge to perform the task used in this experiment. However, it would be important to ensure that the control method designed would not be automating the task just providing the user additional aid in completing the task themselves.

9 Conclusion

In conclusion the results show that dexterity can be used as a means to measure and compare the performance of VR control methods. It is clear from this study that the real world results are consistent and accurate as on average a participant could perform the real world test in a time between twelve and fourteen seconds. The real world times can be considered a gold standard for VR control methods in this task. If a control method can consistently complete the task used in this experiment in a time under fourteen seconds (provided the same conditions were used) than that control method could be considered to be as dexterous as our hands in the real world when performing this task.

The experiment designed in this study cannot, however, be used to claim that a control method is completely comparable to our real world hands. Whilst this experiment may provide a good insight into how realistic a control method can be, that task involved is too specific to be completely transferable to all tasks that require dexterity. Too gain a true answer to whether a control method can be as accurate and as controlled as our hands than there would have to be a variety of tasks involved in the experiment. This experiment can however be used as a base test that, if passed, will show that a control method shows promise and will need further testing.

As well as showing a gold standard for control methods to meet, this experiment has also shown that a control method does not need to be as dexterous as our real world hands in order for a user to consider it not only usable but preferable. As noted previously even though all twenty-seven participants used in this experiment recorded their slowest time, on average, when performing the Leap motion test, fourteen out of the twenty-seven participants said that they preferred using the Leap motion over the Vive controllers. While this is not a statistical majority it is still interesting to

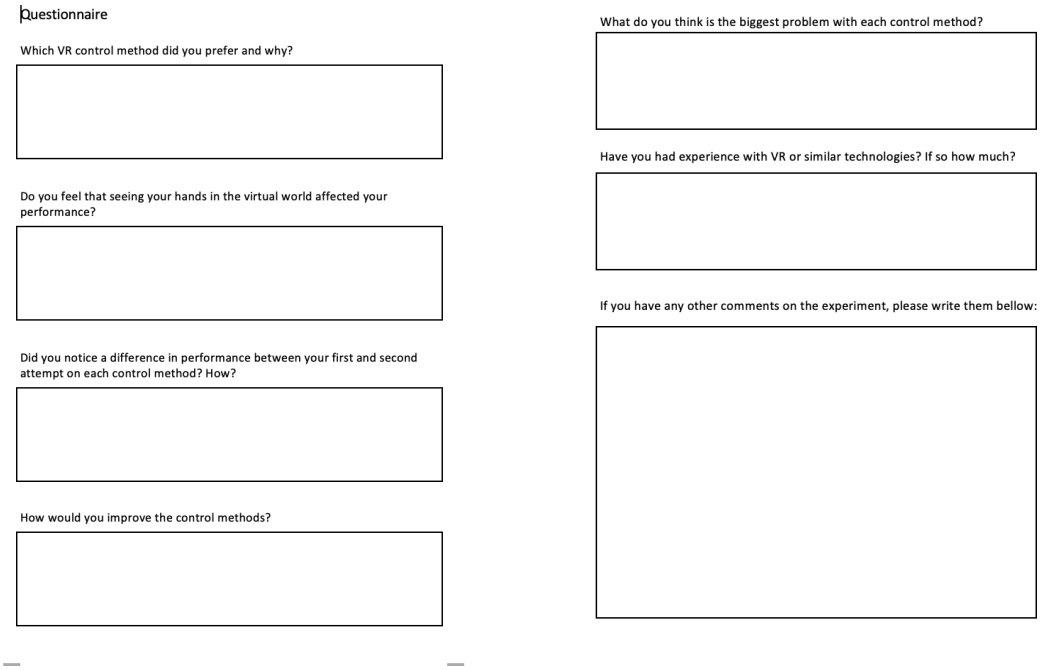
note that this number of the participants used in the study preferred the control method that they recorded slower times on. This shows that making a control method that can perform this task as quickly as possible would not necessarily make that control method realistic. It would potentially be possible to design a control method that could perform this task in a time faster than those that were recorded from the real world tests, however, this control method would most likely not resemble a user's real world hands.

From this it is theorised that people who are willing to use these technologies are excited to see how realistic they can become, the main step in this process is making the control methods look the part. Once interaction with virtual control methods resembles the way in which interact with the real world it is then that control methods must be perfected to be as fast, accurate and dexterous as our hands. The fact that a control method can perform this experiment faster than any other is essentially irrelevant if VR users are not interested in using the control method outside of a research study. The true benchmark test for control methods would resemble a sort of Turing test in which a participant would have to not be able to feel any difference between their interactions in the real world and those made in the virtual world. For the current stage that control method technologies are at during the creation of this study it would not be feasible to expect any of them to pass such a test. Instead it may be more realistic to design control methods for specific tasks. For example, if a Virtual environment is required to train a person for a job that requires the use of specific tools than it may be more advantageous to design a control method that allows the user to interact with the virtual world in the same manner they would in the real world.

Once commercial control methods can resemble our hands in look, feel, dexterity, speed and accuracy than it viable to create training tools solely in a virtual environment. For this to be the case haptic technology would have to be integrated into the control method to allow a user to actually feel a virtual object.

10 Appendix

10.1 Questionnaire


Questionnaire

Which VR control method did you prefer and why?

Do you feel that seeing your hands in the virtual world affected your performance?

Did you notice a difference in performance between your first and second attempt on each control method? How?

How would you improve the control methods?

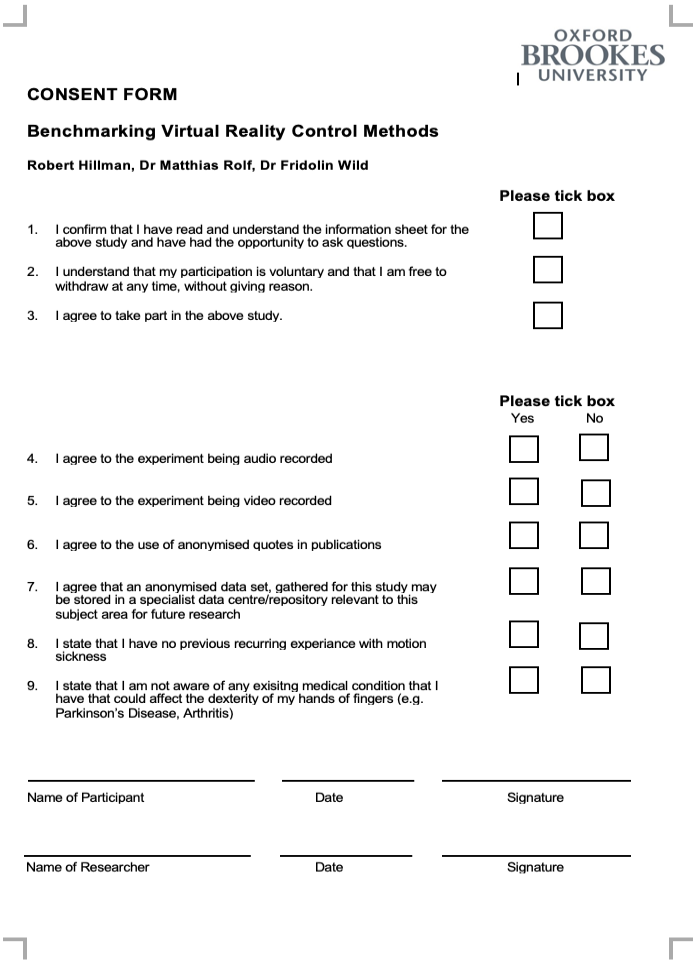
What do you think is the biggest problem with each control method?

Have you had experience with VR or similar technologies? If so how much?

If you have any other comments on the experiment, please write them bellow:

Figure 10.1: Questionnaire participants filled in after the experiment

10.2 Consent Form



OXFORD BROOKES UNIVERSITY

CONSENT FORM

Benchmarking Virtual Reality Control Methods

Robert Hillman, Dr Matthias Rolf, Dr Fridolin Wild

		Please tick box
1.	I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.	☐
2.	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.	☐
3.	I agree to take part in the above study.	☐

		Please tick box Yes	No
4.	I agree to the experiment being audio recorded	☐	☐
5.	I agree to the experiment being video recorded	☐	☐
6.	I agree to the use of anonymised quotes in publications	☐	☐
7.	I agree that an anonymised data set, gathered for this study may be stored in a specialist data centre/repository relevant to this subject area for future research	☐	☐
8.	I state that I have no previous recurring experiance with motion sickness	☐	☐
9.	I state that I am not aware of any exisitng medical condition that I have that could affect the dexterity of my hands of fingers (e.g. Parkinson's Disease, Arthritis)	☐	☐

Name of Participant	Date	Signature
Name of Researcher	Date	Signature

Figure 10.2: Caption

10.3 Information Sheet

OXFORD BROOKES UNIVERSITY

Benchmarking Virtual Reality Control Methods

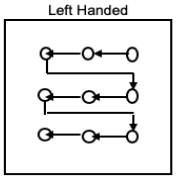
You are being invited to take part in a research study during July/August 2019 at the Oxford Brookes Wheatley campus. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?

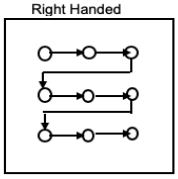
This study aims to assess and compare the results of Virtual Reality (VR) controllers on the given task. The results provided by this study will be published in a report that aims to outline the advantages and disadvantages of different control methods. The experiment that participants will be asked to take part in involves preforming a modified dexterity test both in the real world and on multiple controllers in VR.

The test consists of a participant being seated in front of a wooden board with 9 evenly spaced holes in a grid pattern. 9 pegs will be lined up next to the board on either the left or right hand side based on the dominant hand of the participant. The goal of the participant is to place all 9 pegs into the 9 holes in the board. This task must be completed with the participant's dominant hand and must be performed in the following order:

Left Handed



Right Handed



This test has also be recreated in VR and participants will be asked to perform the same test in the virtual world with a variety of control methods. On average the real-world test takes no longer than 20 seconds and the virtual test no longer than 60 seconds. However, participants will be given 5 minutes to complete the task for each of the tests, the total for all experiments taking no longer than 30 minutes. The time taken to complete each test will be recorded anonymously as only the controllers are being assessed not individual's times. Participants are advised to take breaks in-between tests as to prevent VR sickness, a form of motion sickness, these breaks will not be timed. The tests will also be performed in a random order as to account for a learning effect

Figure 10.3: Information sheet page 1

Why have I been invited to participate?

This study aims to record the results of 30+ participants from a variety of backgrounds with no intentional biases towards race, age or gender. You will be selected to take part in this study due to handing in an application with an attached consent form. Participants will also be selected due to having no existing medical conditions that could affect finger/hand dexterity (such as Parkinson's disease or arthritis) or if they have cases of motion sickness prior to the experiment as these factors could have an effect on the results of the test or your health.

Do I have to take part?

It is up to you to decide whether or not to take part in this research study. If you do decide to take part you will be given this information sheet along with a privacy notice that will explain how your data will be collected and used, and be asked to give your consent. If you decide to take part, you are still free to withdraw at any time during the experiment and without giving a reason.

What will happen to me if I take part?

You will be asked to perform the tests explained on the first page of this information sheet and your time will be recorded for each of the tests. This data will be stored anonymously in a database from which it will be analysed to draw the conclusions for the overall study. After completing the tests, you will be asked to fill in a short questionnaire describing your experiences with the different control methods. As well as your recorded results, video of you preforming the tests may be taken (with your given consent) for use as visual representations of the experiment in the report. Recorded video may also be used in and presentations or demonstrations about the project. You, as a volunteer, have the ability to withdraw your consent for both use of video and use of your results at any point post the experiment until the final research paper has been submitted on the 1st of October 2019.

What are the possible disadvantages and risks of taking part?

The biggest cost involved in taking part in this experiment would be your time. The individual tests will be relatively quick however each participant will be required to perform a variety of tests. You are advised to arrange your experiment for a time that suits you and please allow for at least 1 hour of experimentation time. There are very few risks involved in preforming the experiment however the most likely potential problem that could arise during the experiment would be VR sickness. VR sickness is similar to motion sickness and is caused when a person can see the world moving around them but their body feels as if it is staying still. The symptoms of VR sickness are as follows; *general discomfort, headaches, stomach awareness, nausea, vomiting, pallor, sweating, fatigue, drowsiness, disorientation, and apathy.* If you as a participant experience any of the listed symptoms you are advised to immediately remove the VR headset so you can be directed by a researcher to a safe location where you can rest. If this situation does occur the experiment will terminated and your results will not be used. Any participants who have a previous history of motion sickness must inform the researcher and are not advised to take part in this experiment.

What are the possible benefits of taking part?

As a participant in this study you will be directly supporting the VR field of research. VR is an ever expanding technology with vast amounts of research on headset. However there is little research on the different types of control methods used in VR and how they compare. Your results help grow the amount of research on this topic and will most likely result in the discovery of more research questions in this field.

Figure 10.4: Information sheet page 2

Will what I say in this study be kept confidential?

All data will be stored in a database with complete anonymity by replacing the participant's names with randomly assigned numbers which will act as an ID. No personal data will be stored in this database only the test results and the test ID as previously mentioned. Once the experiment has been completed all consent forms will be photocopied and stored in an encrypted folder and all hard copies will be kept secure. The final results will be published in the form of a dissertation and could potential be used in presentations post publication.

What should I do if I want to take part?

Email Robert Hillman at:
18083100@brookes.ac.uk

With "VR Experiment" followed by your full name as the subject of your email.
Robert can also be found in room at the Oxford Brookes Wheatley campus in room B212 weekdays from 9-5.

What will happen to the results of the research study?

All results obtained from these experiments will be used for the evaluation of the control methods. No results will be used outside of the scope of this research and will mainly be published in a written thesis for a MSc by Research. Some results may be shown and presented at conferences, in which case all data show will be kept totally anonymous from viewers/readers. A copy of the final written thesis can be requested via email by contacting Robert Hillman at 18083100@brookes.ac.uk from October 2019.

Who is organising and funding the research?

This research has been organised and funded by master's student Robert Hillman with the advisory assistance of Dr Mathias Rolf and Dr Fridolin Wild for department of Technology, Design and Environment.

Who has reviewed the study?

This research has been approved by the University Research Ethics Committee, Oxford Brookes University.

Contact for Further Information

For any further information about the study the emails for the researches on this project are listed below:

Robert Hillman:
18083100@brookes.ac.uk

Matthias Rolf:
mrolf@brookes.ac.uk

Fridolin Wild:
wild@brookes.ac.uk

If you have any concerns about the way in which the study has been conducted contact the Chair of the University Research Ethics Committee on ethics@brookes.ac.uk.

Thank you for taking time to read this information, please feel free to volunteer for this experiment if it interests you.

Figure 10.5: Information sheet page 3

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