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A comparative study of virtual reality hand-tracking and controllers

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Bachelor’s Thesis | Abstract

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A comparative study between virtual reality hand-tracking and controllers

In recent years the popularity of virtual reality has grown immensely and with it have come some interesting technologies such as hand-tracking. Even though the virtual reality genre is still dominated by the standard input system, the controller, whether it is for entertainment or educational purposes, there seems to be a growing desire for alternatives.

The goal of this Bachelor’s thesis was to find and compare the advantages and the disadvantages of the controller and hand-tracking. The theoretical part of this paper includes topics such as what is virtual reality, hand-tracking and what devices can utilize it and the requirements for the practical part.

The practical part includes topics like the implementation, the player interview analysis and the in-game data analysis. For the purposes of this thesis, two identical games were created, one supporting controllers and the other one supporting hand-tracking. The game takes place in a ship’s control room and the player is given a set of tasks that need to be completed. While the participants were playing, their in-game actions were video recorded and once they finished playing, the participants were interviewed. According to the data, hand-tracking has a competitive advantage over controllers. Out the of nine participants, close to 90% of the players felt one of the positive experiences of hand-tracking is the freedom and the natural feeling of it.

Keywords:

virtual reality, hand-tracking, controllers, oculus quest

Contents

List of abbreviations

2D	Two-Dimentional
3D	Three-Dimentional
GB	GigaByte
HMD	Head-Mounted Display
Hz	Hertz
LCD	Liquid-Crystal Display
SDK	Software Development Kit
VR	Virtual Reality
WiFi	Wireless Fidelity

1 Introduction

One of the innovative technologies in the virtual reality (VR), sector is hand-tracking. The standard input devices for VR headsets were and still are the controllers, however the invention of hand-tracking has given a new alternative to the user. Instead of having to use handheld gadgets, the VR device creates virtual hands that can be used as input devices, giving the user much more freedom.

Hand-tracking is a new technology and with it come creative ways of interacting within a VR environment. However it still faces many issues. On the contrary, controllers have been consistent , thought progress has been stagnant.

The objective of this bachelor's thesis is to find and analyze the advantages and disadvantages of hand-tracking and controllers, with a focus on proving that hand-tracking can be a valid alternative in either an educational or entertainment setting.

The first chapter is all about virtual reality. It contains information about the history of VR, its modern day uses, hand-tracking technology, how controllers work and the latest VR devices with hand-tracking and controller support. The following chapter presents two game engines, namely, Unity and UnrealEngine and why one was selected over the other. The Requirements chapter, the final theoretical chapter, discusses about the game scenario, the controls and the interactions. Next is the Implementation chapter, where the practical part starts. This chapters documents about how the movement and interaction systems for each version was created. The Interview Data chapter is dedicated to analyzing the answers of the participants and the In-game Data chapter is dedicated to the analyzing of the actions that the participants took during the playthrough. Afterwards comes the Critical Analysis & Improvements chapter, as the name suggests this chapter reflects on some of the difficulties faced, the potential improvements and changes that could be made. Finally, the Conclusion contains the verdict of the thesis, the future of hand-tracking and the improvements.

2 What is virtual reality

2.1 History of virtual reality

Virtual Reality refers to computer generated scenes that are created with the use of VR devices and cutting-edge technology. A user can experience a three-dimensional, also known as 3D, world that resemble the real one. These genereated scenes are projected to each eye separately. Projecting a different image to each eye creates the sense of 3D, which further immerses the player into the VR environment. Most VR devices utilize additional gadgets that allow the user to give more input to the VR device. The gadget can be controllers or tool-shaped devices where the controllers can be mounted on or attached to the controller. [1]

The first VR device was invented in 1838 by Sir Charles Wheatstone, the creator of the stereoscope, a device possesing a slot where the user could swap in and out paper discs that contained 2D, two-dimensional, pictures that turned into 3D looking pictures while looking into the device. Almost a decade later, in 1935, Stanley Weinmaun wrote the Pygmalion’s Spectacles, a science fiction story about a person who is given a pair of goggles by a professor which allows the main character to see and interact with a movie. In 1956, the first machine capable VR was created by an American cinematographer, Morton Heilig. He called it Sensorama. By using of scent producers, chair vibration, stereo speakers and a stereoscopic 3D screen, the users were able to experience 3D video, audio, smell and vibrations during the short films that were created for the Sensorama. Heilig also created the first head-mounted display, also known as HMD, the Telesphere Mask, in 1960. Finally, in 1968, the first HMD with virtual reality abilities was created by Ivan Sutherland and Bob Sproull, their creation displayed a 3D models that changed the viewing angle if the user rotated their head, however the project was discontinued due it being cumbersome to wear. A few years later, in 1975, the first interactive VR device was created by VIDEOPLACE. In 1985, VPL Research, Inc was the first company to sell VR goggles and gloves that were used to interact with the environment. Soon after, in 1991, Sega stepped into the industry, Sega promised to be the first company to bring VR to consumers in a large scale, with the Sega VR headset. It was a visor with LCD, which stands for Liquid-Crystal Display, screen, headphones and inertial sensors that trackeded and reacted to the user based on their movement, though it was never released. In the same year, Virtuallity was the first company to create a VR device that had network and multiplayer capability whilst also being the first to mass-produce their product. At the end of the 20^{th} century and the start of the 21^{st} VR innovation stagnated with the exception of Googles Street Viewer function that gave the ability to look at panoramic views of the world. It was not until 2010, that the prototype of Oculus Rift my Palmer Luckey was created. It possessed a 90 degree field of view, which was never seen before. Not long after, in the video game trade show E3, the Oculus Rift receives its grand revealing and in 2012 Oculus VR is bought by Facebook. In 2015 HTC and Valve teamed up to create the HTC Vive, which included the “Lighthouse” technology. The “Lighthouse” is a device that contains “wall-mounted” or “tower-mounted” sensors that track the position of the user. The most recent VR devices include the Oculus Rift S and the Quest series, where both have sensors built-in the VR headset that allow for the controller and finger tracking without additional tools and the Valve Index that posseses similar features but with a wider field of view of 130 degrees. [2]

2.2 Uses of virtual reality

Virtual reality has an extensive history in the entertainment industry, some examples of entertainment is, the award winning Half Life: Alyx, a game created by Valve, the prequel to the legendary Half Life series. The game lives up to its predecessors, giving the genre of horror a whole new meaning, with its eerie and spine-chilling but also breathtaking moments and making supernatural physics feel quite realistic. [3]

One of the most, if not the most popular VR games is Beat Saber. The concept is simple: the player’s controllers turn into glowing swords of light, also known as light sabers, that are used to slice boxes that are flying towards the player in the rhythm of a song. The boxes have arrows that indicate the direction that they are supposed to be sliced and each successful slice gives the player a random amount of points. Beat Saber can be used as an exercise game that can match the player's limits depending on the pace of a song. [3]

VR has made major strides and with it has brought with it new and innovative ways of teaching. Using VR to teach medical students about human anatomy, the students are able to conceptualize the human body/organs and have shown that the knowledge acquired in VR is easily applied to real patients. Additionally, the same applies to students that have learned to perform surgery in a VR simulation and it has also proven to be much less costly. [4,5]

The military has been one the greatest beneficiaries of the VR technology. Countries all over the world are using VR to individually train soldiers or in a small group setting. It has been used to train soldiers to drive all types of military ground vehicles, aircrafts and watercrafts. In addition, it has lowered the potential real life harm that a person could suffer. It has also been theorized to become a great tool for military strategy planning and visualizing various outcomes[6].

Due to the COVID-19 pandemic, physical meetings became close to impossible. A modern day solution was created for a modern day problem, VR meetings. VirtualHive, Avatour, Hyperfair are some of the names of the new sites/apps that were created for the sole purpose of meetings but they did not stop there, many of the VR meeting providers also allow their users to customize their VR avatars, allow for full fledged VR convention-like halls for presentations, job fairs and interviews.

2.3 Hand-tracking

Hand-tracking is a new technology that not many VR devices are capable of, the only ones are the Quest 1 and Quest 2 created by Meta, Varjo by Varjo and the Vive Focus 3 by Valve. All the previously mentioned devices work in a similar fashion; they have cameras on the outside of the device that capture the user's hands and their hand movements, after which a 3D model is created in the VR environment that mimics the user's real life hands, these virtual hands are used to interact with the VR environment.

There are also VR headset accessories, such as the Ultraleap Stereo IR 170, that enables had tracking on devices that do not normally supports it. [7]

Each device has their own unique way of operating, for example, the Oculus Quest primarily uses the pinch gesture to do certain actions, whilst the Varjo device uses both pinch and grab to interact with apps and/or buttons. The most important pieces of hardware for Hand-Tracking are depth perception cameras, the field of view camera capabilities and powerful enough equipment to match frame rate with real life speed. Without accurate depth perception, the whole concept of Hand-Tracking falls apart, inaccuracy will plague the device. The field of view of the cameras is recommended to be wider than the device's display, for the hands to be loaded before they appear in front of the player. Lastly, it is essential for the frame rate to be high, for it to match the speed of real life movements and to not cause motion-blur. [8]

Some of the issues that hand-tracking faces are the accuracy of the movement/position/gesture in low light settings, therefore it is recommended to use hand-tracking in well lit rooms, thought Varjo does not have to deal with such an issue due to it having built in lighting to illuminate the player's hands. Quick movements were also disincentivized because they could be the cause of inaccuracy and lastly, when a player's hands left the field of vision of the cameras it could cause inconsistencies. However, the creators of Varjo on the 7th of May 2021 released their new neural network, the Gemini, which can generate dynamic digital skeletons of the user's hands. Gemini fixed two major issues, the initialization and the interaction between the hands, the initialization is fixed by generating the virtual hands before they come in to the player's view therefore reducing inconsistency and with the help of the robust hand models the interactions between the two hands is better than ever. [8]

On the 28th of April 2022 Meta released their experimental version of Quest 2's Hand Tracking 2.0, saying "a new method of applying deep learning to better understand hand poses when the device's cameras can not see the full hand or when the hand is moving quickly". Meta claims this new version of hand-tracking technology is able to handle fast moving hands and two-hand interactions. [9]

Table 1. Available VR devices capable of hand-tracking

Device Name	Hand-Tracking Support	Controller Support
Oculus Quest 1	Yes	Yes
Oculus Quest 2	Yes	Yes
HTC Vive Focus 3	Yes	Yes
Varjo	Yes	No
Pico Neo 3 Pro	No but can with accessory	Yes

2.4 Controllers

Controllers have always been the main gadget to use to manipulate or interact with interfaces or games with VR devices. Controllers tend to be wireless and have to be either charged with a wire or use batteries. Controllers do not have a standard model, therefore each VR device has its own unique shape. They usually have buttons on the frontside that can be pressed to either activate a certain feature, like open a main menu or settings screen, or to interact with interfaces and on the backside they have trigger shaped buttons that have their own set of interactions. [10]

2.5 Latest Virtual Reality Devices

The Meta Quest 2, previously known as Oculus Quest 2, is the latest VR headset by Facebook. The Quest 2 operates with an android variant operating system when used in its standalone capacity and when it is connected with a cable or Wireless Fidelity, WiFi for short, to a personal computer, it operates under the Oculus VR operating system. The standalone version can be operated with either controllers or hand-tracking, the Oculus VR can only be operated with controllers. The Quest 2 has two models, the base model has 64 GB, short for GigaByte, of storage and the more expensive model has 128GB of storage, also it only is sold in one color variant which is white. It has a display of 1832x1920 pixels per eye and has a refresh rate of 120Hz, short for Hertz. It contains four integrated cameras that are used for play area detection and hand-tracking. [11]

The predecessor of the Meta Quest 2 is the Meta Quest 1, which is also made by Meta. The Meta Quest 1 operates with an android variant operating system while on the standalone mode that can be operated with either hand-tracking or with controllers. Just like its the successor, it can be connected to a computer via cable or WiFi and the Oculus VR operating system which can only be operated with controllers. Its refresh rate is 72Hz, the resolution is 1440x1600 pixels per eye and the it contains four integrated cameras that are used for the detection of the play area and for hand-tracking. It can be purchased with either 64 or 128 GB of storage and it is only available in the colour gray. [12]

The HTC Vive Focus 3 is a VR headset by Valve, it operates with an android variant operating system and can be operated with either hand-tracking or controllers. The HTC Vive Focus 3 can be operated in a standalone fashion or can be connected to a computed via WiFi and by using the Vive Business Streaming application. It possesses four integrated cameras for hand-tracking, its refresh rate is set to 90Hz, the resolution for each eye 2448x2448, contains 128 GB of storage and it can only be purchase in the colour black. [13]

The Varjo XR-3, which was created by Varjo, can only be used via connecting it to a computer and it can be operated using hand-tracking. It contains six cameras for the purpose of hand-tracking. Its display refresh rate is 90Hz, the display refresh rate is set to 90Hz and as it is a computer power VR headset it does not contain any storage. It can only be found in black colour. [14]

The Pico Neo 3 Pro Eye made by Pico Interactive, operates with an android variant operating system that can be operated with controllers by default. Mounting the Stereo IR 170 by ultraleap it enables hand-tracking capabilities for the Pico Neo 3 Pro eye [15.]. It can used in standalone fashion or can be connected to a computer with WiFi. It contain 128 GB or storage, its refresh rate is set to 90Hz and the resolution display is 1832x1920 per eye. It can be purchased in either black or white colour [16.].

3 Game Engines

3.1 Unity

Unity is a game engine created by Unity Technologies, it can host a multitude of game platforms, such as mobile, computer, console and many more. Unity has three-dimensional, two-dimensional and virtual reality game creation capabilities, not only that, it is able to create high-definition animation. Unity has been used to create animations for vehicles such as the Volkswagen ID.4 EV and software like Hyundai's Smart design. It has been used to create Honda's FIT Virtual world and multiple virtual reality driving simulators. The animated video "The Heretic" went viral in January of 2020, showcasing Unity's capabilities accumulating 4 million YouTube views and garnering praise. The popular children's movie Wallace and Gromit by Aardman Animations was also created with Unity and many series such as Zeze Zebra, Leolina - The Kid Astronaut, Big Dinosaur and Magic and Machines. Lastly, IV studios created Nike Avatars, which were four different ads for a new "video-game themed" shoe collection. Whilst Unity is free to use, the free-to-use does have limitations. Once an app or game created with Unity reaches over $200.000 in annual revenue, Unity Technologies requires the developer to subscribe to the Unity Pro. [17]

3.2 Unreal Engine

This chapter is about the game engine Unreal Engine, a free-to-download programme mainly used for the creation of video games. It was first created in 1998 by Epic Games and its main programming language is C++. Unreal Engine takes advantage of the new ray-tracing technology, on top of that having advanced dynamic shadow options, screenspace and true 3D reflections, versatile lighting tools, and a flexible node-based material editor. Creating multiplayer games is made easy with its customizable and vigorously tested client/server architecture that can be added instantly to any project. Whether a amateur or a professional, Unreal Engine has a robust GitHub repository that contains C++ code that can be applied to any project, customized, add further code to it or just simply to be studied, Epic Games continually update the code and add new code that they themselves use on their own games. Lastly, for those who are more artistically inclined, the Unreal Engine contains great features to make game creation easier and streamlined, “Blueprints” is a sort of plug-and-play system that allows the user pick and choose interactions, customize user interface, modify input controls, and many other features. Unreal Engine can also be used in film and animations, with its in-camera visual effects, virtual scouting tools, tablet-driven virtual cameras and multi-user controls. With the aforementioned ray-tracing technology, real-time compositing, post-process effects, and advanced particles, physics, and destruction the user can create real-time photorealistic live-action or animations. [18]

3.3 Engine choise

The reason why Unity was picked over Unreal Engine. Simply put, Unity has much more publicly available resources, be it official or from a 3rd party. Plug-ins that make VR integration instant and the large community of programmers publishing their code or solutions to common problems is unmatched. Furthermore, Unity uses the C# programming language, while UnrealEngine uses the C++ programming language, this forces anyone using UnrealEngine to do memory management, a factor that Unity usually does not have to deal with.

4 Requirements

This thesis topic was given to the author by the Turku Game Lab. At the time of the request the only available VR device capable of hand-tracking was the Oculus Quest 1. The commissioner, Sami Laukkanen, requested for the use of the Quest 1 for the purposes of the thesis.

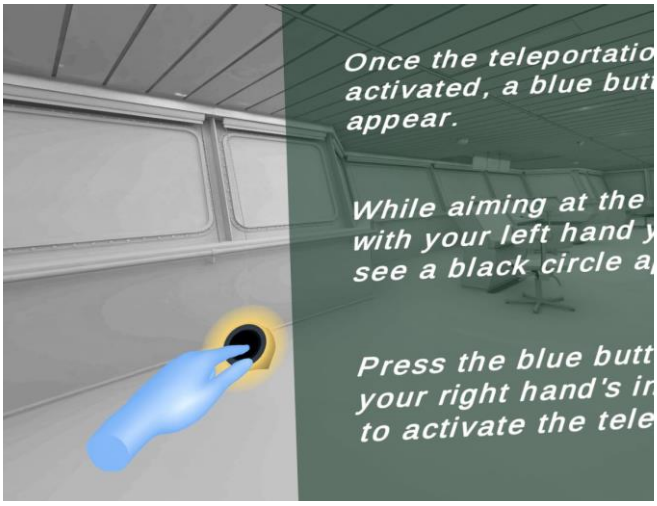
4.1 Game Scenario

Before being able to start working on the game, a few details had to be expanded up on first. The game had to be able to be played with both hand-tracking and controllers. The playthrough had to be identical to the other and the tasks given to the player had to have the exact same goal. The total amount of tasks was four and the player had to complete the current task for the next to become available (Picture 1). Another requirement was to have the ability to video record the a player’s perspective.

Picture 1. Red square indicates the starting position, numbers indicate the task location and order.

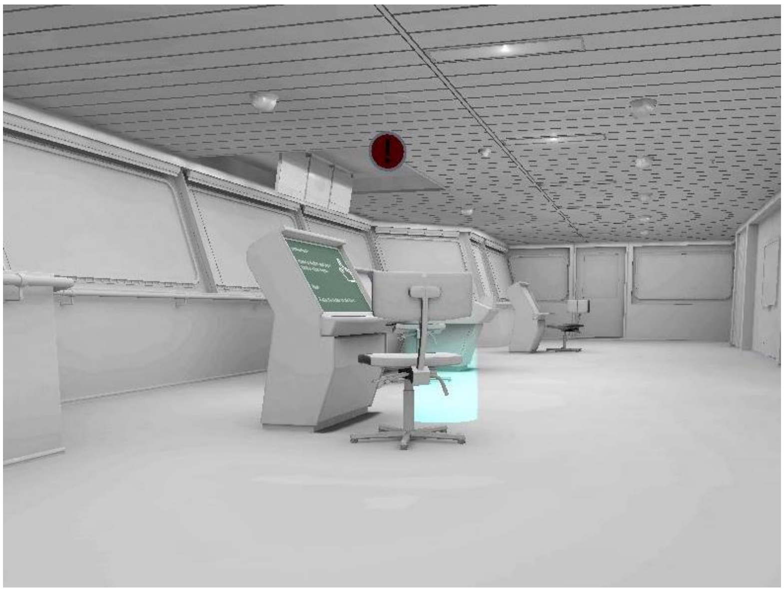
The game takes place in a ship’s control room, the ship asset was previously used in a different project and it was provided by the Turku Game Lab for the purpose of this bachelor’s thesis.

The player starts in the leftmost corner of the room, where they are greeted with a tutorial on how to move around. After the player has tried to move at least once, they instructed to press the button nearby. Once the button is pressed, the official tasks become available (Picture 2).



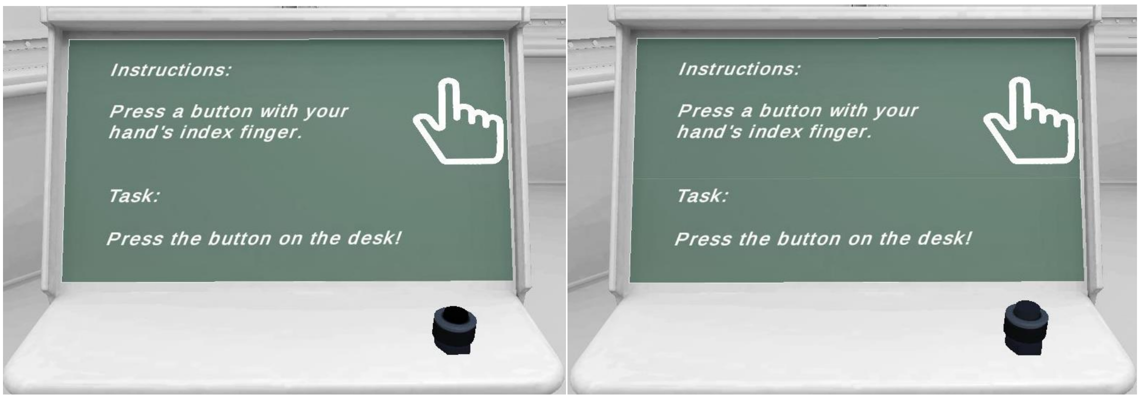
Picture 2. The player pressing first button

The player needs to able to know where the following task is located, therefore it was essential for there to exist indicator to allow the player to find the task with zero difficulty. Next to every uncompleted task is a blue coloured circular column to guide the player in the best position for them to complete the task and above the task there is a red and black exclamation sign that blinks to indicate that the task is not complete (Picture 3).



Picture 3. Players perspective of Task 1 and indicators.

The player’s first task is to once again press a button but as seen in picture 2. this time their path to the task is obstructed by a chair therefore they are forced to make multiple positional adjustments to get near the task area. Each task has its own set of instructions for how to complete it and what the the task is (Picture 4).

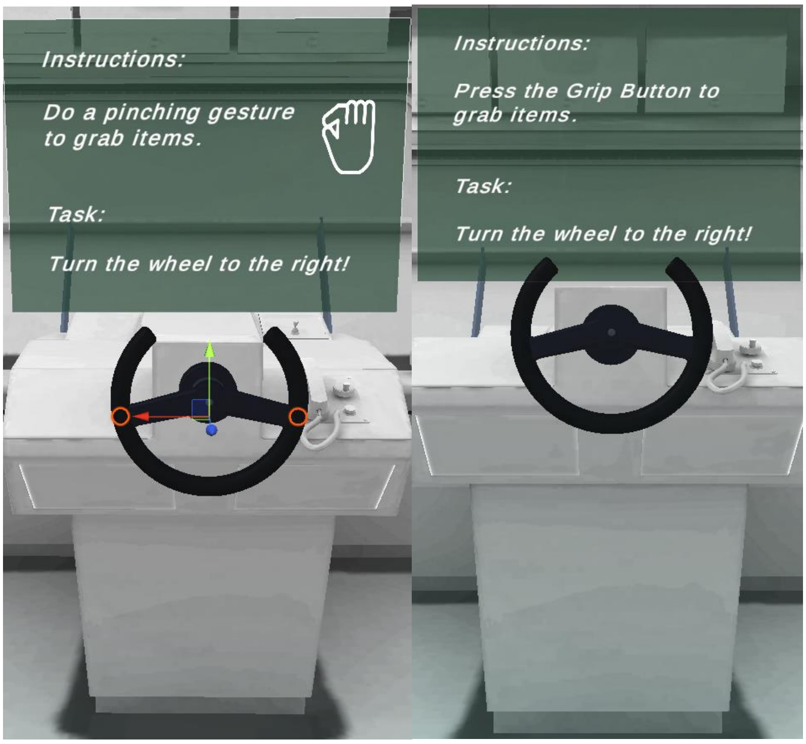


Picture 4.Hand-tracking(left) and controller(right) button task.

When a task is completed a green check mark sign appears as confirmation to the player (Picture 5).

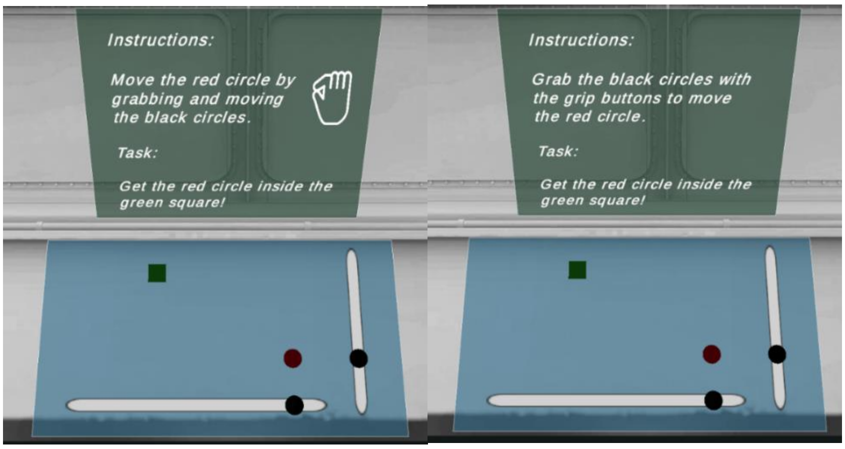
Picture 5.Completed Task 1 and green indicator.

The second task is the steering wheel, where the player needs to grab and turn the wheel. The wheel contains two grab locations, in case the player wants to turn it with one hand or both (Picture 6).



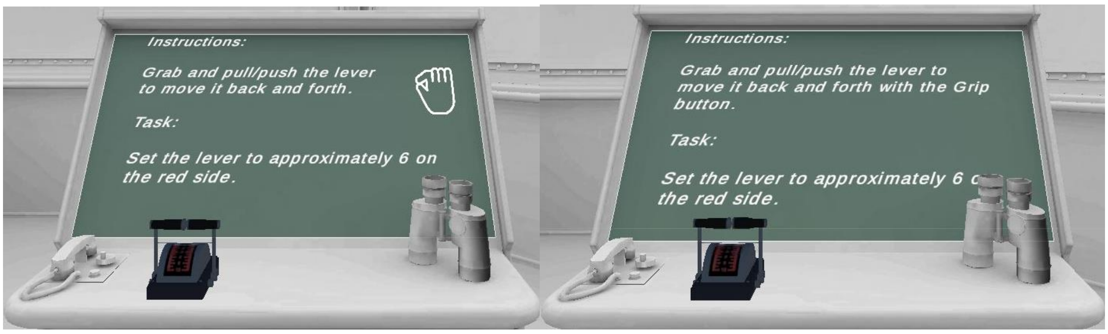
Picture 6. Hand-tracking(left) and controller(right) wheel task.

The third task is the slider game, where for the player needs to get the red circle inside the green square by grabbing the black circle on the sliders. The horizontal slider moves the red circle to the left and right and the vertical slider moves it up and down (Picture 7).



Picture 7. Hand-tracking(left) and controller(right) slider task.

The forth and final task, the lever. The player needs to grab the lever and pull it downwards and set it to 6 (Picture 8).



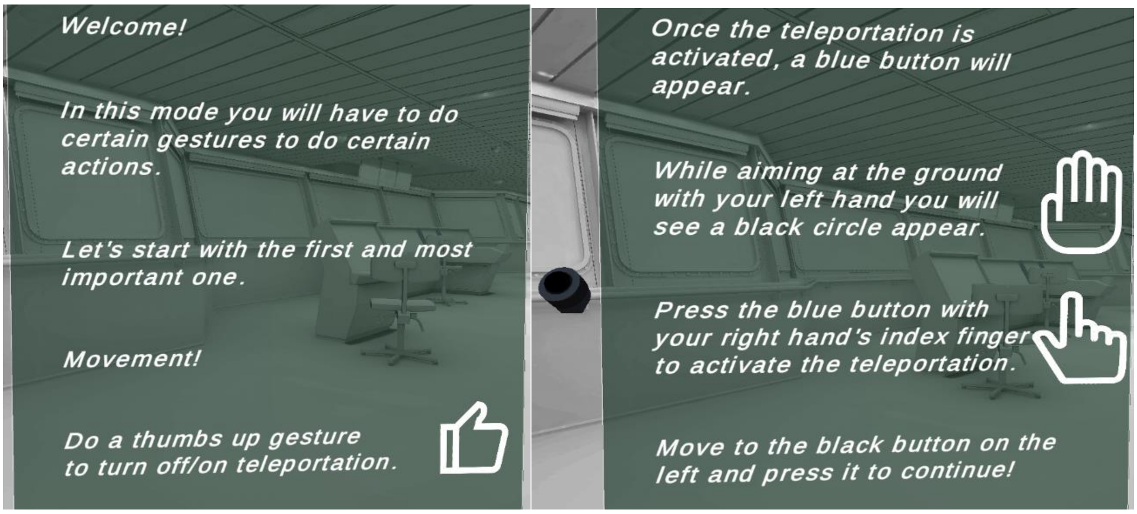
Picture 8. Hand-tracking(left) and controller(right) lever task.

4.2 Controls

The requiremements for the the controls were being able to move around while stationary, grabbing or holding an object and being able to press buttons. Using the Oculus Quest as the VR headset meant that installing the Oculus Integration plug-in was a no-brainer. The plug-in contains many basic functions such as grabbing, buttons that can be assigned to do anything a programmer wants and many examples scenes that can be used for testing purposes. It also makes enabling basic functionality for hand-tracking and controllers as easy as dragging and dropping them in the game scene.

4.2.1 Hand-tracking

Tackling the movement system for hand-tracking proved to be harder than expected. The point of VR is to be immersive, therefore the movement needs to be immersive aswell, it can not be intrusive or complicated and it has to happen smoothly. Hand-tracking does not have a standardized way of moving, as many hand-tracking games are meant to be played stationary while either sitting or standing, therefore movement system had to be created. While, there does not exist a standardized way of moving with hand-tracking, one exists for controllers and that is with teleportation. The only way for the player to interact with the inveronment is with their hands, the easiest way to create a movement system would be with gesture detaction. A few iterations of movement were created. The first iteration was, if the player opened their palm and closed it, then they would be teleported wherever their hand was pointing to. This was an unsatisfactory way to moving due to hand disappearance and lighting inconsistency the accuracy would suffer by either teleporting to the wrong location or the teleportation would activate when not wanted. The second iteration worked similarly to the previous iteration however the teleportation worked with one hand activating the teleportation and the other would point to the wanted location. The final interation was an improvement of both the previous ones. The player could activate teleportation with a simple thumbs up gesture. This movement system ensured that the player would not accidentally teleport, they would only need to remember a single gesture and that it was simple enough to get used to after only a few tries (Picture 9).



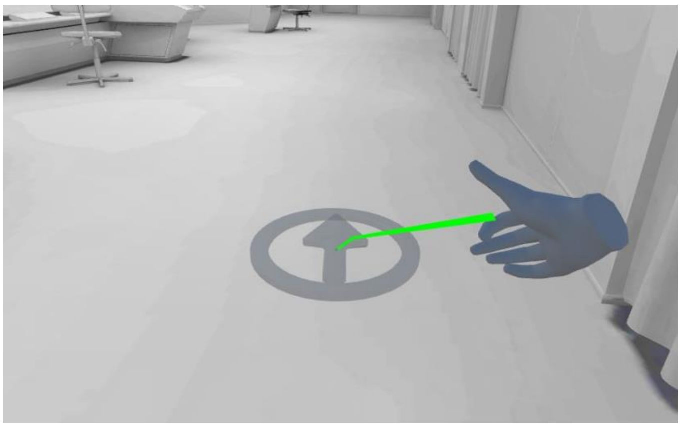
Picture 9. Hand-tracking instructions.

Adding button pressing to hand-tracking was simple because the Oculus Integrantion had pre-existing buttons and were easily modifiable.

Grabbing was also extremely simple, the player simply had to do a pinching gesture near an object that can be grabbed or held.

4.2.2 Controllers

For decades the standard for VR has been the controllers, thus the limitations for them are numbered. The Oculus Integration plug-in makes movement easy and extremely modifiable. The plug-in allows any button on the controller to be assigned any function, it also contained a default movement system that could be costumised (Picture 10).



Picture 10. Player teleportation with controllers.

The button pressing with controllers can be quirky, due to the virtual hands fazing through objects and not having colliders. This can be easily fixed by adding an invisible object with a collider on the finger tip of the index finger.

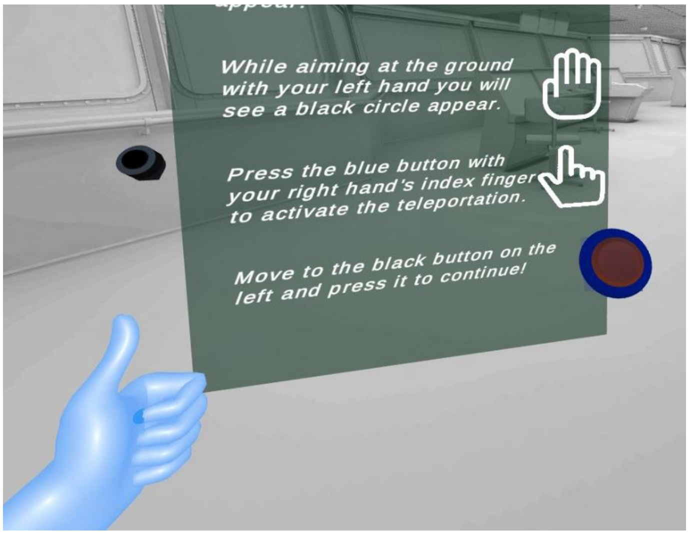
Grabbing and holding, just like the movement, is a standard function with controllers, therefore minimal effort is required.

5 The Implementation

Originally, the plan was for the player to able to swap from hand-tracking to controllers and vice versa at the end of a playthrough however due to the controllers staying active they would cause unexpected bugs that would interfere with hand-tracking. To prevent those issues two apps were created and when launched one would be played with hand-tracking and the other with controllers. At the end of each playthrough and all the task were completed, a black button appears that when press closes the game and brings back the player to the menu where they can pick the other version. This was beneficial for those new to VR, giving them a slight warmup for what was coming next.

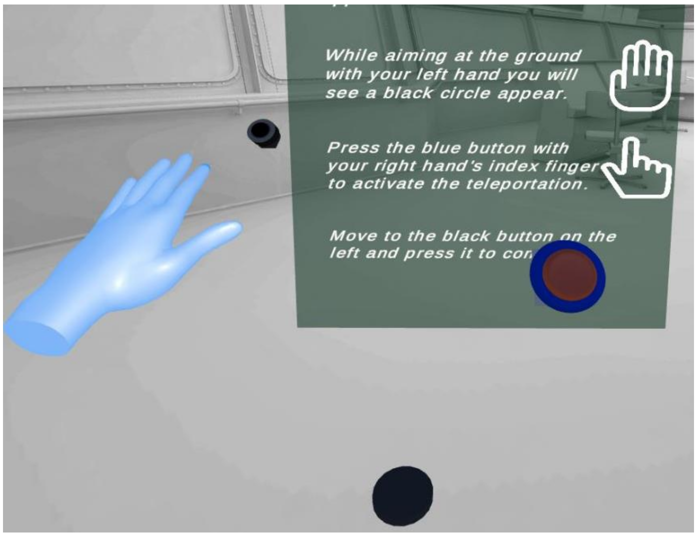
5.1 The movement system

As discussed in chapter 5.2, the Oculus SDK, an abbreviation for Software Development Kit, made the enabling of hand-tracking and controller support really easy. In addition, Oculus prodives excellent support for developers with well written and easily understood documentation making it even easier to costumize or modify any script. Creating a movement system for hand-tracking was no easy feat. Firstly, a gesture detection system was created, it also required the ability to save gestures and recognize them and be able to give the player some space for error. Once the gesture the gesture detection system was completed, the creation of the movement system could begin. Making a thumbs up gesture would activate the teleportation. While the teleportation is active, a red and blue appears near the player’s right hand (Picture 11).



Picture 11. Teleportation active in hand-tracking.

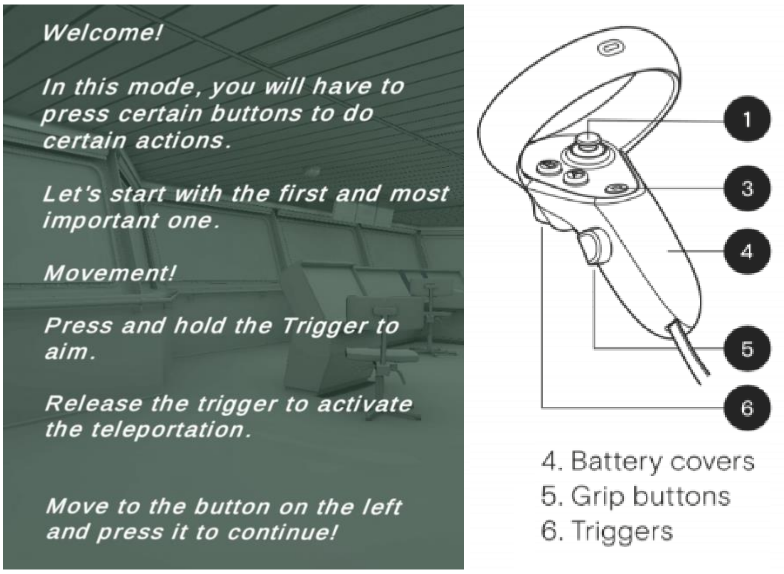
From the player's left palm a ray is cast that detects the ground and creates a black circle whenever and wherever it detects it (Picture 12).



Picture 12. Player aiming their palm the ground in hand-tracking.

Pressing the red and blue button would cause the player to teleport to the location of the black circle. By doing a thumbs up gesture again the player could deactivate the teleportation.

The movement system for controllers was easy to implement. By adding some of the Locomotive scripts to the player, a developer can decide what controller but activates teleportation, can adjust the distance and how fast it happens. The button assigned to teleportation was the trigger button, it could be held for as long as the player needed and once released the player would teleport to the location of the circle (Picture 13).



Picture 13. Controller instructions.

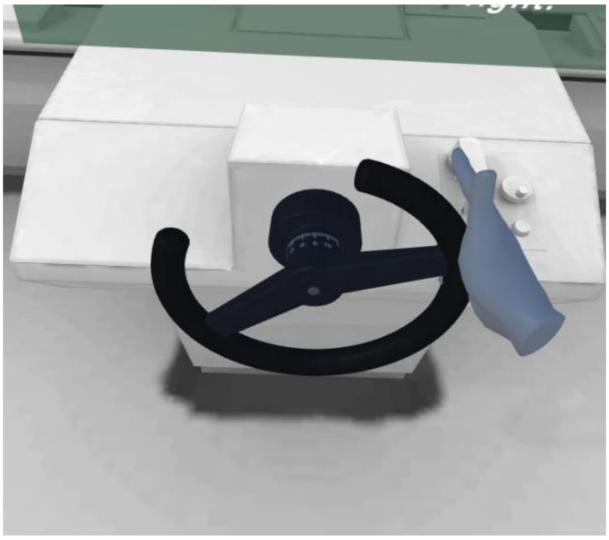
However some of the default button functions had to be disabled. One of those was the ability to move and the other was to rotate the player with the analog sticks on the controllers. Hand-tracking did not possesses such capabilities, thus giving controllers an unfair advantage.

5.2 The interactables

As mentioned in the beginning of this chapter, the Oculus SDK made the interaction process simple and easy. Making objects grabbable was as simple as adding the Grabbable script to them, which is included in the SDK. For hand-tracking a script was made, that allowed the player to grab any object that contains the Grabbable script by doing a pinching gesture (Picture 14).

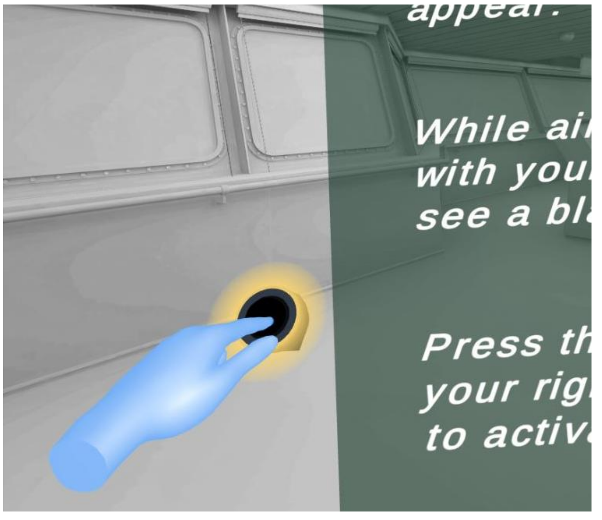
Picture 14. Player grabbing and pulling the lever downwards with hand-tracking.

Giving the grabbing ability to controllers was even easier, adding the Oculus provided OVR Grabber script allowed the player to grab and hold any object that contained the script Grabbable. The script allowed the developer to choose which button on the controller would be assigned the grabbing function (Picture 15).



Picture 15. Player grabbing and holding the wheel with controller.

Pressing buttons was trivial. By adding the InteractableToolsSDK object to the scene, two blue spheres appear on the fingertips of the index finger, that allow the player to press buttons (Picture 16).



Picture 16. Player pressing button in hand-tracking.

As mentioned in chapter 5.2.2, due to the virtual hands fazing through object in the controller version, an invisible object was added on the fingertip of the index finger, making button pressing possible.

6 Interview Data

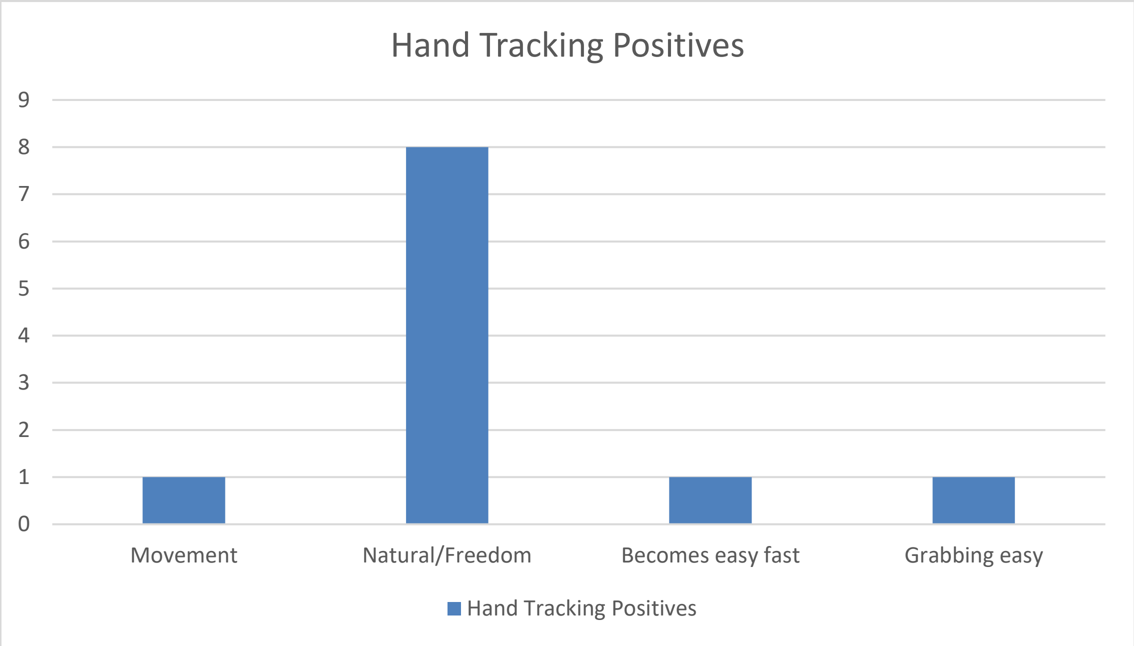
In this chapter the participant's interview answers will be broken down and analyzed. The total participant count was nine individuals. There was a crucial element to the interviewing process and that was the questions themselves, the questions were asked in an open-ended fashion to avoid "Yes" and "No" answers and to let the players voice their thoughts without leading them to a certain answer, however some questions were specific on purpose. Before the participants started playing, they were asked to grade their level of expertise from a) "None" which meant 0 hours spent in VR, b) "Little" which equated to 5 hours or less spent in VR and c) "A lot" which corresponded to more than 5 hours spent in VR this can be seen in Graph 4. Furthermore, the participant were asked to stare their age; all participants were over the age of 20 and under the game of 30.

Once the participants played the game one time with each version, they asked to express their overall thoughts on the experience, to which as seen on Graph 5 seven out of nine claimed to have had a positive experience and would have liked for more or to continue, on the other hand only two players expressed their experience was negative which will be discussed later.

After the players had some time to gather their thoughts, they were asked yet another open-ended and vague question, if they could change something what would it be. Many answered they would have like to have the ability to determine the gestures themselves, one of them being instead of pinching, making a balled up fist. Some found the monochromacy of the world bland and would have liked more color differentiation, others complained that the wheel task was too complicated and some complained about the lack of feedback. Finally, one player complained about the weight of the VR glasses and that they felt strain on their neck after finishing playing, though they did understand they could not do anything about it.

This is when the questions started to become more specific and pointed, the players were asked to express the positives of Hand-Tracking and as seen on

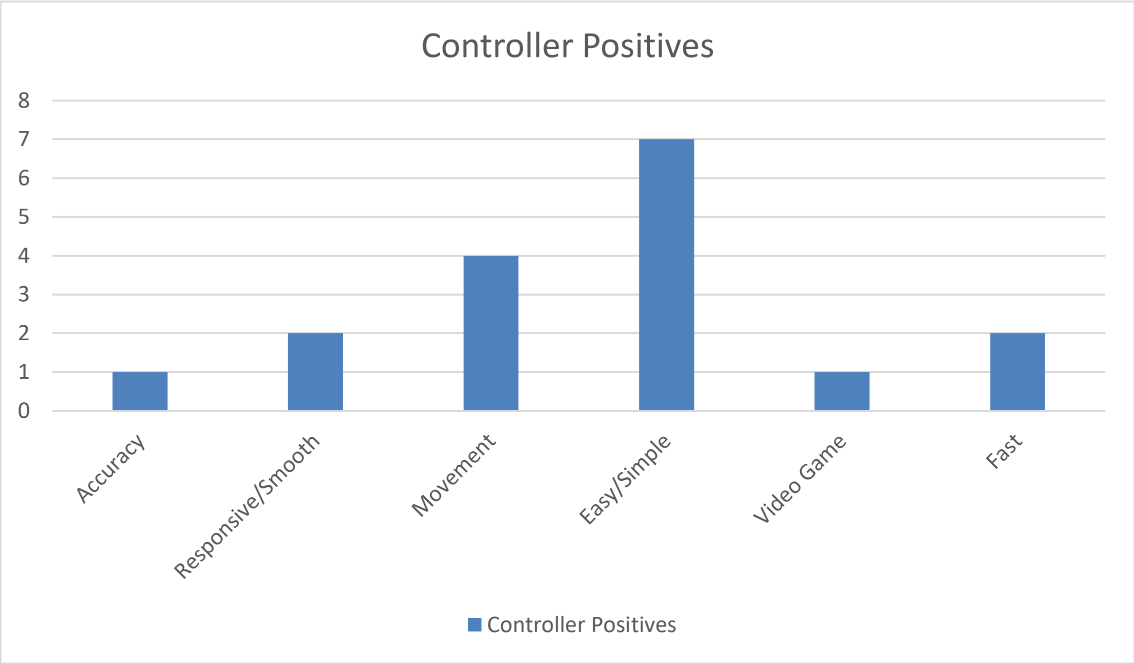
Graph 1. overwhelmingly players liked the natural feel, the freedom of not having to hold controllers and the fact that real life movements matched in-game movements, many said that they never knew or imagined that the technology of hand-tracking even existed.



(Graph 1.) List of positives with hand-tracking by participants

The same question was asked but for the Controllers. On Graph 2. overwhelmingly the players found it easier to control and understand. Likewise, many felt that the movement was a positive because it felt easier and smoother and a few liked the responsiveness, accuracy and the speed.

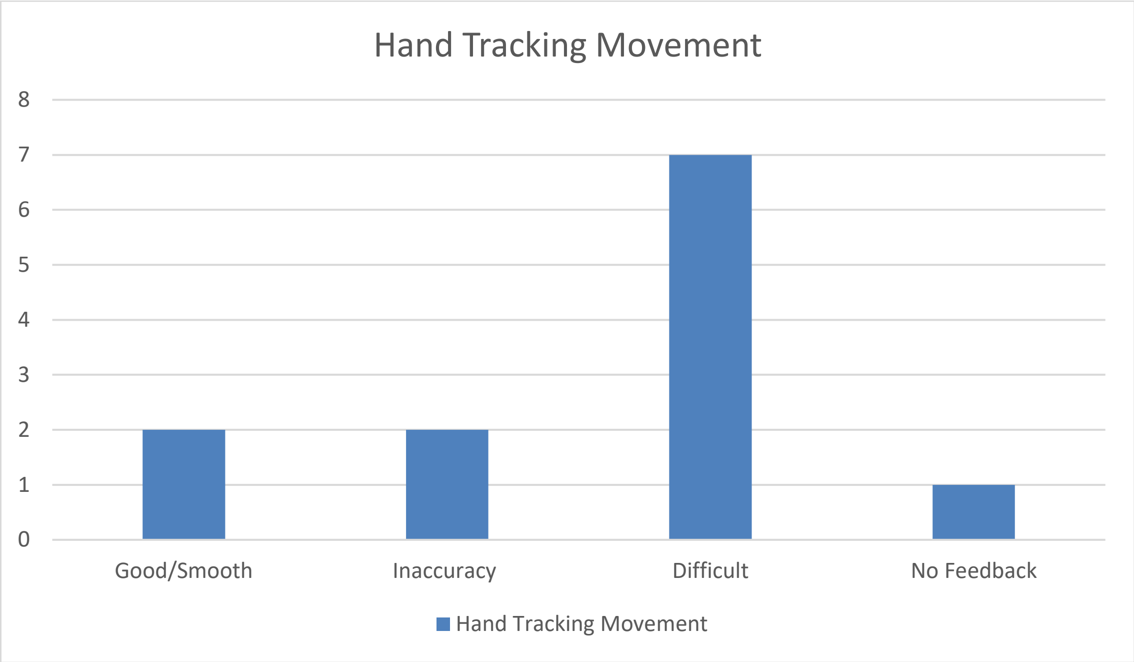
As always, there can not exist positives without negatives, the players were asked to convey the negatives on Hand-Tracking. Five out of nine participants found the grabbing of the wheel too difficult and therefore a negative, followed by three out of nine participants finding the difficulty of the movement as a negative, players thought that having to aim with one hand and pressing a button was too confusing. Some off shoot comments like the hands disappearing and the inaccuracy were made but not by a significant number of players.



(Graph 2.) List and of positives with controllers by participants

Moving on to the negatives of the Controllers, there were not many and the maximum amount of negatives were two however the ones that were brought up were that the controllers have too many buttons that have no purpose thus creating confusion and by extension it caused the movement to be difficult and lastly, the lack of freedom comparing to hand-tracking.
The comparison between the two different movements is extremely meaningful, therefore the players were asked to specifically rate each of them. Seven out of nine players thought the movement was too difficult due to the multi-step process whereas only two thought the movement system was good and/or smooth as seen on Graph 3., though they both acknowledged it was a little confusing in the first few tries.

When asked to comment on the Controller movement, players quickly made similar comments as previous, such as the easiness and the speed at which the player can move.



(Graph 3.) Comments about hand-tracking movement by participants

Another significant element of the game were the instructions, players were asked if the instructions were sufficient or if they felt they were lacking. Most players thought that they were well written and understandable, however some exclaimed that they would have liked some color differentiation or highlighting of specific instruction, for example the “Trigger” word in the very biggening. Two out of nine players would have liked if there were multiple language options, in case there was participants who’s English skills were not up to par. Lastly, only a few players thought the instructions were either too complicated and unintuitive or would have like for there to be more guidance, one player even complained that there was too much text.

Last but not least, as the final question, players were asked to express their frustrations with the game, if they had any. There were only two complaints, the lack of feedback and the wheel task. Three out on nine players felt as though when they were doing a certain action, there was no affirmation or indication that the action is happening and as for the wheel, four out of nine players felt frustrated when they thought they was grabbing it but in reality, they were not.

7 In-game Data

This chapter is dedicated to the breakdown of the in-game player data, observations from their playthrough and a summary of all their combined data. On average, the majority of the participants had a hard time moving around with Hand-Tracking, however as the players progressed forward their comfortability grew exponentially when nearing the last task, unlike with Controllers, where it is the total opposite, players were able to move in the environment with ease from the very start. Pressing the first and second button in Hand-Tracking was seemingly as easy as pressing it in a real life environment. When it comes to pressing the two buttons with Controllers, eight out of nine participants had found it difficult to press the first one but when they moved on to the second one, only two out of nine had difficulties pressing it. Continuing to the wheel task, almost every player, in both versions, struggled to finish this task and in three cases, due to the virtual hands disappearing, the task became impossible to finish. The slider task difficulty in both cases is quite similar, where four out of nine encountered hardship with Hand-Tracking and three out of nine encountered hardship. The last task, the lever, was the easiest task out of them all, where every participant in both versions completed it effortlessly. The average playthrough duration for those who started with hand-tracking was 16 minutes and 42 seconds, whereas the average duration for those who started with Controllers was 12 minutes and 30 seconds. Taking a closer look, the average time for playing through the Hand-tracking edition was 8 minutes and 7 seconds, while the average time for Controllers was 4 minutes and 15 seconds.

8 Critical Analysis & Improvements

This chapter is dedicated to general improvements, what could have been done better, shortcomings, unfortunate circumstances and reasonings for certain choices. Starting with COVID-19, the biggest hindrance to this project, originally the goal was to have approximately twenty participants to play and test the game but it quickly became clear that the health and safety concerns would be a massive hurdle to overcome. After a few days of deliberation the goal post was moved lower and the participant number became fifteen, once that was set in stone, the process to gauge interest began however once again another challenge appeared, the “covid hesitancy”. E-Mails inviting people to participate were sent to a large number of groups with very little engagement, out of over 200 invitations, two individuals responded and only one person ended up showing up. The plan had to change, asking random individuals to participate proved to be a much more effective method of luring people, while most refused listing discomfort due to the global pandemic, some decided to accept, in the end the final number of participants was nine. Another challenge was the way of playing and testing and the interview process, initially the idea was to have half of the player group play and test the game simultaneously by starting with Hand-Tracking and then moving on to Controllers and the other half doing it vice versa. When both halves were finished, they would all be interviewed at the same time and so that the answers would be mixed and the players would be able to have a discussion at the same time, unfortunately this was not possible. Due to COVID, after every use of the Virtual Reality device, they would have to be cleaned, which would take an enormous amount of time. Ultimately, the participants played and tested the project one at a time and interviewed individually, though if the previous participant started with Hand-Tracking and the next would start with Controllers. Moving on to the shortcoming of this project. Majority of players experienced some sort of difficulty with a certain task inside the game, that task was the wheel, while it looked like to the player that they could grab and hold it from anywhere, in reality there were only two points of grabbing(task image), which led the player to feel frustrated and confused.

Another shortcoming was the lack of feedback or indicators, many players expressed they would have appreciated if while holding onto or pressing something, that there would be some kind of indication and that only having a small particle effect only when a task is finished was not sufficient. Additionally, a minor adjustment that would have made the player experience better, would be replacing some text with either short animations or having important parts of some text highlighted or in a different color would have helped alleviate confusion. Regarding the reason for picking the Oculus Quest 1 over any other device was because it supports both controllers and hand-tracking. The differences between the Quest 1 and Quest 2 were not significant enough at the time of the development, with Meta releasing their Hand-tracking 2.0 on the 28th of April 2022, which was well after the development phase. Varjo does not support controllers therefore it was automatically ruled out. Having picked the Quest 1, naturally the Oculus Integration was also installed for the sheer fact it provides the best SDK. In addition, SteamVR was used for development purposes due to it working best in conjunction with Oculus Link, the official application by Meta for connecting a computer and an Oculus device.

9 Conclusion

This chapter contains topics including the summary and the verdict of the thesis, the future of the technology and the potential improvements that could be made to the project.

In a world where the standard for anything VR related is still dominated by controllers, there seems to be room for other options, namely hand-tracking. Whilst, controllers still have a competitive advantage with them being more accurate, consistent and beginner friendly, a growing void has apparead. Hand-tracking gives the user much more freedom and a natural feeling that a controller could never, though the technology is still new and has a long road ahead of it; consistency errors and lack of lighting issues will still persist unless a drastic improvement happens to the current hardware.

This thesis shows that there is space for not only hand-tracking video games but also educational simulators. The feeling of realism, that many expressed as a positive, could be used in great situations, such as a training ground for students or professionals before going out to the field and encountering the real deal. This project aimed to show that hand-tracking is a valid tool for learning and to a certain extent it accomplished its goal.

For hand-tracking to elevate and progress to the next level, it is paramount that the hardware such as the depth perception cameras and the field of view of the cameras keep improving, while simultaneously the hand recognition software inside the VR devices improves too. The disappearance and the accuracy of the player’s virtual hands is an issue that still persists in the default versions of the current VR devices, however there are promising technologies being developed, such as Ultraleap’s Gemini neural network and Meta’s Hand-tracking 2.0 making the future of hand-tracking brighter and better.

To reiterate, this thesis has shown that hand-tracking could be the future of Virtual Reality, whether it is the eight out of nine players that found the freedom and natural feel of hand-tracking as positive or whether it is a more effective learning method, hand-tracking is here to stay.

If the project could be re-implemented, changes would definitely be needed namely, using a different VR device. Quest 2 would be a strong candidate with its new hand-tracking system. The tutorial for the movement system would be created with either video or step-by-step images and would add more grabbing locations for the wheel task.

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Appendix 1. In-game player data

Participant 1

The player starts with the Hand-Tracking version of the game, the player misses the first button and struggles to get a grasp on the movement. They wander around the room for a few short minutes, after which they realize where the objective is located. The player returned to the starting location and pressed the first button with relative ease. The player continued to the next objective but again had trouble with the movement, a few attempts later they were able to move to the second button and press the button with no hardship. The player seems to have gotten a better handle on the movement and now has moved to the wheel objective. The player finds it difficult to grab the wheel but after a few attempts they are able to finish the task. The player moves to the slider objective with no issues and finishes the task with ease. The player quickly moves to the last objective and completes it with haste. Moving to the Controller version, the player has no trouble moving around and is able to press the first button effortlessly. The player then moves to and presses the second button with no issues at all, once that task is complete, it is again the wheel objective, where the player had difficulties grabbing on to it, only this time only taking a couple of tries to complete the task. The last two objectives, the slider and the lever task are completed smoothly.

Participant 2

The player starts by ignoring the instructions, pressing all the buttons on the controllers and moving around the room for quite a long time. The player asks for instructions and they are guided to the starting position, where they seem to have an issue with depth perception by moving too far from the first task and when near the task, not reaching far enough to fully press the button. The player completes the first task, then moves to the second objective, where the aforementioned issue still persists, failing to fully press the second button and pressing buttons on the controllers causing them to move away from the objective. The player has a harder time pressing the second button, but finally they are able to complete the task and move to the wheel objective. The wheel task is completed with relative ease, the player moves to the slider objective, in which the player has a hard time grabbing the sliders by not reaching far enough or not being close enough to the task. Finally, after completing the slider task, the player moves to the final objective, the lever task, that is finished with minimal effort. Now that the Controller version is done, the player starts the Hand Tracking variant, where the player is more careful with their movement and is paying close attention to the instructions. The player's movement is shaky, both physically and figuratively, but is able to press the first button comfortably. The player quickly moves to the second objective, presses the second button swimmingly and tries to move to the third objective but seems to be having trouble moving to its location. Once the player makes their way to the wheel, they are having trouble grabbing it, the same happens with the fourth objective. Finally, the player is comfortable with the movement, which allows them to move to the fifth and last objective, which gets finished with no issues.

Participant 3

This player has a very rocky start, the movement seems to be very confusing and pressing buttons seems also troublesome. A few minutes pass, the player has now moved closer to the first objective but yet again is having difficulties, only this time pressing the first task button. The player is attempting to press the button but is moving their hands too fast or is not pressing the button all the way. The first task is now complete, in spite of that, the player faces another hurdle, they have to move to the second objective and are having a hard time moving around. After a few minutes the player manages to move to the second objective and presses the button comfortably. Yet again, the same issue persists, movement is still challenging, nevertheless the player makes their way to the wheel objective. Due to what seems like a perception of depth problem the player is having trouble grabbing the wheel, eventually they successfully grab the wheel but cause the game to bug out. The reason why the game bugged out is because while the player is holding the wheel and the virtual hands disappear, it causes the grabbing points that are being held to disappear too. The game is restarted and fast-forwarded to the last objective, where the player finishes the task and moves to the slider objective. While on the slider task, the player manages to cause the game to bug out two additional times which means the game has to be restarted and on the third time the task is completed. Finally before moving to the Controller version, the player seems to have gotten a grip on the movement moves to and completes the lever task smoothly. Moving around with controllers seems much easier but pressing buttons is a persistent issue, the player presses the first button with hardship however presses the second button with no issues at all. Surprisingly, the wheel task is finished effortlessly, but the player manages to bug out the slider game yet again, after a fourth restart, the task is completed and with relative ease the lever is completed as well.

Participant 4

Starting with controllers, the player freely navigates around the room, however finds the pressing of the first button troublesome. Moving to the second objective with minimal effort but yet again having trouble pressing the button.The player quickly moves to the wheel and finishes the task with a small amount of hardship. The slider task is completed easily and last but not least, the lever task is finished comfortably. Continuing to Hand-Tracking, the player almost instantaneously seems to comprehend the movement and presses the first button easily. The player flies by the second button, where he grabs the wheel, again, with no trouble at all. The same exact goes for the slider and lever task.

Participant 5

Beginning with Hand-Tracking, the player spends a lengthy amount of time reading the instructions; after reading them, the player attempts to move but seems confused and troubled. The first button is pressed smoothly and seemingly moving around has improved. The second objective is finished and it is time to tackle the wheel task, where the player struggles to complete it. Advancing to the slider task, the player spends a long time reading the tip and looking at the task, a few moments later the task is completed fairly smoothly.

At last, the player struggles to grab the lever but eventually manages to finish the task. Moving to the Controller edition, the player has a faster start, moving around is easier but pressing the first button seems harder. The second button press is easier, though again grabbing the wheel is proven to be bothersome, which seems to be caused by the lack of depth perception. Contrary to the wheel, the slider and lever tasks are completed effortlessly and moving from one task to the next seems smooth.

Participant 6

Movement with controllers seems easy, likewise the first and second button press tasks are finished with ease. Grabbing the wheel seems to be a hurdle for a moment but after a few attempts it is also completed. Lastly, the slider and lever tasks are finished easily. Carrying-on to the Hand-Tracking, the movement system seems difficult, however moving from the first button to the second one, whilst also completing the task, moving around is more free flowing. The third objective, the wheel, poses a little hardship and again the last two tasks are completed effortlessly.

Participant 7

Beginning with Hand-Tracking, immediately the player seems to have a hard time with the movement and getting to the first objective is a struggle. After moving to the second button, the player's comprehension of the movement system has drastically improved, however they get stuck on the wheel task, where they struggle to grab the wheel. The game comes to an abrupt stop and restart, the reason being the player's hands disappearing while holding onto one of the sliders from the fourth task. Finishing with the lever task, the player moves on to the Controller variant. Movement is smooth but pressing the first button seems to be challenging. The rest of the tasks are completed smoothly, while the player is gliding from task to task.

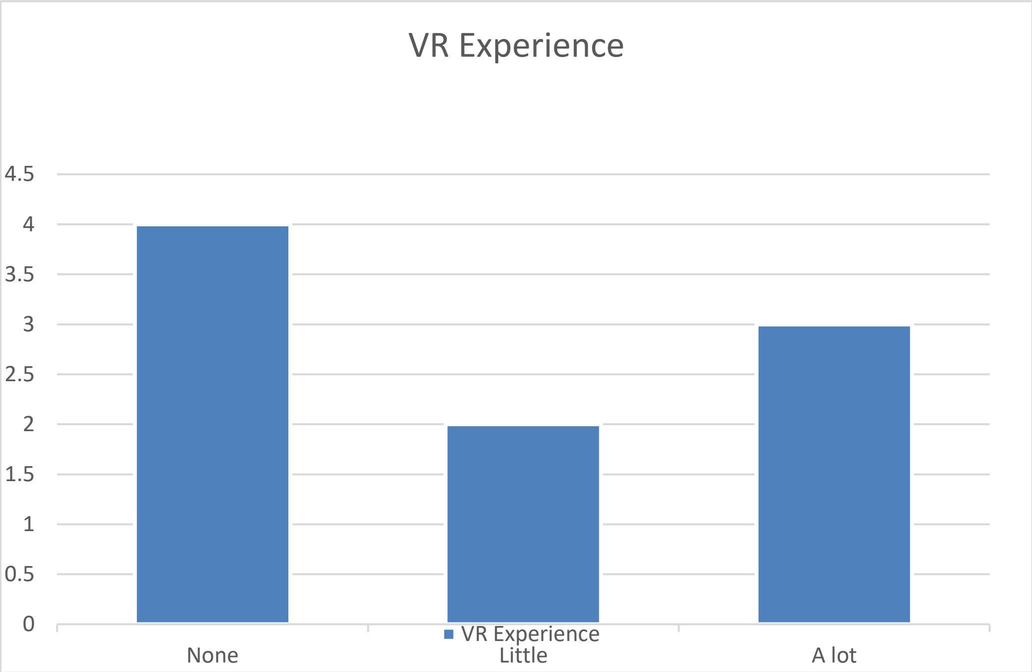
Participant 8

The player starts with the Controller edition, where from the get-go they struggle with the movement. Pressing the first button is a struggle too, due to them pressing all the buttons on the controller, however the second button task gets finished easier. The player continues to the wheel, where they struggle to grab it, but the slider and lever tasks are completed comfortably while the movement improves as well. Moving on to the Hand-Tracking version, the player visibly struggles with the movement, while on the contrary they have an easy time with the buttons of the first and second task. Grabbing the wheel proves to be another problem, but the biggest problem is the fact that the game bugs out because the player is still holding on to the wheel when their hands disappear. The player is fast tracked to the wheel, which is completed and finishes the last two tasks and seemingly has gotten much better at moving around.

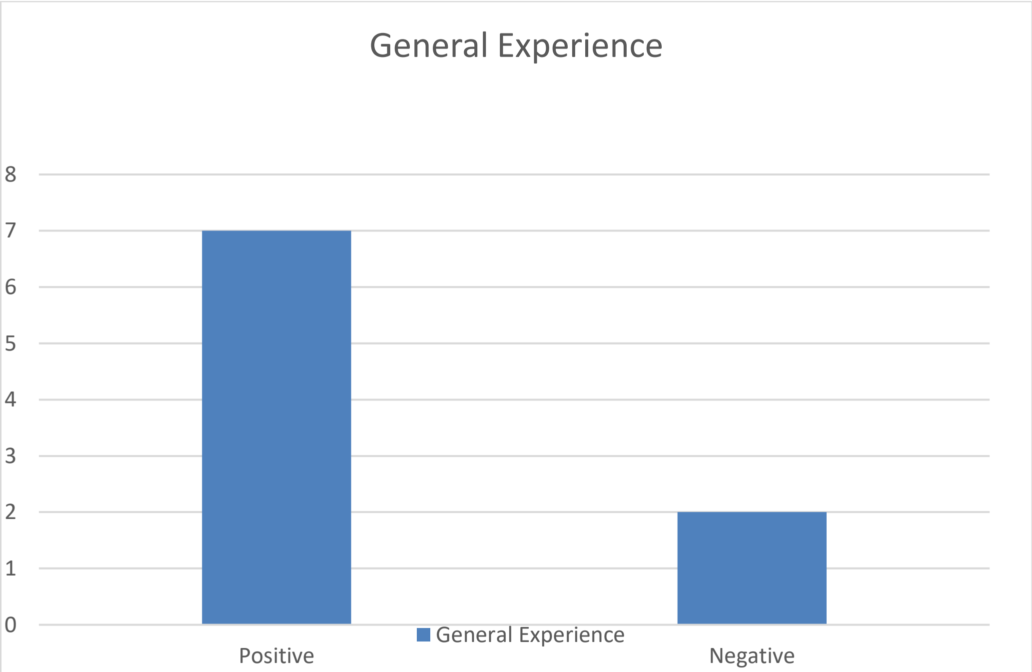
Participant 9

Starting with Hand-Tracking, from the very beginning the player catches on the movement and flies through the first two tasks. The wheel though seems to be an issue, the player has a clear lack of depth perception, where they are attempting to grab the wheel but they are not close enough. However the slider task is completed smoothly and so is the lever task. Advancing to the Controller version. The player finds the movement difficult, however eventually moving to the location of the first task, where things do not get easier. After that, moving to the second task, finishing it and moving the wheel again, the player struggles to grab it ostensibly being confused about which button to press. Moving to the slider task, where yet again they struggle to grab the sliders but finishing the lever task is easy.

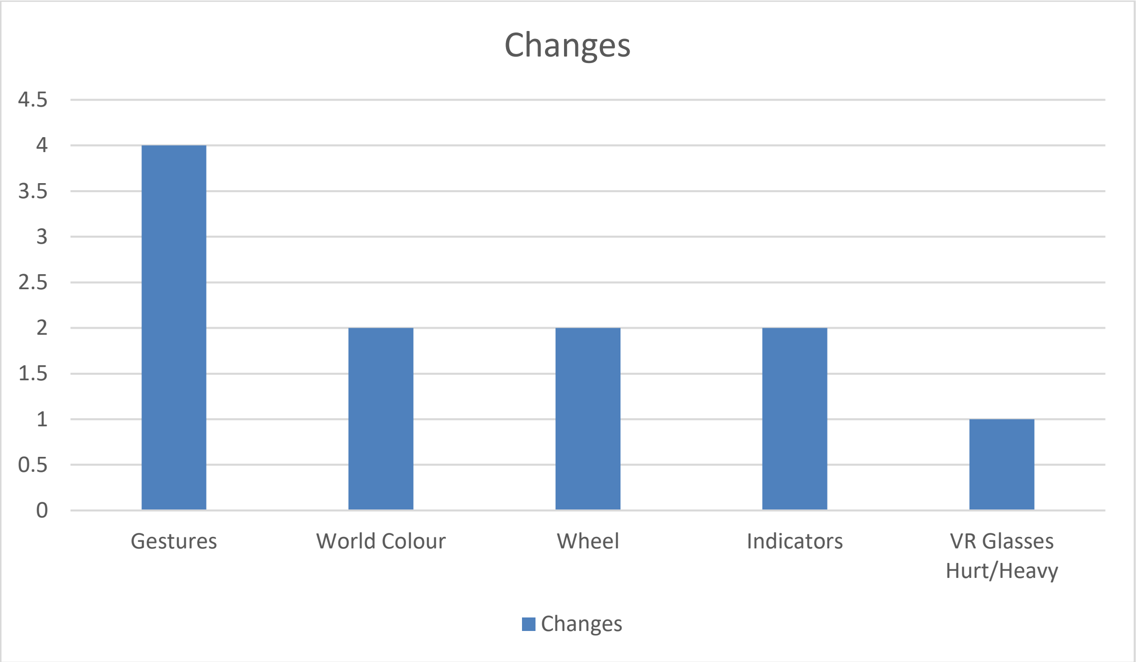
Appendix 2. Interview Data



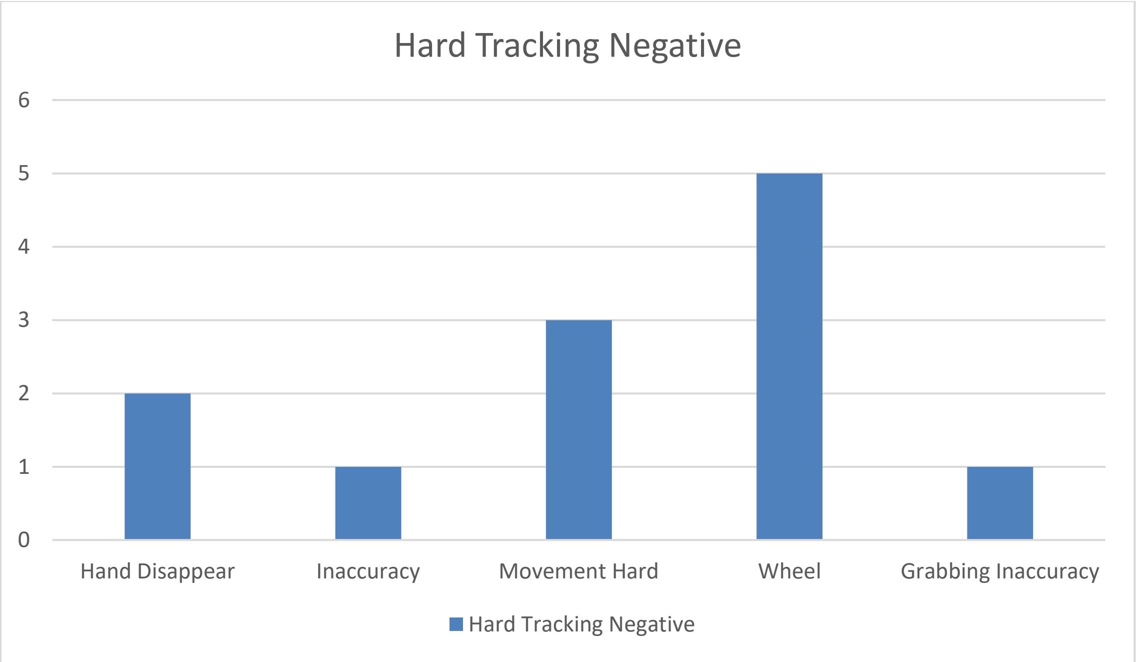
(Graph 4.) Number of participants with prior VR experience



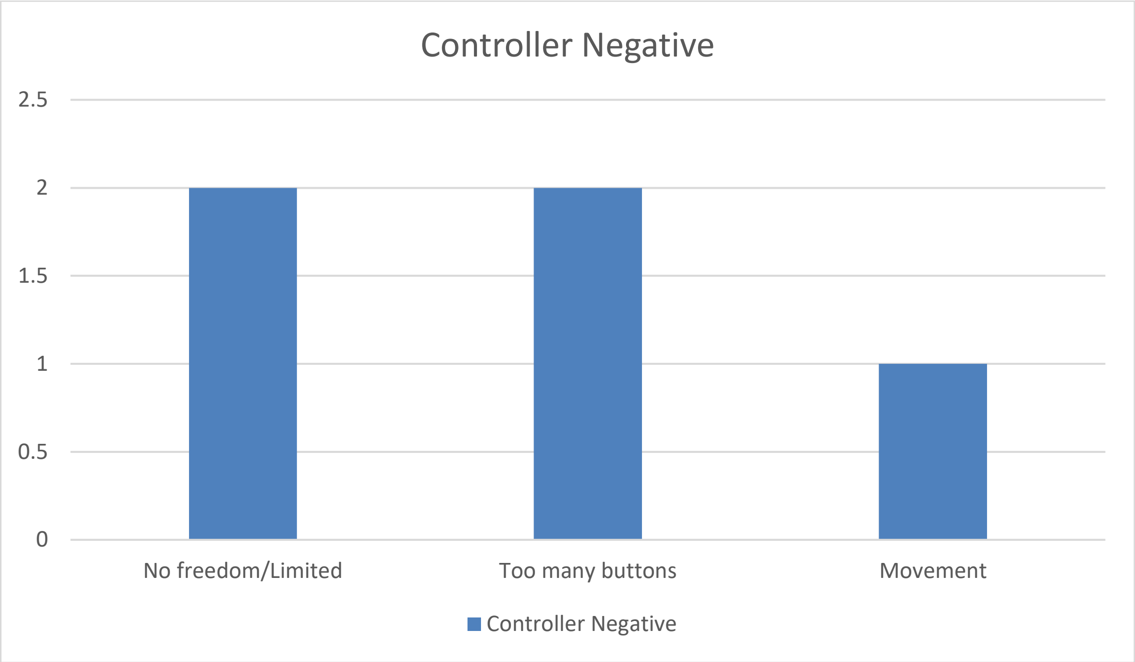
(Graph 5.) Participant's general experience



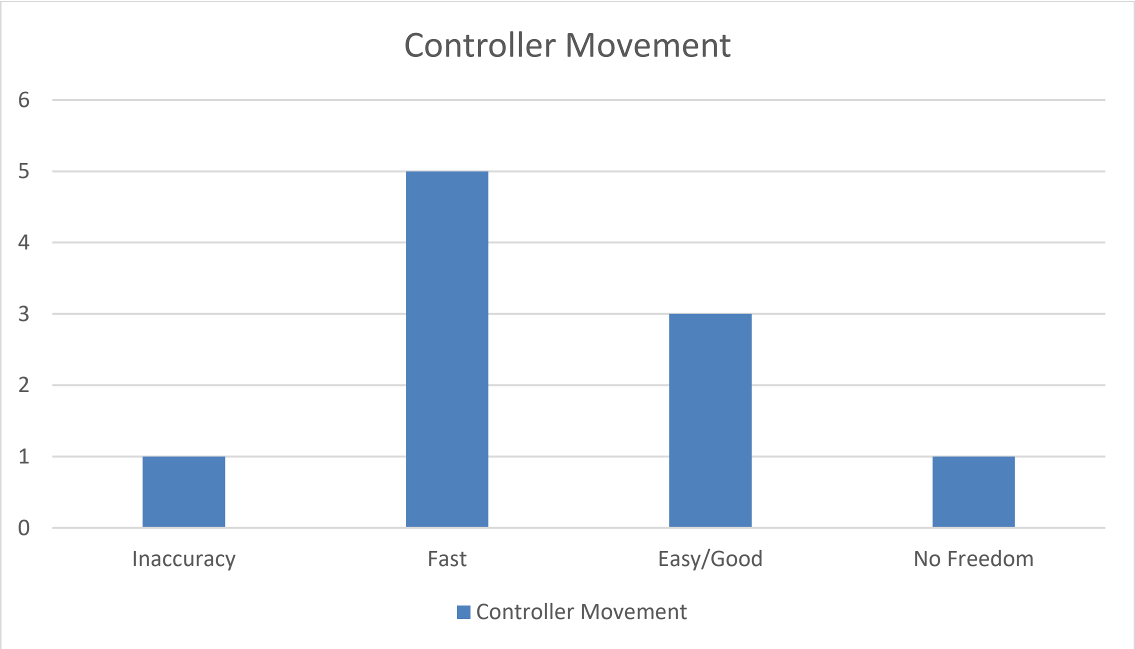
(Graph 6.) List of changes desired by participants



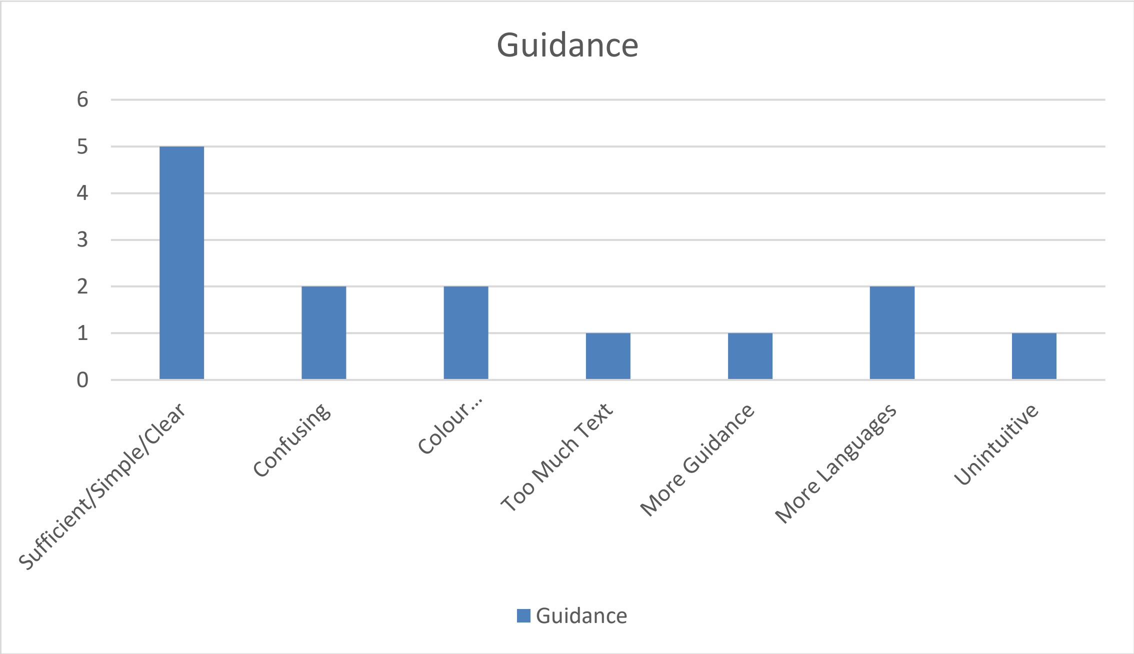
(Graph 7.) List of negatives with hand-tracking by participants



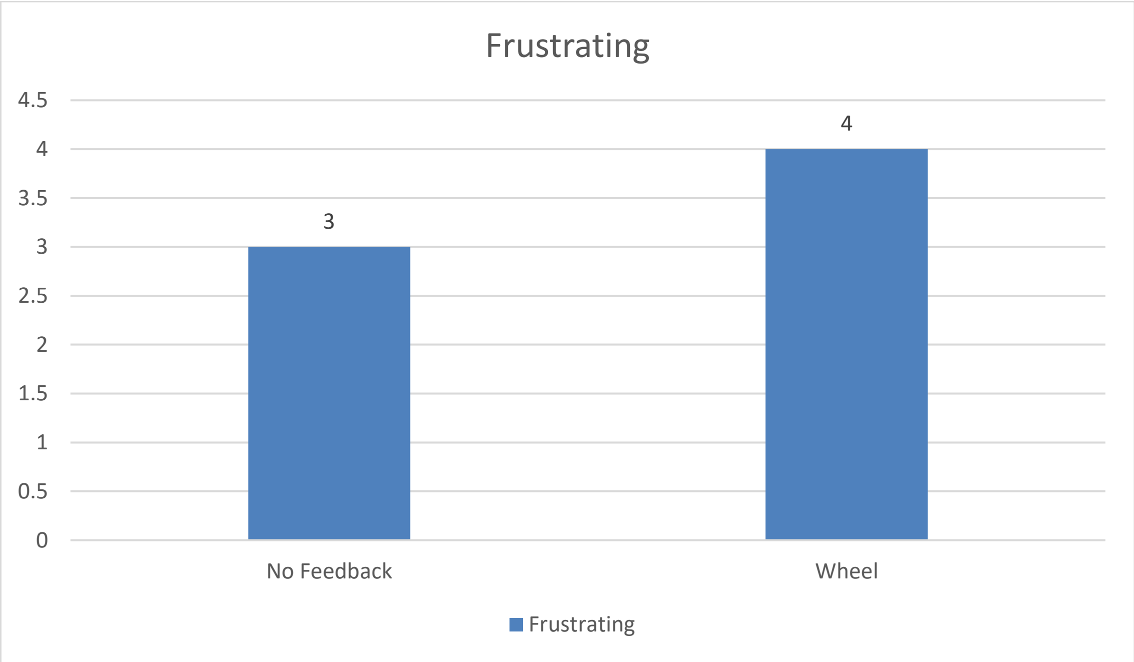
(Graph 8.) List of negatives with controllers by participants



(Graph 9.) Comments about controller movement by participants



(Graph 10.) Comments about guidance by participants



(Graph 11.) List of frustrations by the participants