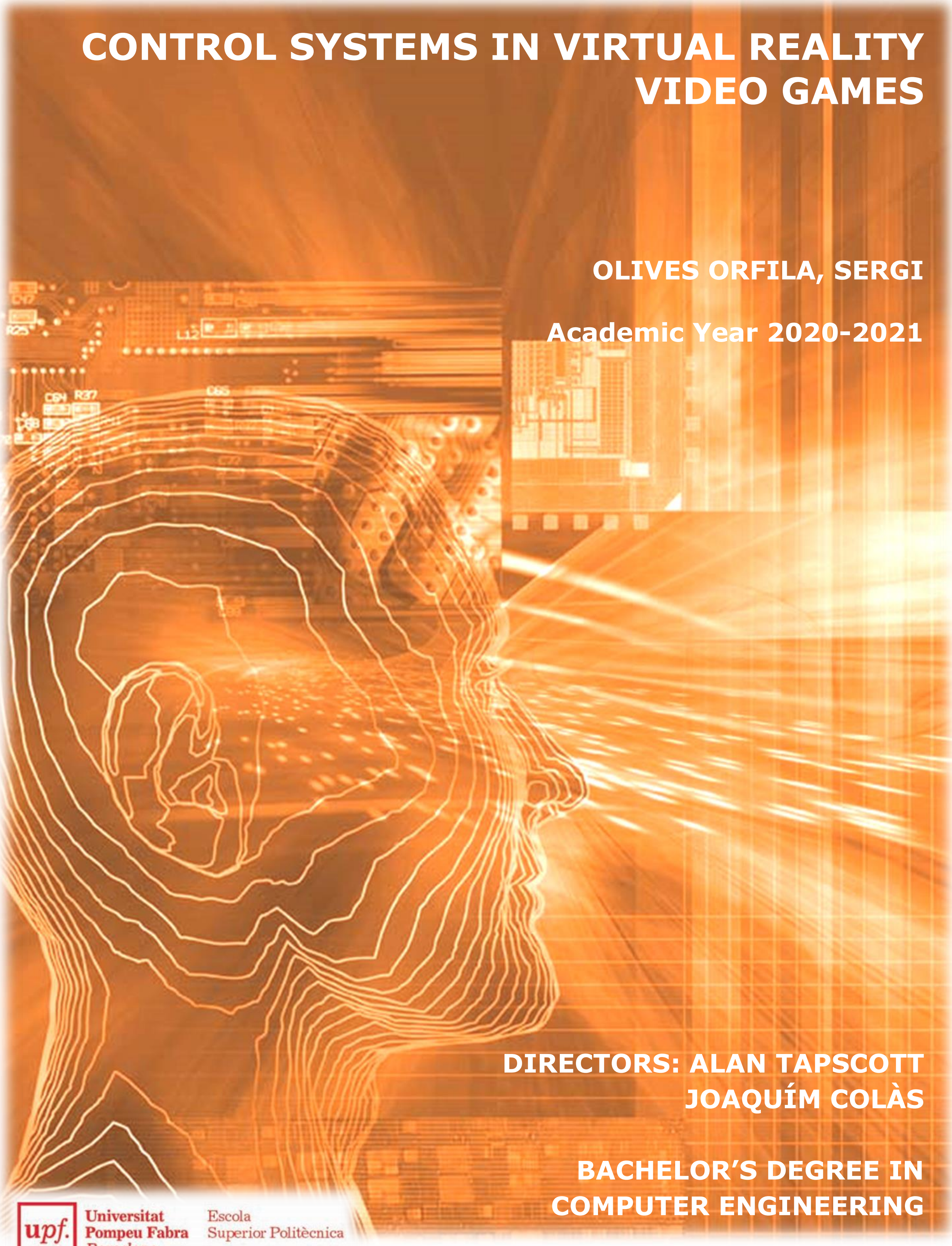

CONTROL SYSTEMS IN VIRTUAL REALITY VIDEO GAMES

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Abstract
Video games have always moved towards the standardization of control systems. At an interaction level, the goal of games is to have the best possible user experience, therefore game controls and mechanics should be easy to understand, simple to use and similar to other existing control systems. Virtual Reality video games are no exception, but they are a younger branch of the games industry more focused on experimentation than on standardization. This work researches some of the current control systems available in Virtual Reality games and performs a user study with one of the most polarizing and central game mechanics and control systems: locomotion, or how the player moves inside a game. The goal of the study is to gather information on the locomotion game mechanics by analysing the player behaviour when using multiple control systems simultaneously. The results of this work show that control systems are heavily related to the game genre and design, and they tend to be as simple as possible although there is not a standardized control system for every given game genre. Some in-game mechanics such as picking up and releasing objects, or shooting guns seemed to be standardized, but other central mechanics do not feature this standardization, such as locomotion or inventory systems.

Resum
Els videojocs sempre han tendit a la estandardització dels sistemes de control. A nivell d'interacció, l'objectiu dels jocs és oferir la millor experiència d'usuari possible, per tant els controls i mecàniques del joc han de ser fàcil d'entendre, simples d'utilitzar i similars a altres sistemes de control ja existents. La Realitat Virtual no n'és una excepció, però és una branca molt jove de la indústria dels videojocs més centrada en l'experimentació que en la estandardització. Aquest treball investiga alguns dels sistemes de control actualment disponibles en jocs de Realitat Virtual i desenvolupa un estudi amb usuaris amb una dels mecàniques i sistemes de control més polaritzats i centrals dels jocs: la locomoció, o com el jugador es mou dins el món virtual. L'objectiu de l'estudi és recollir informació sobre les mecàniques de locomoció analitzant el comportament dels usuaris mentre utilitzen múltiples sistemes de control al mateix temps. Els resultats del treball indiquen que els sistemes de control estan molt lligats al gènere del joc i el seu disseny, i que tendeixen a ser el més simple possible, tot i que no existeix un sistema de control estàndard per a tots els gèneres. Algunes mecàniques dels jocs tals com agafar i deixar anar objectes, o disparar armes si tenen un estàndard, però altres mecàniques centrals no presenten aquesta estandardització, com per exemple la locomoció o els sistemes d'inventari.

Resumen
Los videojuegos siempre han tendido hacia la estandarización de los sistemas de control. A nivel de interacción, el objetivo de los juegos es ofrecer la mejor experiencia de usuario posible, por lo tanto, los controles y mecánicas del juego deben ser fáciles de entender, simples de utilizar y similares a otros sistemas de control ya existentes. La Realidad Virtual no es una excepción, pero es una rama muy joven de la industria de los videojuegos que se centra más en la experimentación que en la estandarización. Este trabajo investiga algunos de los sistemas de controles actualmente disponibles en juegos de Realidad Virtual y desarrolla un estudio con usuarios con una de las mecánicas y sistema de control más polarizados y centrales de los videojuegos: la locomoción, o como el jugador se mueve dentro del mundo virtual. El objetivo del estudio es recoger información sobre las mecánicas de locomoción analizando el comportamiento de los usuarios mientras utilizan múltiples sistemas de control al mismo tiempo. Los resultados del trabajo indican que los sistemas de control están muy ligados al género del juego y su diseño, y que tienen tendencia a ser lo más simple posible, aunque no

existe un sistema de control estándar para todos los géneros. Algunas mecánicas de los juegos tales como coger o soltar objetos, o disparar armas sí que tienen un estándar, pero otras mecánicas centrales no presentan estos estándares, como por ejemplo la locomoción o los sistemas de inventario.

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1. INTRODUCTION

As an introduction to the document, we are going to explain the objectives and the reasons that are behind the project, the structure of the document and the planning that we followed.

1.1 Goals and Objectives

The goal of this work is to analyse the current scenario for Virtual Reality (VR) in the video games industry and the control systems (or schemas) that are being used in them and determine if there are any standards about what control schemas are being used or not and why is that happening. To start with the topic, we will introduce some data about the industry.

Almost two billion people were playing video games during 2015 and this number is expected to increase up to 3 billion by 2023[1]. In 2020, the Entertainment Software Association (ESA) conducted an interview [2] to the American population about gaming where more than 214 million people said that they play video games. An estimation of 171 million people is playing VR experiences [3] worldwide and the most popular online store for PC, Steam, had an increase of 1.7 million players using VR from 2019 to 2020, about 2% of the total monthly player base of 120 million players. Moreover, also in 2020, VR games revenue was a small fraction of 0.4% of the total gaming industry revenue (including both hardware and software) [4].

All this information is needed to understand that investing in VR for companies is more of a shot for the future since it is not as big as the mobile or PC video games market. This is important for our work since we wanted to know if there are any standards in control schemas for VR games as it happens in games for other platforms. For PC, console and smartphone gaming, there are standards for game structure, controls and monetization, since they have been in the market for years with a huge player base and a lot of different games. Slowly, these standards have been consolidated in the non-VR games, mainly looking for the best way to attract and retain players. Since VR games are not at the same position and they present other problems based on the physical aspect of VR (motion sickness, fatigue, playing area) [5], developers need to bring new ideas to the games. VR game development is relatively young compared to non-VR game development and each game that is being launched, proposes a different solution to these problems.

Because of these reasons, this work is based on analysing VR games that have had commercial success, analyse the control systems and conclude if there are any standards for a given control system or not, and propose a reason for why that is happening. Moreover, we will take one of these systems and do an experiment with a VR scenario with real users analysing one of the standards or variations in order to take into account the experience of a player's sample.

1.2 Structure of the Document

The document starts with an introduction of the work where we explain the goals of the project and the planning that we followed.

The second chapter contains a state of the art part where we talk about VR games history in comparison to non-immersive games, basic concepts of VR and related works to the thesis.

The third chapter is one of the two key chapters (along with chapter 4) of the work, where control systems of VR video games are analysed and compared to each other to understand what are the differences between them. This is where we start finding relations and conclusions about standards and variations in control schemas.

Then, in the fourth chapter, we selected one of the control systems to develop an experiment around it. We will talk about what system has been selected and why, the goals for the experiment, how we are going to approach it, both from the hardware and software point of view, and how the experimentation process will be developed with real users.

In the fifth chapter, we are going to collect the results from the study and in the sixth chapter we will talk about the conclusions from the analysis and results and present the future work that could be interesting after the project has finished.

Links and annexes to additional work are also present in the thesis.

1.3 Work Plan

The work process can be divided in five blocks:

- **First investigations block.** This is the first block of work and it starts on the first meeting that we had to discuss about project topics. It consists of more than three months iterating over different ideas around video games until we decided to go for the actual topic and objectives of this project.

- **Virtual Reality games analysis block.** This phase of work started when the topic was decided to be around VR. During this block, we analysed different VR video games, the key part for our work.

- **Development block.** The longest phase of the project. Again, it starts when we decided that the thesis topic will be related to VR. Work started to be done in order to investigate game engines, VR capabilities and finally develop a prototype for the study.

- **Experimentation block.** Two weeks of experimentation with different users using the previously created prototype. Results are extracted and compared to the state of the art.

- **Writing block.** Last piece of work, write the thesis collecting all the work done during the year.

In addition, meetings were held with the supervisors every two weeks to assess the work done and talk about future steps.

The following Gantt diagram represents the work calendar and time used in every of the five phases.

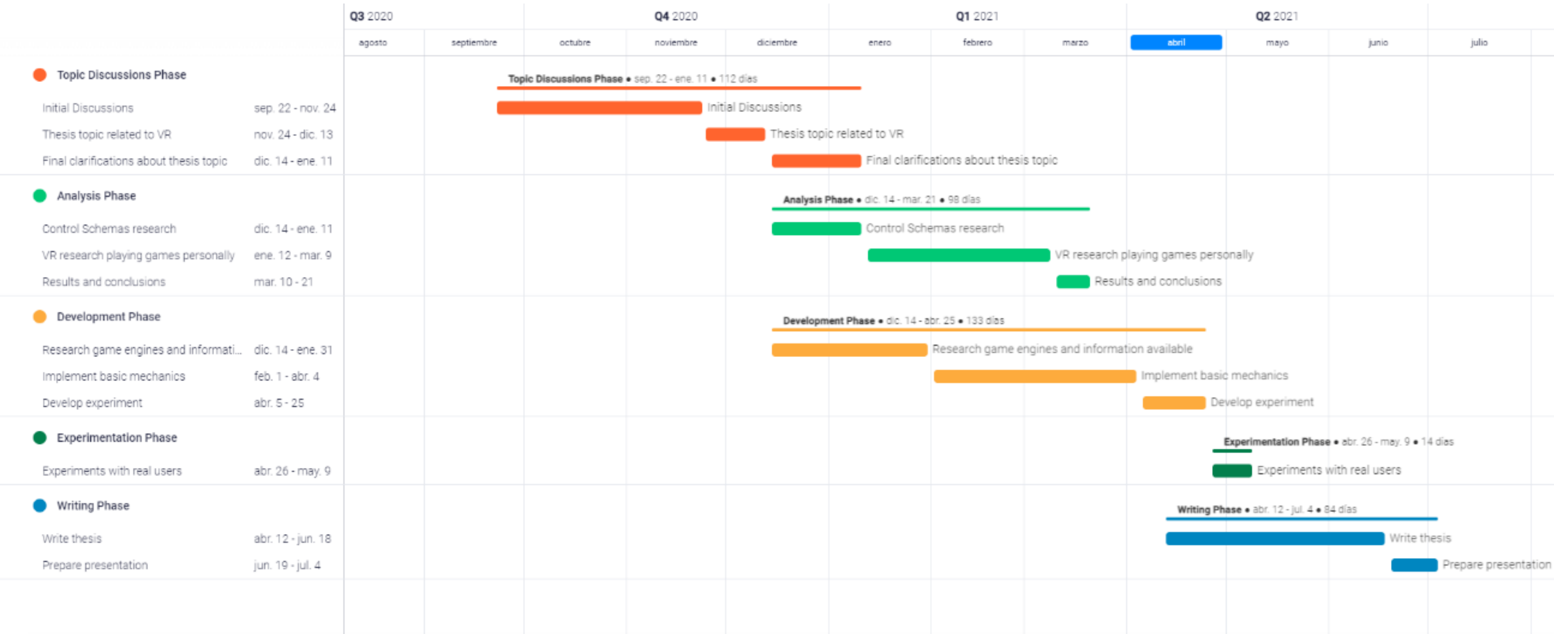

Figure 1 - Gantt diagram representing the calendar of tasks for the thesis.

2. BACKGROUND

In this part, we are introducing the necessary background to understand the work. The first subchapter talks about the history of Virtual Reality games in comparison to non-VR games to understand from where we start and the current status of the industry at this moment. Next, we are explaining the basic concepts of VR and terminology such as hardware, interaction techniques and comfort modes. Finally, related work to VR will be explained in order to present the state of the art and the basis of this work.

2.1 Historical comparison of VR and non-VR games

For this project, it is important to do an overview of the history of Virtual Reality to understand where we come from, and also observe the gaming industry and compare it to the VR branch of it in order to predict what the future will look like for this new platform.

Virtual Reality games are gaining momentum right now and that is because hardware and software during the last years of the 2010s and beginning of 2020s are having a huge improvement in quality and availability: reduced motion sickness, hardware costs less money and games are more involved in nowadays society. But the first concepts of Virtual Reality are dated back to 1838 where the idea of a stereoscope was defined. The idea behind the stereoscope is the binocular vision: if the brain combines two different images of the same object from different perspectives, one from each eye, it can reconstruct a single image that has a sense of depth and immersion. And here is where all the concept of Virtual Reality is based.

During the following years, head-mounted displays (HMD) started being developed, first as fixed devices and then evolved to being wearable. In 1961, an HMD was already developed with motion-tracking features.

During the following years and also nowadays, a lot of VR experiences related to military training were developed, especially aircraft related. It is a great tool to train without being in danger. Also, NASA used VR for astronaut training. This affected the industry and the future of VR, since different companies related to the military industry invested huge quantities that led to opportunities for improving the hardware (HMDs and controllers) and software (VR experiences, design and graphic quality).

The first handheld controllers were invented in 1982 as gloves and started the work on gesture recognition to be later commercialized in 1985. Controllers are such an important topic nowadays and depend totally on the company that develops the VR setup, as it happens with non-VR games. Due to the big amount of companies investing in their own headsets, there is a lot of variety in controllers although we can start to see common components in all of them with different buttons for the thumbs and trigger buttons for the rest of the fingers. Companies are also going for a more ergonomic design for their controllers.

In the early 1990s, VR was available to the general public thanks to arcade machines. During the years, most of the popular arcade games such as Pac-Man had a VR version. During the same decade, video game companies like VictorMaxx, SEGA or Nintendo launched their VR hardware to the general public but they were a commercial failure due to lack of graphic quality, support from the companies and that they were uncomfortable to use.

In the first decade of the 2000s, full body interaction experiences were part of the mainstream in the video games industry. Sony developed the Eye Toy while Microsoft had the Kinect. They were cameras that detected the player's body and they could interact with video games in the PlayStation and XBOX consoles, respectively. Other approaches to player gestures were available with the Wii controller or the PlayStation Move, with two controllers, one for each hand, that the player used to interact with the game. Companies used these controller tracking technologies for the modern VR experiences.

It was in 2012 where the first VR HMD was fully funded by crowdfunding, the Oculus Rift, raising 2.4$ million. By 2014, Oculus was sold to Facebook for 2$ billion. Also, other video game and technology companies started working on VR hardware, like Sony or Google.

By 2017, hundreds of companies were developing products for VR, including hardware and software. Most of the big companies in video games and technology like Sony, Microsoft, Google, Apple, HTC Vive, Steam and others had already released a version of their own headset or had one in progress.

The biggest moment for the VR industry in the last few years comes in 2019. Oculus announces the launch of Oculus Quest, a standalone HMD that does not require a powerful computer to play, allowing a most economical way to experience VR with a prize closer to the PlayStation or XBOX consoles. It becomes another console, not an expensive way of gaming. Moreover, using a standalone device is more immersive and comfortable to the user, no cables are needed and you have everything you need in the HMD. This popularized VR for the average consumer and it affected the numbers: Steam announced that the number of devices connected monthly surpassed 1 million users and Beat Saber, was the first VR game to sell over 1 million copies during 2019.

Understanding VR history and the current situation is really necessary for this work: we need to understand that VR, at the moment, is not comparable to the whole video games industry. For example, arcade machines started being developed by the 1970s while VR support came 20 years later, and not with the quality of conventional games. In 1977, Atari launched his first console, available to play at home. In comparison, in 1994, the first VR HMD for commercial purposes was launched, to be available for the general player at home, although it was not a commercial success. These products were not supported by the companies for long since they did not have the success they expected and the VR industry collapsed for almost 10 years. It was not until 2015, that Oculus launched the first modern VR HMD for personal use and although it was a commercial success, it was not as popularized as video games and a lot of discussions appeared. Is VR the future of video games or is it just another way of gaming? In addition, the cost of having VR at home was considerable: 599€ was the launch cost but you also needed a powerful computer to run games. This computer could cost easily over 1,000€. With the launch of the standalone Oculus Quest, as mentioned before, it appears the possibility of reaching a wider audience and with the improvements that come constantly, VR is moving towards a stable position as another console available to play games and live new experiences.

In this project, we are analysing the different standards for control schemas in VR video games and from the history that we know, VR is a really young branch of video games.

A lot of studios and companies are working with different products and since it is really new, VR is a whole field of experimentation to be done.

But, eventually, different standards will appear, different formulas that work the best for the player will be discovered and applied to each experience as it happens with conventional gaming. To give an example of standardization, moving the player using a keyboard in a PC with WASD keys was popularized by a professional player of Quake and Doom called Dennis Fong, also known as “Thresh”. This player became so good at these games using WASD keys to move around that popularized this control schema at a level that nowadays all keyboard controls in video games move the player this way. Shooting using a mouse is also a standard, the player can shoot a gun pressing the left-click of the mouse. Another example can be jumping, usually triggered by the user when he or she presses the “Space” key in the keyboard.

It is also important to know that this standardization will not become possible for all types of games. As it happens in non-VR games, these formulas that work as a commercial product, usually work for specific genres of video games but not for all of them and since VR can be a great platform for different genres. We need to take into account that games are all different and it is difficult to compare them as a unit.

Are there any standards for control schemas in VR gaming? Which are the different approaches made by different games on the same game mechanic? Why do we have a given standard and under which conditions? These are some of the questions that this project aims to answer.

2.2 Basic Concepts of VR

In this part, we will present some definitions of terminology used in VR that are relevant for the thesis.

a) Basic Concepts

Degrees of Freedom (DOF): the number of degrees of movement that an object has depends on how many independent parameters define its state. For example, a train that moves in a straight track has only one degree of freedom (1DOF) since it can only move in one axis. Rigid bodies have at least six degrees of freedom (6DOF): three for rotations and three for translations.

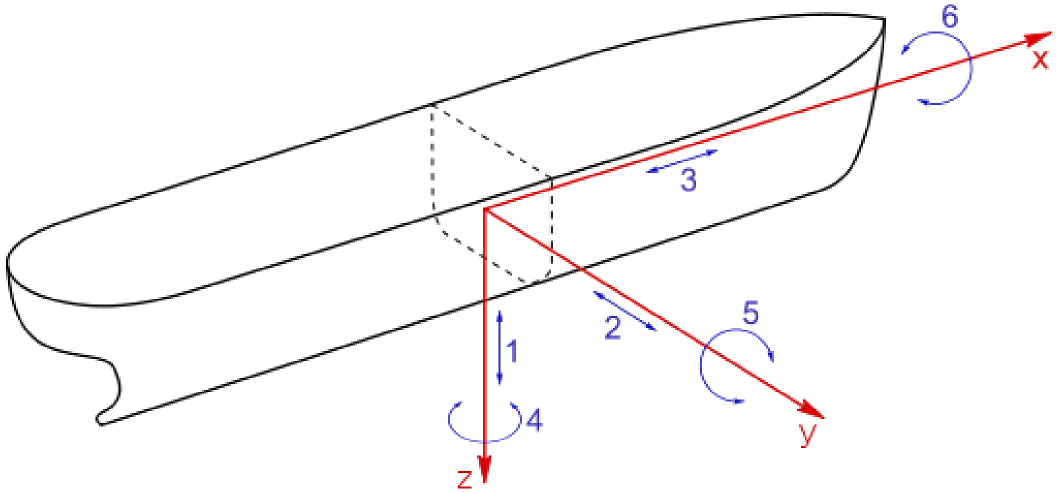

Figure 2 – A ship with six degrees of freedom

Positional Tracking: this concept is related to how virtual reality software can detect the position of the user and any device that wears or has in his or her hands. Positional tracking can be achieved with different techniques and methods such as magnetic or acoustic tracking, among others. For Virtual Reality, there are two main methods related to optical tracking: the outside-in and the inside-out techniques.

The outside-in method has been used in the first models of VR positional tracking. It consists of multiple cameras pointing to the play area that track infrared markers located in VR devices. This method has more accurate readings although it requires extra hardware.

The inside-out method switches the concept, now the headset contains multiple cameras and sensors that map the surroundings using the SLAM method (Simultaneous Localization and Mapping). This technique requires less hardware since you don't need any extra outside camera and it is more portable, you can play in any area. On the other hand, it requires a more powerful system to support the higher processing needs. This method is more used in the new models of VR systems.

Motion Sickness: it occurs when there is a difference between the actual and expected movement of the body. This is the most challenging problem of VR: how to reduce motion sickness while playing. To do a comparison, motion sickness also happens in cars or ships where a person is moving and seeing that there is a movement but there is no actual movement from his or her body and then, they start feeling sick. The most common consequences are nausea, vomits, cold sweat, headaches and sleepiness. In VR experiences where the user moves inside the scene, motion sickness can occur although there are different techniques to reduce it like moving the body in reality while moving in the virtual scenario.

Haptic Feedback: it consists in the use of touch to give feedback to the user depending on their interactions. For example, whenever a user grabs an object, a controller vibrates. These systems are used to give immersion, enrich the experience and to give the sense that you are really touching the virtual world.

b) Hardware

Head Mounted Display (HMD) or VR headsets: stereoscopic displays (it contains two different screens, one for each eye, that show the same scene from a different point of view) that the users wear on their heads. The headsets also have stereo sound and head motion tracking sensors like gyroscopes or accelerometers, among others. They can also be used as controllers.

Old versions of HMDs had 3DOF: you can only rotate your head but if you move your body in the player area, you will not move in the virtual world. Newest HMDs models have 6DOF since you can rotate your head but also move in the scene just by moving the body.

Tracking Cameras: devices used to track HMDs or other devices in the play area. Used in the first commercial VR HMDs although right now, most of the HMDs are using the inside-out technique to track the position. Some of these tracking cameras are a solution for large play areas or for multiplayer experiences with several people inside the same room.

Handheld Controllers: These are the most used hardware to interact with VR experiences. The controllers come in pairs, one for each hand with several buttons displayed symmetrically and motion tracking. They have different buttons: multiple ones for the thumbs, one for each index finger and one more for the middle, ring and little finger. The controllers also have haptic feedback and six degrees of freedom

Other devices: there are other interesting devices and techniques that are proposing different solutions for VR experiences. For example, haptic gloves that let you feel an object when you grab it. It has force-feedback devices in each finger to give a higher immersion in the experience. Other techniques related to controllers are the possibility of using your own hands as controllers although you cannot have the haptic component to this solution. Other interesting approaches are the omnidirectional treadmills, a whole new solution to movement and motion-sickness. These type of devices consist of foot sensors and treadmills that can move in any direction for the user to move their legs to move in the VR scenarios.

c) User Interaction

Locomotion: by definition, locomotion is the act of moving from one place to another. In VR, this is a very interesting topic and a problem at the same time, we need to let the user move in the VR space when the real area is not big enough to cover the virtual area.

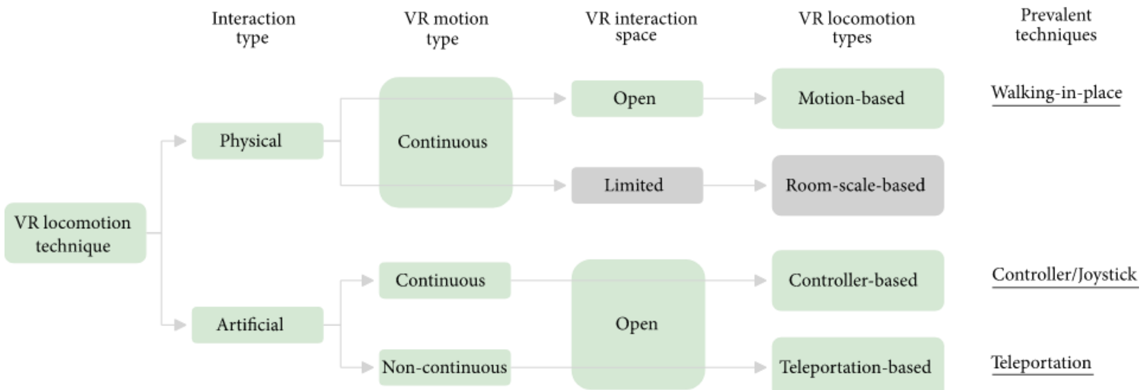

Figure 3 – Classification of VR locomotion techniques

There are multiple locomotion techniques for Virtual Reality video games and they can be classified into which interaction the player must perform with the VR hardware [6].

The interactions can be physical, the player does a physical motion with his or her body that will affect the behaviour inside the game, or artificial, where the player will use the handheld controller buttons or triggers to behave in the virtual environment.

Physical interaction is always continuous, meaning that the movement of the player will not be interrupted and it will be continuous in the space. On the other hand, teleportation-based locomotion systems are non-continuous, meaning that when the teleportation is performed, the player will move to a given position in the virtual environment interrupting the continuous movement since he or she will jump from one place to another.

All locomotion systems are open when talking about VR interaction space except the room-scale-based locomotion. In this context, open means that the player can move wherever in the virtual scene and can only be limited by the developers of the experience. Room-scale-based locomotion is limited in this sense, because the player can move in the virtual environment as much as he or she can move in the room that is available. This works well in experiences that always use the same room but playing VR games at your own home is a problem because not everyone will have the same space. That's why room-scale-based is reserved for specific experiences and is not used in commercial games for everyone to play at home. In some games, the player may be able to do some steps in the real world to move around, but they will also need another locomotion technique to be able to explore the whole environment. For all the reasons mentioned above, we don't take into account the room-scale-based locomotion options that some analysed VR games offer to us since we are looking for at-home experiences that can be played by everyone in a limited space.

In conclusion, we have four locomotion techniques:

- **Motion-based locomotion:** it takes into account the body motion of the player to move inside the virtual space. The most commonly used interaction is called Walk-in-Place that consists to track the motion of the player using the motion of their hands or the head, since there are sensors located in the HMD and the handheld controllers that permits the software to understand that the player wants to move.
- **Room-scale-based locomotion:** depending on the space that the player walks in the real world, it will walk the exact same distance in the virtual space.
- **Controller-based locomotion:** the player interacts with buttons and joysticks of the handheld controller to move in a continuous form inside the virtual space. The most common interaction is to use the joystick of the handheld controller to let the player move in any direction, called Free Locomotion. The interaction is similar to moving an avatar in a non-immersive game with a controller.
- **Teleportation-based locomotion:** the player presses buttons or triggers of the handheld controller to jump from one place to another in the virtual space. The most common interaction for this technique is called Teleporting Locomotion that consists in pressing a trigger or a button that will show a ray in the scene where the user will jump or teleport to when the trigger or button is released.
    - **Anchored teleporting**: this is a variant of teleportation where the player can only be teleported to a given set of positions designed by developers, then the movement is limited.

Grabbing: it refers to the ability of the player to pick up virtual objects with his or her hands.

Other actions: VR offers a lot of possibilities with the simplest of set-ups: just a HMD and one handheld controller by hand. VR developers can create mechanics related to pressing different buttons and they can use the positions of the HMDs and handheld controllers, relative to one another, to create specific gestures for the different experiences. For example, a user can reach with a handheld controller to his or her back, press a button and obtain an object from a virtual backpack.

d) Comfort Modes

Virtual Reality always strives for comfort, immersion and the desire to deliver the best user experience. For these reasons, developers add comfort modes for the players to use while they are playing [7]. These modes are usually optional but they are also part of the accessibility features of the games. It is important to remember that there are a lot of types of players with a lot of differences and some of them may have some disabilities that will not let them play standing up or doing certain body gestures. We will now list some of the most used comfort modes in VR games:

Reduced Field of View (Reduced FOV): the idea is to reduce the field of view of the player or FOV when he or she is moving to reduce motion sickness. It can be accomplished by reducing the area that the player sees by blurring the surroundings or just having black surroundings around the FOV area.

Snap Turn or Snapping: this concept is related to how to move the orientation of the camera in a VR world. It appears as one of the solutions to motion sickness and it consists in the ability of the player to turn the camera a certain amount of degrees instantly. For example, when the player presses a button in the left controller, the camera will rotate to the left 30º.

Teleport-move: this is the most used solution to motion-sickness. The idea is that the player moves by teleporting himself or herself to a position that they have indicated. Since there is no continuous movement, it reduces motion sickness.

Head-based and Controller-based movement: this option is added to improve the user experience. When the player moves forward there are two options: consider the forward direction where the user is looking at (head-based movement) or consider the orientation of the controllers or hands (controller-based movement). The player can usually choose between both options.

Body postures: most of the games also have a body posture selector for the player. You can choose if you prefer to play seated or standing because maybe you feel dizzy or you have a disability. In some games, you can crouch at some given points and some games also have a button to crouch or stand up when pressed to make the game more accessible to all players.

2.3 Related Work

Current studies of Virtual Reality and video games are focused on different topics that are interesting for this work: usability and user experience (UX), human-computer interaction and locomotion solutions.

When talking about usability, there is no clear statement about video games and VR. There are papers indicating that “VR enhanced overall satisfaction, enjoyment, engrossment, creativity, sound, and graphics quality” [8] and on other side, there are other works that say that there are no significant improvements for the user experience (UX) in VR games in comparison to non-immersive games [9,10] although there is a higher sense of immersion and emotional response [11]. In this case, we have to mention that most of the work that has been done is comparing non-immersive or conventional video games (played on PC or consoles) to VR games and it has some problems since results may not be generic for all games.

Other interesting related work are papers talking about human-computer interaction with VR. Virtual Reality control schemas are not better than using a mouse and a keyboard. The last one is still the preferred system to use [12]. At this point, it is more difficult for the users to control a game in VR than in a non-immersive environment. There are also papers comparing different control inputs for VR games. An experiment was done comparing handheld controllers and an XBOX controller in two different types of games and it was shown that there were no differences in terms of UX in the shooter game but in a strategy game, the use of handheld controllers felt more natural [13]. These results support the idea that we can’t talk about VR video games as a single unit but we have to take into account that there are significant differences in game genres and some may work better for VR and some may not.

Other works to take into account are the ones related to locomotion in VR since it is one of the greatest problems of the area. Experiments comparing different locomotion techniques and the user experience with them had been performed [6]. Some conclusions could be extracted from this work. Walk-in-place methods are the most immersive and natural while controlling movement with a joystick is easier to use, more familiar. Locomotion in VR can cause motion sickness and that affects negatively to the user experience. Teleportation is the locomotion technique that causes less motion sickness.

In summary, most of the work related to VR and video games is focused on comparing immersive experiences on VR and non-immersive experiences on PC. Other works compare different control inputs and they follow the same idea: compare a control input designed for non-immersive games to an input designed for VR. User Experience can be really different depending on the game genre and this has to be taken into account, it is difficult to generalize results from experiments to video games, we need to be specific to which kind of game we are referring to. Moreover, it is important to realise that VR gaming is not a popular platform to play at this point and that control schemas similar to the existing ones like using a joystick or pressing buttons, will be easier to use for the players than doing gestures since they are more familiar to games using joystick and button controllers than motion controllers like the handheld controllers used in VR.

3. ANALYSIS OF CONTROL SYSTEMS IN VR GAMES

In this chapter, we are going to analyse different games developed for VR platforms in order to find similarities and differences in their control systems. This is the main part of the project. In the following subchapters, we will talk about the goals of the analysis and which topics were interesting for the work, procedure, and under which conditions the analysis was done.

3.1 Goals of the analysis

The goal of this analysis is to find out what control systems VR games use. From this extraction of data, we will determine common practices in the industry, or on the other hand, if a certain game mechanic has a variety of control schemas. From the analysis, we will be able to know if a certain mechanic has a standardized control system.

As an example of this case, we could analyse a non-immersive shooter game that is played with keyboard and mouse. A game mechanic that has a standardized control system in the industry is shooting and aiming that is done by pressing the left and right mouse button, respectively. With the same type of game, we can find a non-standardized control system like it is opening the inventory of the player: games can use a variety of buttons to show what objects the player has available, like pressing the button “E”, “I” or “F” in the keyboard.

After doing the whole analysis, we are expecting to see some standardized and non-standardized control systems for given mechanics and we will try to explain why this is happening.

3.2 Conditions and Procedure of the Analysis

For this analysis, it is important to talk about in which conditions it was done and what procedure was performed.

In total, 25 video games developed for VR were played between 30 and 60 minutes in order to analyse the control systems that they offer. It is important to notice that in this short time of gameplay we may have missed some control systems that may be explained later in the game but we have covered the basic ones.

This list of games that was selected had to meet a certain criterion. We wanted games that were launched in the last years, the oldest game was launched in 2015 because we want to have the current approach to the problems that VR has, it was not interesting for us to analyse games that were made during the 1990s because a lot of improvements in the technology and user experience have appeared. Also, they had to be compatible with Oculus Quest 2 technology and Touch Controllers since it is the piece of hardware that we have available to play and analyse the games. Games from later than the 2010s are more difficult to find and play in VR. The last important aspect of the selection is that we wanted to have a list of AAA games (in the games industry, AAA games are the ones with important publishers and huge amounts of budget behind) and games with a lot of success from the public and popularity, since these games are probably the ones using standardized control systems because of the pressure they have to be a commercial success. On the other hand, VR games from independent studies are more experimental and usually, they don’t follow the tendencies of the industry. The work looks at VR games as a whole and for that reason we wanted to have games from more than one genre. We selected at least two games per genre to compare them. There are two reasons behind it: the first one being that we want to have a diverse dataset and the second one comes with a first hypothesis that control systems may have differences or similarities depending on the game genre. The analysis process was always the same for each game without taking into account the game genre. Genres are only relevant for the results chapter.

Each one of the listed games below, contains a link to the page store of the game for more information. The list of genres and games is the following one:

NARRATIVE GAMES

- The Talos Principle
- Scanner Sombre
- The Room VR: A Dark Matter
- L.A. Noire: The VR Case Files

ACTION GAMES

- The Walking Dead: Saints and Sinners
- Half-Life: Alyx
- Journey of the Gods
- GORN
- BONEWORKS
- Stormland
- SUPERHOT VR
- Batman Arkham VR
- In Death

RHYTHM GAMES

- Beat Saber
- Ragnarock
- Pistol Whip

RACING GAMES

- Touring Karts
- VRacer Hoverbiker

SHOOTING GAMES

- Hot Dogs, Horseshoes & Hand Grenades (H3VR)
- Space Pirate Trainer

SPORTS

- Creed: Rise to Glory
- Sports Scramble

SIMULATORS

- Keep Talking and Nobody Explodes
- Job Simulator
- Surgeon Simulator VR: Meet the Medic

All games were played in a $3m^2$ area with an Oculus Quest 2 HMD and Touch controllers developed by Facebook. This device has the advantage that it can be played in wireless mode so it is easier to move freely and without distractions or obstacles in the play area.

We will talk about what kind of controllers were used since most of the information about the control systems is related to which buttons on the controllers the player interacts with. Then, it is important to get familiar with the button names that will appear during the next parts of the thesis.

The following image contains two handheld controllers from the point of view of the player and the names of the buttons that we will refer to.

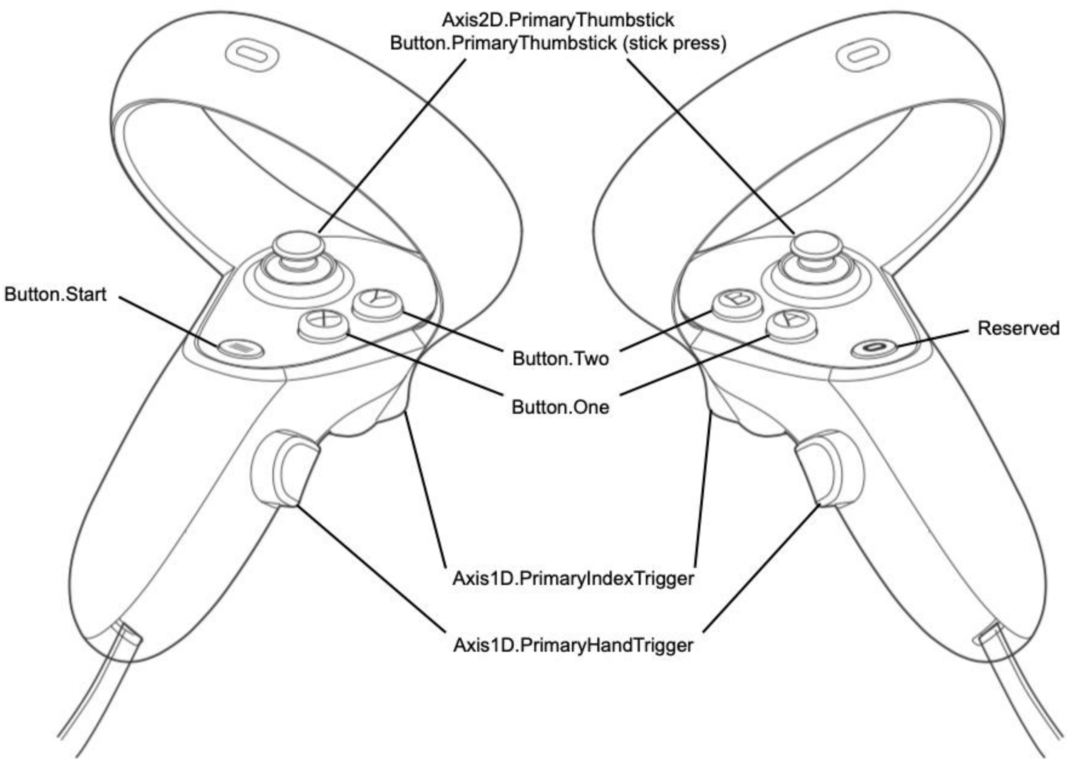

Figure 4 – Naming of the different components of the Oculus Touch controllers

Each one of the fingers of the hands can interact with the controller:

- Thumbs can press:
    - Button.One,
    - Button.Two
    - Press and move the joysticks,
    - Button.Start,
    - and Reserved button (used to access the main menu of the device).
- The index finger can press the Index.Trigger.
- The middle finger can press the Hand.Trigger.

The process for each game was to try the first minutes of each one of them and test all control systems available. For some games, more than one control system was available for given mechanics. Then, the control systems were written down with detail next to some personal thoughts about them.

We avoided the use of room-scale locomotion options in some games where it was available since it was not coherent on how most people would play with VR. For playing at room-scale, a lot of space is needed, a thing that not a lot of people have at home and it would have caused many difficulties to this work.

3.3 Results from the Analysis

In this chapter, the results from the analysis are presented in tables. We will show the main mechanics of the games and what control systems are used for each one of them.

Each one of the rows of the table represents each one of the 25 games, divided in blocks depending on their genre. The columns represent game mechanics and control systems such as locomotion, menu and combat features. We will define in detail each one of the columns for each one of the tables.

In total we have three different tables. The first one refers to locomotion systems, the second one is about object interaction and the third one represents the results from combat systems and menus.

The colour code of the tables is really simple, just green or red meaning that a game has a given control system or not.

This part of the thesis is a collection of results from the analysis. The full analysis of the 25 VR games can be found in this Google Drive link.

a) Locomotion

In the following part, we will talk about locomotion systems in VR video games and which options we, as players, have available.

The table shows each one of the games in each row, ordered by game genre, and different systems in the columns:

- **Locomotion:** this column will have green colour if the player can move in the virtual environment. If the player is always static and can't move with any type of control system, it will have red colour.
- **Teleporting:** indicates if the player can move in the scene using teleportation systems. If teleportation has anchored mode, it is indicated by text in the column.
- **Free locomotion:** the column indicates if the player can move using the joysticks in any direction, as he or she was using a conventional controller.
- **Physical locomotion:** indicates if the player can move with any type of physical motion.
- **Snapping:** indicates if the game let the player use the snap turn or not.
- **Other observations:** any extra relevant information for locomotion systems.

Teleportation, free and physical locomotion columns indicated in the table can appear as green for the same game. If that is the case, the player must choose one of the locomotion systems to play, unless otherwise is stated.

NARRATIVE GAMES	Locomotion	Teleporting	Free Locomotion	Physical Locomotion	Snapping	Other observations
The Talos Principle						
Scanner Sombre						
The Room VR: A Dark Matter		Anchored				
LA Noire: The VR Case Files		Can be used together				Player can also teleport to anchored positions
ACTION GAMES						
The Walking Dead: Saints and Sinners						Ability to climb walls using player's body
Half-Life: Alyx						
Journey of the Gods						
Gorn						
Boneworks						Ability to climb walls using player's body
Stormland						Ability to climb walls and fly using player's body
Superhot VR						
Batman Arkham VR		Anchored				
In Death		Can be used together				
RHYTHM GAMES						
Beat Saber						
Ragnarock						
Pistol Whip						
RACING GAMES						
Touring Karts						
VRacer Hoverbiker						
SHOOTER GAMES						
Hot Dogs, Horseshoes & Hand Grenades (H3VR)						
Star Wars Pirate Trainer						
SPORT GAMES						
Creed: Rise to Glory						
Sports Scramble						
SIMULATOR GAMES						
Keep Talking and Nobody Explodes						
Job Simulator						
Surgeon Simulator VR: Meet the Medic						

Table 1 – Locomotion Analysis

b) Object Interaction

The next table is the summary about interaction of objects in the analysed games. We will talk about what the player can do to interact and use objects. The format follows the same pattern as the previous table, the differences are in the column names and meanings. The columns are the following ones:

- **Can pick up objects:** it indicates with green or red colours if the player can pick up objects by doing any interaction with the controllers. All the games analysed can pick up objects using the Index.Trigger or Hand.Trigger from the Touch controllers. If the player can pick up objects by walking close to them, for example, the column will have a red colour since the player has not done any interaction to grab it. In order to let the object go, the player must stop pressing the pickup trigger.
- **Pick up trigger:** this column indicates which trigger from the Touch controllers the player must activate to pick up an object. If both colours are green, it means that the player can choose whether he or she wants to use the Index.Trigger or the Hand.Trigger to interact with them.
- **Pick up from distance:** in this column the colour indicates if the player can pick up objects from a distance larger than a realistic one, for example grabbing objects from 3 meters of distance.
- **Object respawn:** it indicates what happens with an object that is released and it is not in its original position. If the column is green, the object will respawn at its original position in some seconds.
- **Interactable objects:** this column indicates whether the game contains interactable objects to be used when it has been picked up. For example, a gun is an interactable object, the player must pick it up with the Hand.Trigger and can shoot by pressing the Index.Trigger.

		Pick up trigger				
NARRATIVE	**Can pick up objects?**	**Index**	**Hand**	**Pick up from distance**	**Object Respawn**	**Interactable objects**
The Talos Principle						
Scanner Sombre						
The Room VR: A Dark Matter						
LA Noire: The VR Case Files						
ACTION						
The Walking Dead: Saints and Sinners						
Half-Life: Alyx						
Journey of the Gods						
Gorn						
Boneworks						
Stormland						
Superhot VR						
Batman Arkham VR						
In Death						
RYTHM						
Beat Saber						
Ragnarock						
Pistol Whip						
RACING						
Touring Karts						
VRacer Hoverbiker						
SHOOTERS						
Hot Dogs, Horseshoes & Hand Grenades (H3VR)						
Star Wars Pirate Trainer						
SPORTS						
Creed: Rise to Glory						
Sports Scramble						
SIMULATORS						
Keep Talking and Nobody Explodes						
Job Simulator						
Surgeon Simulator VR: Meet the Medic						

Table 2 – Object Interaction Analysis

c) Combat and Menus

The last table is related to the combat systems and menus of VR games. Same pattern and colour code as before. These are the details for each one of the columns:

- **Melee combat:** this set of columns indicate if there is melee combat in the game and what types are available: body and fists combat, one handed weapons like small swords or two handed weapons like bigger swords or axes. If more than one column appears with green colour, it means that the player can use more than one type of melee weapons at the same time.
- **Ranged combat:** similar to the melee combat column but indicating if the player has one or two handed weapons available. One handed weapons can be guns like small fire guns or a crossbow while two handed weapons are usually rifles or bows. If more than one column appears with green colour, it means that the player can use more than one type of ranged weapons at the same time, unless otherwise is stated.
- **Inventory:** this column indicates if a game has an inventory system and how the player can access the items in their inventories. They can be stored in a backpack or a body location, to which the player must reach and close the hand as he or she wants to pick up an object from the real world, and the player will obtain the item that was stored in that position. Another option is to open an UI panel that shows the player inventory when pressing a specific button. In any case, the players can pick up objects from the inventory or store them there. If more than one column is marked as green, it indicates that the player can use different inventory systems at the same time.
- **Menu:** these columns indicate whether the game menu is interactive or it is UI based. In the case of UI menus, if nothing is indicated, the way to interact with the UI and select the desired options is using the controller forward direction and buttons/triggers to select the option. If the column contains the word “Head”, it means that the direction that is taken into account to select a menu option is the head forward direction.

	Melee Combat			Ranged Combat		Inventory			Menu	
NARRATIVE	Body	One hand	Two hands	One hand	Two hands	Backpack	Body	UI	UI	Interactive
The Talos Principle										
Scanner Sombre										
The Room VR: A Dark Matter										
LA Noire: The VR Case Files									Head	
ACTION										
The Walking Dead: Saints and Sinners										
Half-Life: Alyx				Only one gun						
Journey of the Gods										
Gorn										
Boneworks										
Stormland										
Superhot VR										
Batman Arkham VR									Head	
In Death										
RYTHM										
Beat Saber										
Ragnarock										
Pistol Whip				Only one gun						
RACING										
Touring Karts										
VRacer Hoverbiker									Head	
SHOOTERS										
Hot Dogs, Horseshoes & Hand Grenades (H3VR)										
Star Wars Pirate Trainer										
SPORTS										
Creed: Rise to Glory										
Sports Scramble										
SIMULATORS										
Keep Talking and Nobody Explodes										
Job Simulator										
Surgeon Simulator VR: Meet the Medic										

Table 3 – Combat and Menu Analysis

d) Other Mechanics

There are two mechanics that are common in some VR games, especially in action games and combat focused experiences: weapon reloading and player healing.

Weapon reloading for fire guns has four phases: obtaining ammunition from the inventory, dropping the empty magazine, inserting ammunition in the gun and unsafe the gun. This is the case for the games LA Noire, The Walking Dead: Saints & Sinners, Half Life: Alyx, Boneworks & Hot Dogs, Horseshoes and Hand Grenades (H3VR). We found some differences in how each games deals with each phase of the reloading process:

- **Obtain ammunition:** the player must reach for a body position (back, belt or chest, depending on the game) and close the hand to get ammunition to be ready to use in the gun.
- **Drop the empty magazine:** in order to put new ammunition in the gun, we must first drop the empty magazine.
  - In LA Noire, you can insert a new magazine without pulling out the empty one.
  - In The Walking Dead and Half Life games, the magazine is dropped by pressing the Button.One from the handheld controller that has a gun in game.
  - In Boneworks and H3VR, the magazine must be taken off from the gun with the other hand picking it up.
- **Insert ammunition in the gun:** this step is straightforward. Once the player has ammunition in their non-dominant hand, he or she gets the hand close to the dominant hand (or weapon hand) and the ammunition is automatically inserted in the gun.
- **Unsafe the gun:** in this last step, most of the fire guns have a safety mechanism that must need to be deactivated to be able to shoot. The player must interact with it, usually needing to pull back the top part of the gun, as it would be done in the real world. After unlocking the trigger, the gun is ready to be fired.

Other games use ranged medieval weapons like bows and crossbows. Their reloading phase is simpler: obtain ammunition and insert it in the weapon, then it will be ready to shoot. For the games Journey of the Gods and In Death, the player is able to shoot using a crossbow. Pulling the string from the crossbow back, as you would do to insert an arrow in the crossbow, is enough for an arrow to appear in the crossbow and to be ready to be shot. In Journey of the Gods, for each time you pull back the string, you will receive three arrows that can be shot consecutively, as if it was a semi-automatic gun. In the game In Death, the player must pull the string back for each arrow that he or she wants to shoot.

There is another different case in the rhythm game called Pistol Whip that also uses a reloading mechanic. This game consists of shooting people at the rhythm of frenetic techno music. The gun has 15 bullets and the reloading process consists in just pointing the gun to the floor and the ammunition will be restored to the full magazine again. The idea is to force the player to do some kind of movement to reload the gun but keeping the fast pace of the game without having a too complex gesture for the mechanic.

Another relevant mechanic in action games and combat-related games is the healing system for the player. The most used options are time-based healing, item healing and location healing:

- **Time-based healing:** receiving multiple impacts in a short period of time can cause the death of the player, when time passes, health is partially recovered until the player reaches full health again. Games implementing this healing system are:
    - LA Noire: The VR Case Files
    - Journey of the Gods
    - Gorn
    - Boneworks
    - Pistol Whip
    - Creed: Rise to Glory
- **Item-based healing:** in order to heal, items previously collected in the game must be consumed. It can be food, beverages, pills or the player must do a gesture like putting a syringe in his or her arm or roll a bandage over the arm to heal. Games implementing this healing system are:
    - The Walking Dead: Saint and Sinners
    - Stormlands
    - In Death
- **Location-based healing:** this healing system is based in safe rooms distributed around the scenario. When the player arrives at one of these locations, the idea is to recover from the fight, recompose and prepare for the next challenge: it is not only a physical but also a mental stop. At these rooms, usually there are ammunition and healing stations that the player can reach to recover partial health. Games implementing this healing system are:
    - Half-Life: Alyx

Moreover, in action games where fire guns are involved, they have single arm guns as pistols. For this kind of guns, the player only needs one hand to use them but he or she can support the primary hand with the secondary hand by grabbing the gun and working as a support. Shooting with both hands on the gun will provide stability and better aim when shooting.

e) Control Mappings to Oculus Touch Controllers

To finish with the results from the analysis, we will show the picture of the Oculus Touch controllers with all the actions that each button performs when it is used.

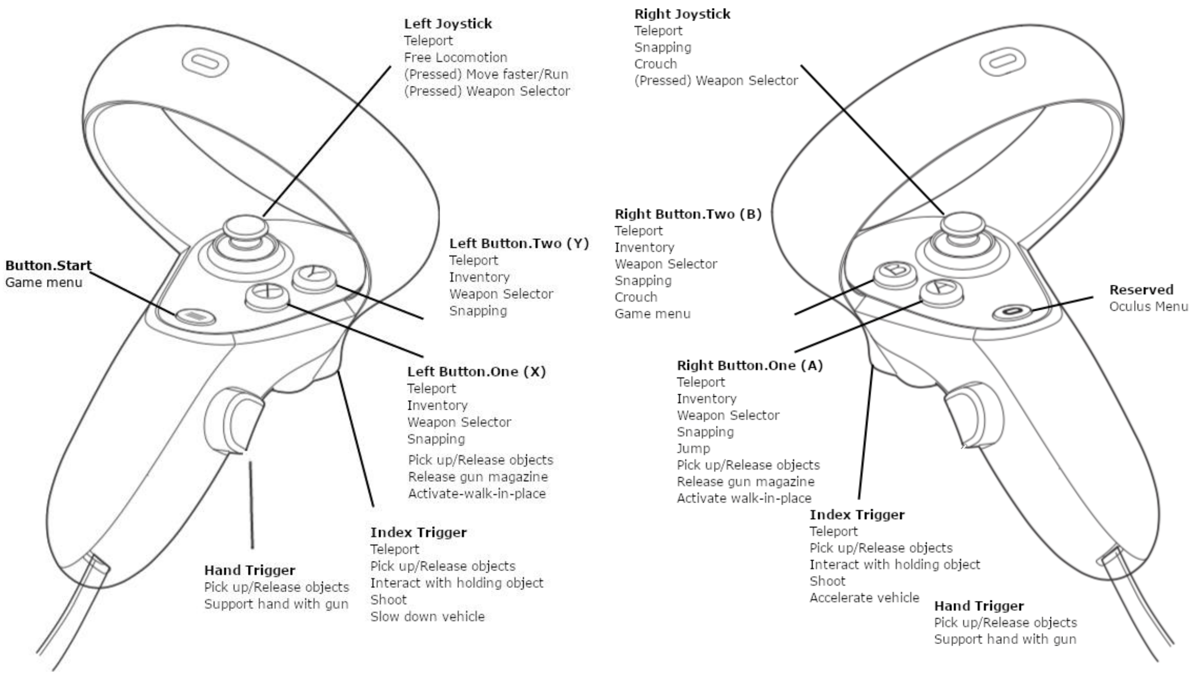

Figure 5 – Mapping of all the found mechanics to the Oculus Touch control schema

This figure represents the handheld controllers used in the analysis of the thesis. Next to them, there is a list of interactions that happened at least in one game of the dataset. This means that, for example, left joystick interaction, in at least one game of the 25 that we have analysed, it will work as a teleportation trigger, to move in free locomotion and if it is pressed it can be used to move run, or even to select a weapon from a UI panel.

The goal of this picture is to summarize what can happen in any given game if you interact with a button, trigger or joystick.

For clarification, we will define some of the terms that appear in the figure:

- **Weapon Selector:** a UI panel that lets the player select a weapon from a given set is shown on screen.
- **Inventory:** open UI inventory.
- **Activate walk-in-place:** walk-in-place locomotion system must be activated by pressing Button.One from both hands. This is done to avoid the player moving his or her hands because of other gestures where the game can confuse what the player wants to do. If some button is pressed, it is clear what is the intention of the player.
- **Support hand with gun:** for example, if the right hand is grabbing a gun, with the other hand the player can also grab the gun at the same time to support, improve stability and get better aim to shoot.

3.4 Discussion of the Analysis

In this subchapter we will discuss the results obtained from the analysis of the 25 VR chosen games. We will talk about locomotion, object interaction, combat and other mechanics, and we will also discuss the control mappings to Oculus Touch controllers that are being done in different games.

a) Locomotion

From the locomotion table, we can see that narrative games and action games use locomotion in their design while rhythm and simulator games are static experiences for the player. There are some exceptions in action games such as Superhot, it could be also classified as a rhythm or puzzle game since the idea is that enemies come to the player from different positions trying to kill him or her. Then, the player must find the best way to get out of the situation by killing everyone in the room.

In shooting games, H3VR has locomotion while Star Wars: Pirate Trainer does not. This is also because of design; in H3VR the player is free to move wherever while in the Star Wars game is like an arcade shooting gallery.

Also, in sports games we can see differences between Creed: Rise to Glory and Sports Scramble, being the first experience with locomotion and the second a static one. In Creed, you must move around the ring while boxing your opponent while in Sports Scramble you only need to do a given gesture for the sport you are playing and the virtual avatar will move by itself.

If we take a look at the types of locomotion in games, we can also see some differences: teleportation is highly used in narrative games while action games prefer to use free locomotion. Also, physical locomotion is not very present in VR games, although both racing games have physical interaction to move. This can be happening because doing the gesture of driving in VR may raise the immersion levels of the players. On the other hand, walk-in-place technique is not very common and that may be because of several reasons: forced or unnatural gesture of walking (the player needs to move its hands a lot to move inside the game), fatigue and complexity of the control system. In order to walk-in-place in VR, the players need to activate it somehow, usually pressing buttons of the controllers since it is necessary to indicate to the game that the player, in fact, wants to move by swinging its arms. If no button was pressed, whenever the player moved its hands, he or she would move, and that causes a lot of problems when trying to use your hands for other purposes like object interaction.

We can also see that anchored teleportation is not widely used, only in three games, but those have some things in common: they are not open-world games. LA Noire, Batman and The Room are series of scenarios that are linearly connected and have puzzles to be solved in all of them. From this idea, there are always certain areas that are more interesting than others containing clues and objects, and that's why these games have the possibility of performing anchored teleporting to these locations of interest where the objects are placed. Although LA Noire at first could look as an open-world experience, it is an episodic game and the tasks are clear at all times and follow a linear path with some small branching of the story without letting the player explore all the city.

From the table, we also see that a simultaneous combination of locomotion techniques is rarely used. Games may have more than one locomotion system available and they let the player use one or another system, but they usually can’t be used at the same time. This could be more a design decision and a solution to provide the best mode for the player without creating a complex control schema too difficult to master because it has a lot of different interactions and controls. All VR games tend to use a simple control system, avoiding the use of controller buttons and exploiting the possibilities of body motion and gestures that VR offers.

Snapping is primarily used in action games. That could be understandable because of the need for faster movement in this genre but also as a comfort mode, it could be beneficial to pair it with free locomotion to avoid motion-sickness. On the other hand, narrative games already have teleportation as the primary locomotion technique that does not cause motion-sickness.

To finish with the locomotion discussion, we can also see that some games implement body gestures to not only move at a floor level but also in heights: the player is able to climb walls using the handheld controller.

b) Object Interaction

Whether the player can pick up and interact with objects while holding them is a design decision from the development team so we can’t say that in an action game you can always pick up objects because that can be false. Letting the player pick up objects and interact with them, implies a costlier development, and it is easier to pick up objects automatically when walking close to them rather than implementing a whole new system to pick them up.

In any case, there are differences in how the player should pick up an object. 7 of the 15 games that let the player pick up objects, use both Index.Trigger and Hand.Trigger for it while the rest only uses one of the triggers. Sometimes, there are objects that can only be picked up using the Hand.Trigger since they are interactable objects like guns. For interactable objects, something will happen if the player holds the object and presses the Index.Trigger, like shooting, and that’s why to hold a weapon, the player must need to keep the Hand.Trigger pressed while the Index.Trigger is used to shoot.

From other columns, we can see that picking up objects at a long distance is only used in action games, probably because of this idea to have a fast gameplay and to help the player to have a better experience. Since locomotion in VR can be complex and disorienting, the fact that the player can bring objects closer to him or her, rather than moving himself or herself, helps the player to have a large set of options to interact with the virtual world. Also, picking up objects from a distance can be considered another comfort mode for the player.

Another interesting idea from the table is what happens when an object is released from the player’s hands. In most of the games, the object will have physics and will fall down staying in a new position in the scenario, depending on what the player has done with it. But for the games of Batman and The Room, whenever the player releases the object far from its original position, the object will appear again at its starting position. That happens because in these games, the only locomotion technique available is the anchored teleportation, then the player cannot move freely around the environment and if an object has been thrown to a location that is impossible to access using this anchored teleportation, we have lost the object forever. Then, the solution here is that when the object is thrown away, far enough from the original position and some seconds have passed, then the object will respawn at its original position to be ready to be used again.

c) Combat and Menus

Combat in VR video games also depends on design and the type of game. Action games have some kind of combat and also other games from other genres like shooting or sport games that involve combat, as in the case of the boxing game Creed: Rise to Glory.

Looks like ranged combat is much more established than melee combat, usually studios prefer to have a ranged combat than melee but as we said, this idea really depends on the game design.

Some relationships that we can find are related to the type of melee and ranged combat, there are different options: fists, one or two handed melee weapons and one or two handed ranged weapons. Most action games are using both hands for the combat and only three of the analysed games use single handed fire guns: Half Life: Alyx, Journey of the Gods and Star Wars: Pirate Trainer (always holds one gun per hand). In Half Life, only one hand is allowed to have a melee weapon or fire gun, leaving the other hand to pick up things and as a support: dominant hand is the one that cares about the enemies, the non-dominant hand cares about object interaction.

In all games, if the player is holding a single handgun or a rifle, he or she can also grab the gun with the other hand in order to improve the stability and aim of the gun.

If we analyse different options of inventories in VR games, we see that they are more common in action games that have objects that can be relevant for the gameplay. We found that the inventory can be used in body locations like belts or pockets, where the player can leave and get objects previously stored by closing the hand when the handheld controller is near that part of the body. Also, UI inventories are present in VR although they are less immersive but, at the same time, cost less to develop and it is easier to understand for the player. When the player opens a UI panel as the inventory is easier to know what is there, what can be used. Using the body as the inventory is more difficult to be aware of what items or weapons the player has available and needs to make an extra effort to remember what objects have and where they are stored. On the other hand, as we said body inventory is more immersive and faster to use in an action game, while using a UI implies more time to store or retrieve objects and if that’s used in action games there are two possibilities: the game is paused and the player losses immersion or the game does not pause and then the enemies have the opportunity to hit or kill the player while he or she is using the inventory.

In the discussion about game menus we have to talk about the differences between interactive menus and UI menus. Interactive menus offer a more fun and immersive experience than UI menus. Moreover, the player feels as if he or she is already inside the game. UI menus, on the other hand, can feel like another step until you can start playing, causing the player to be bored on this type of menu. As a positive note for UI menus, it is easier to find all the buttons that the game menu offers, in interactive menus the player can be lost and may have more difficulties to find different options of the game because he or she does not understand what an object can mean and if the player must interact with it or not. Interactive menus can be more confusing than UI menus. Also, familiarity is quite important for the player, interactive menus are not that common in non-immersive video games so that could be a reason why the players would prefer a UI menu.

As another characteristic, UI menus can use head direction or controller direction to indicate which option the player wants to select. The idea is that you point to a given button in a menu with your eyes or pointing forward with one of the controllers, then the player presses the Index.Trigger of the controller and interacts with that button. This decision is more related to design constraints but there are some cases where it is recommended to use one or another. Head direction can cause more fatigue since it implies the movement of the head to point to menu buttons but it is more immersive, the player looks forward to what he or she wants to interact with. On the other hand, controller direction is more usable and easier for the player, and it can even be more familiar to him or her. The idea is similar to the Wii or PS Move controllers, devices that have been a great success in our society during the last decade, so most of the players could already be familiar with this control system. Also, controller direction is more precise and works better for menus with a lot of options, head direction can have problems with precision and may be problematic in a crowded menu with a lot of options.

d) Other Mechanics

Reloading in VR video games is maybe one of the most standardized processes since it tries to be as close as what happens in reality while being as usable as possible. Games that have inventories and limited ammunition systems, force the player to obtain ammunition for their guns from the inventory while games that do not have this system, have a simpler reloading process that only consists in unlocking the gun trigger and the player already has bullets to shoot. The second option is the simpler one and costs less to develop although it is not as realistic as the first one. Depending on the type of game and type of player, maybe a realistic approach to reloading is better but for an action game, you want the player to be able to move as fast as possible.

We also have the healing mechanic in action games that can be classified in three categories: time-based healing, item-based healing and location-based healing. Selecting the best healing mechanic depends on the design of the game because, for example, using location-based healing means that there must be some “safe locations” in every one of the scenarios (and probably more than one location per scene) for the player to prepare for the next fight. This implies work to be done in a scenario and architecture of the level. Item-based healing works better in an open environment where the player can collect items and store them in an inventory, so they can be used whenever is needed in any point of the game. Time-based healing is easier to implement and also easier for the user to play with since if you take a lot of damage, just cover yourself and everything will be fine. The player does not need to care about items or finding locations to heal himself.

e) Control Mappings to Oculus Touch Controllers

Taking a look at the control mappings of the Oculus Touch Controllers, we can see that there are a lot of differences on how developers use the handheld controller’s options for their games. It is difficult to see patterns in there, since for example, up to 5 buttons can be pressed in different games to use the teleportation. On other mechanics, we can see that there are buttons that are commonly used for them, like using the Index.Trigger or the Hand.Trigger to pick up objects but it is still very dependent on the game design. It also affects the amount of buttons that the game needs to satisfy all the available interactions, then the developers may need to do some sacrifices to combine all game mechanics and map them to the control schema.

3.5 Conclusions of the Analysis

From the discussion of the results, we can define some standards in the VR game industry and some differences that appear around control systems.

It is important to remark that these conclusions are obtained from a dataset of 25 popular and successful games from 2015 until early 2021 and that there can exist some experimental games that use other control schemas not mentioned in this project but we are more interested in games with significant commercial success and an established position in the market.

a) Locomotion

One of the first conclusions that arise from this analysis is that action and narrative games have some type of locomotion systems implemented while in other genres, like rhythm and simulators, the players are in a static position. Narrative games prefer to use teleportation as the main locomotion system while action games are commonly using free locomotion. On the other hand, physical locomotion is rarely used in VR games although the racing genre uses physical motion for interacting with the vehicles. The modified teleportation method, the anchored teleporting, is used for a specific type of games with a linear story, puzzle mechanics and a non-open world environment.

Most of the time, the players do not have more than one locomotion system available at the same time. They can choose from different options (if the game is designed that way) but only using one locomotion system at a time.

The snap turn comfort mode is widely used in combination with free locomotion in order to reduce motion-sickness that can be caused by this locomotion technique.

b) Object Interaction

Not all games implement an object pick up system but the ones that do it use different buttons to interact with those objects. In seven of the analysed games, the player can pick up objects or release them by pressing or releasing both Index.Trigger and Hand.Trigger of both controllers. In the other eight games where the player can pick up objects, he or she must select the preferred trigger to grab objects between the Index.Trigger and the Hand.Trigger.

If a player can grab objects and it is interactable, like a gun, the object must be picked up using the Hand.Trigger while the Index.Trigger is used to interact with the gun, in this case, shooting with it.

We have also concluded that in some action games the player can grab objects from the distance. This is a comfort mode used in this type of games that helps to reduce motion-sickness caused by free locomotion by changing the perspective of the game. Now, the player is not moving towards the object, but the object is moving towards the player. This helps to reduce moving time in the scene reducing the exposure to motion-sickness.

Moreover, in all games where the locomotion system available is the anchored teleportation, whenever the player throws away an object from its starting position, after some seconds, the object will reappear in its original position.

c) Combat and menus

If we talk about combat systems, we can say that ranged combat is more used in action games in comparison to melee combat and all games that have some type of melee weapons, also have some ranged weapons as an alternative.

In all analysed games, all weapons can be used with one or two hands. In the case of fire guns, only one hand is needed to pull the trigger and shoot, but we can support the gun with the other hand to improve stability and aim.

Inventory systems can be used in both narrative and action games and can be of different types: body inventory, like using a belt, backpacks or pockets, and UI inventory. Body inventory is way more immersive although UI inventory can be more usable.

Menus in VR games can take two forms: interactive menus and UI menus. The difference in the use depends on design, budget and the user experience that the game wants to deliver.

d) Other mechanics

As per other mechanics in VR games, we can talk about reloading weapons and healing, two mechanics normally used in action games.

Reloading guns in VR games looks to be as realistic as possible. The process of reloading a gun is the following one: grab ammunition, release the empty magazine of the gun, insert ammunition in the gun and unlock the trigger. Some games can skip the first or the second step for a faster reloading and a simplified process.

Healing in combat games can be of three types: time based, item based and location based. The difference in usage depends on design, budget and user experience.

e) Control Mappings to Oculus Touch Controllers

We cannot conclude that there is a standard in the control system of any genre. Although there are similar games with the same mechanics, they don't necessarily use the same control mappings.

One affirmation that we can say for sure is that the games are looking for the simplest possible control schema that satisfies the player and game needs. Most of the games do not use all the buttons available at the handheld controllers.

Some games have substitutions of physical gestures. For example, the player can crouch by pressing a button. This is done as comfort and accessibility mode, for players that can't physically crouch or that prefer or need to play seated instead of standing up.

Some mechanics have common control mappings. In order to open the game menu, the start button must be pressed. If the player wants to pick/up or release an object, they need to interact with the Index.Trigger or the Hand.Trigger and the Hand.Trigger is also used to shoot guns. In the case of locomotion systems, the left joystick is used to control free locomotion and in order to activate the walk-in-place locomotion, both Button.One of each controller must be pressed.

So, we can say that the use of the start button, the left joystick, the index and hand triggers, and the Button.One (only if the walk-in-place locomotion is available) are standard in VR games.

On the other hand, other mechanics have a more diverse control mapping like teleportation, snapping, opening the inventory and the weapon selector menu.

4. USER STUDY

After the analysis of VR games is performed, we decided to do a user study for one of the central mechanics in any game but also one that has a lot of different implementations by different games.

We will talk about what type of study we performed and why, the goals of the study, the methodology behind it and all the work that was needed to be done before testing a VR prototype with users.

4.1 Locomotion Study

We decided to do a user study related to locomotion in Virtual Reality games comparing fast paced, like action games, and slow paced games, like narrative games. The idea came from the analysis we performed about locomotion systems where we discovered some differences depending on the game genre. Focusing on the games that had some type of locomotion system, action games used free locomotion as a primary and recommended locomotion technique while narrative games used teleportation. This difference in the use of the locomotion technique is going to be tested with a group of users comparing two different scenarios with different paces.

The main goal of this study is to compare the player behaviour using different locomotion techniques at the same time in two different scenarios. The first scenario is a slow-paced scenario where the player can spend as much time as they want in the scene and exploration is encouraged, while the second scenario is a fast paced gameplay where speed is encouraged. The idea is that the first slow paced scenario can be similar to a narrative game while the second scenario has the feeling of an action game where the player needs to be moving constantly and under pressure. We want to find out what the participants prefer in each of the scenarios and the reasons that are behind those preferences to eventually compare them to the VR games of the industry.

One of the main reasons for selecting this type of study related to locomotion is how suitable this mechanic is for an experiment. Other mechanics like shooting or inventories need other elements in the gameplay to work, like enemies, health systems and locomotion, among others. We wanted to create an experiment as controlled as possible where we only test one mechanic. Experiments with other mechanics could be really big and the player may lose the scope of the study, get distracted by other elements of the game and even get a worse player experience because of certain mechanics that may be not working correctly. We wanted to work with locomotion for this reason, as a standalone mechanic works perfectly and a whole game can be developed only with locomotion techniques as the main mechanic. We have a perfect candidate for doing a user study in VR.

4.2 Prototype

a) Hardware and Physical Space

The prototype that will be played by users was developed for the Oculus Quest 2 platform with controls for the handheld controllers Oculus Touch since it is the hardware that was available for the whole project.

With this in mind, the prototype was designed to be played in a play area of minimum 3x3 meters for the player to be free enough to feel immersed in the virtual world and not worried about the surroundings. Obviously, this play area had to be free of obstacles where the player could have any type of crash with them. The user study was performed in three different spaces with these conditions, at my home and in two television sets that the University Pompeu Fabra let us use. I'd like to thank the UPF again for their support for this project.

Also, since the Oculus Quest 2 can work as a standalone device, it was interesting to create an experience that was non-dependant on a desktop computer, then the player could put the HMD on without any cables. It allowed a better experience for the player that did not need to worry about cables and was more immersed in the VR environment.

Using the Oculus Quest 2 HMD had some restrictions for the development. For the player there are no issues, the experience is better and it is a great improvement from other HMDs that need to be plugged to a computer. But for the sake of the project, using this HMD can be problematic because of two reasons.

The first reason is that the Oculus Quest 2 is a standalone device, it is a computer itself but because of design decisions, the operating system of the HMD is Android. This means that, as developers, we need to design a game taking into account that we are working with an Android OS and not a powerful computer so it has its limitations in power while the games need to run smoothly and at a high frame rate to avoid motion-sickness. For this reason, art and code needs to be as optimized as possible for the best performance.

The other main problem of the HMD collides with one of the principles of any playtesting: observe the player behaviour related to what happens in the environment. Because it is a standalone device, we can't see what the player is doing while playing. There are different options to solve this problem. We could live stream or record the gameplay to Facebook and compare the player reactions with what is playing but it has a certain delay and we did not want to depend on a social network to work. The option that we went for, was to encourage the player to express himself or herself as much as possible and with high detail while they were playing. Of course, this depends a lot on the person and some people may be more shy or more talkative. That's why we also decided to do a final semi-structured interview at the end of the playtesting in order to try to understand the reactions and the feeling the player had during the study. Since we already knew what the player needed to do at each step, it was easy for us to understand what could happen at any given time, but their input was crucial to understand what was happening.

b) Technologies

Now, we are going into detail about technologies used for the prototype development. Of course, we are using Oculus technology to be able to experience the game in the Oculus Quest 2 HMD. For the game development, we decided to go for Unity3D as the game engine for our development. Personally, we have experience using the engine for more than 3 years now and it helped to decide which tools were better to be used. For the approach of the project, we wanted to select a set of tools that we were familiar with for better development and to focus our efforts in the whole thesis and not on learning how to use a new game engine. Also, Unity was a great fit for VR development for the amount of tools, support and community that it has.

In order to implement VR characteristics and mechanics we used Unity XR Interaction Toolkit framework to develop the prototype. It contained basic scripts and all the necessary components for VR experiences and it can also be used for Augmented Reality (AR) development although this feature was not used for the project.

For the interests of the study, recording of different metrics related to the user interaction is required. In order to save this information, we used REST calls to a Firebase Realtime Database, by Google, that let us save the information of each player in real time in a JSON file format. We decided to use this technology because of the previous experience using Firebase in other projects and that it is compatible with Unity3D. In this case, there exists a plugin of Firebase API in Unity for Android builds but for it to work, the running device needs to have Google Services installed on it. The issue comes when Oculus devices do not have Google Services and the approach needed to be changed to use REST calls to save and retrieve data from the database. We collected metrics for each one of the different scenes of the prototype. These are the metrics we recorded:

- Game time,
- How many times the player used teleportation,
- How many seconds the player used walk-in-place locomotion,
- How many seconds the player used free locomotion and
- How many times the player used snap turning.

Moreover, for us to compare different player studies, we decided to use ratios for each one of the metrics. The idea is to have a number for the last four metrics: teleportation, walk-in-place, free locomotion and snap turning, that can be compared for each player. The ratio value is how many times a player did an interaction with a locomotion system per minute, so we can compare the frequency of use of each system per user in a 60 seconds scale. To obtain the ratio value for the teleportation, for example, the following formula is used:

$$\frac{Times\ a\ player\ has\ teleported \times 60\ seconds}{Total\ game\ time\ in\ seconds}$$

Then, four more values are obtained:

- Teleport ratio per minute
- Walk-in-place ratio of seconds per minute
- Free locomotion ratio of seconds per minute
- Snap turn ratio per minute

We will now explain the JSON structure that is built in Firebase for each participant.

Figure 6 – JSON structure in Firebase for one participant of the study

This figure is the JSON structure of one participant. As we can see, we are creating a unique random identifier that works as the id for each of the participant and it has three children: the timestamp the game has been executed for the first time, if it is a real player or a debug test and an array of scenes that have been played. In total, there are 5 scenes per participant: the three locomotion tutorials, the slow paced scenario, also called “Calm” and the fast paced scenario called “Stress”. For each one of the scenes, we are saving the 9 metrics that we have explained before.

As a note, game time, free locomotion time and ratio, and walk-in-place locomotion time and ratio are presented in seconds.

Of course, for the three tutorials, only one locomotion system is available at each time. This means, for example, in the teleportation tutorial the totalWalk and totalFree will always be 0 since the player cannot move using these two locomotion systems in the given scenario.

c) Implementation

The prototype for the study was developed with the goal of feeling as much as possible as a game and not as an experiment for the players. With this goal in mind, we decided to use a cartoonish art style. We used this asset pack from the Unity Asset Store: POLYGON Vikings - Low Poly 3D Art by Synty that fits our needs not only for the style but also for the graphic optimization. Since the models are low poly, it means that they have a reduced amount of polygons and triangles, resulting in a better frame rate performance, a key metric for VR games and user experience. This asset pack was used as a basic framework for our scene since it had some prebuilt scenarios with a Viking village and mountains. Our work was to rearrange the different assets for our needs and create new scenarios if it was necessary for each one of the scenes. At this point, I’d like to thank the help of Marc Arroyo who helped in the design and the building of the environment. This collaboration came because I was helping him and some other colleagues to develop a demo of a game called Eleanor’s Song, for his final project of the degree as a student of Audio Visual Communication Bachelor's degree during the academic year of 2019-2020. For this reason, we are still working together on some small projects related to video games and he wanted to be involved in the development of this prototype in which we worked together in design and world building.

Now, we will explain the structure of the prototype and what are the scenes the players will need to go through and what are the goals and reasons of why that scene is necessary for the study.

The source code of the project developed in Unity3D and the scripts that we created are available in GitHub and there is also a walkthrough video of the prototype available in YouTube. If anyone wants to try the prototype by themselves, there is also the build uploaded to Itch.io ready to be played for the Oculus Quest 2 platform.

INTRODUCTION

This first scene is an introduction to the prototype we developed for the study. This scene sets the tone for the whole game, and introduces the background of the story: the player arrives as a young man or woman to a Viking's village to train and grow as a Viking. The goal for the player is to show his or her strengths to the Vikings and their Gods in order to be accepted in the village.

We want the prototype to feel as a game as much as possible. We want the users to forget that they are doing an experiment while they are playing. And for this reason, I would like to thank Victor Carretero for giving his voice for the introductory scene of the prototype as the chief of the Viking village that helped to set the tone of the game and raised the levels of immersion for the players.

The player is travelling on a Viking boat or drakkar that can't be controlled while hearing the voice of the chief of the village while looking at the surroundings and feeling how it really is to be in a VR environment. When the drakkar arrives at the village, the player sees the name of the game and needs to raise his or her hands to go to the next scene.

Figure 7 – Title scene of the prototype

TUTORIAL OBJECT INTERACTION

This one and the following three scenes are tutorials for the players. Since most of the users of the study have little to no experience in VR games, we thought it was necessary to create different tutorials explaining the control system of our prototype. We also wanted to let the player assimilate the controls and to show the different options and mechanics that the game has, without overwhelming him.

The first tutorial is about object interaction, how to pick up or release objects. At the beginning, the player has a table in front of him with four different objects: a hatchet, a skull, a fish and three gold bars. The idea of this scene is that the players must pick up all objects and try to do something with them in the VR environment. This is the list of available actions for each of the objects:

- Hatchet: cut a wooden pole that is standing at the player's left.
- Skull: throw it at one of the four barrels standing in front of the player. If the skull gets into one of the barrels, confetti will be thrown in the air.
- Gold bars: put the gold bars in a chest at the left of the player. The chest contains three gold bars with a semi-transparent material, to help the player understand that something is missing there and that they must put the gold bars that are on the table in the chest.
- Fish: eat the fish. The players must pick up the fish and move the hand that is holding it to their heads, then the fish will be eaten in the VR scene.

At a control schema level, the player is introduced to the mechanic of picking up and releasing objects. To pick up objects, they need to press the Hand.Trigger of one of the Touch controllers. Then, to release the objects, they need to release the trigger. If they release an object while moving the arm, the object will have some velocity and will be thrown away as if it is an object with real physics. In case the player presses the Index.Trigger or Hand.Trigger button without grabbing an object, the virtual fingers will move with an animation. If an object is picked, the hand will be substituted for the object.

In this scene, there is no locomotion system implemented. This is going to be explained in the next tutorials. In any case, since the player has a large space to move in the real world, they can take some small steps to move in the scene if they want to get closer to any of the objects. If an object is thrown away, after some seconds it will reappear in its original position on the table.

In order to advance from one tutorial to another, there is a golden cross in the scene, next to the gold chest, that must be picked up. Whenever it is picked up, the player will move to the next scene: the teleportation tutorial.

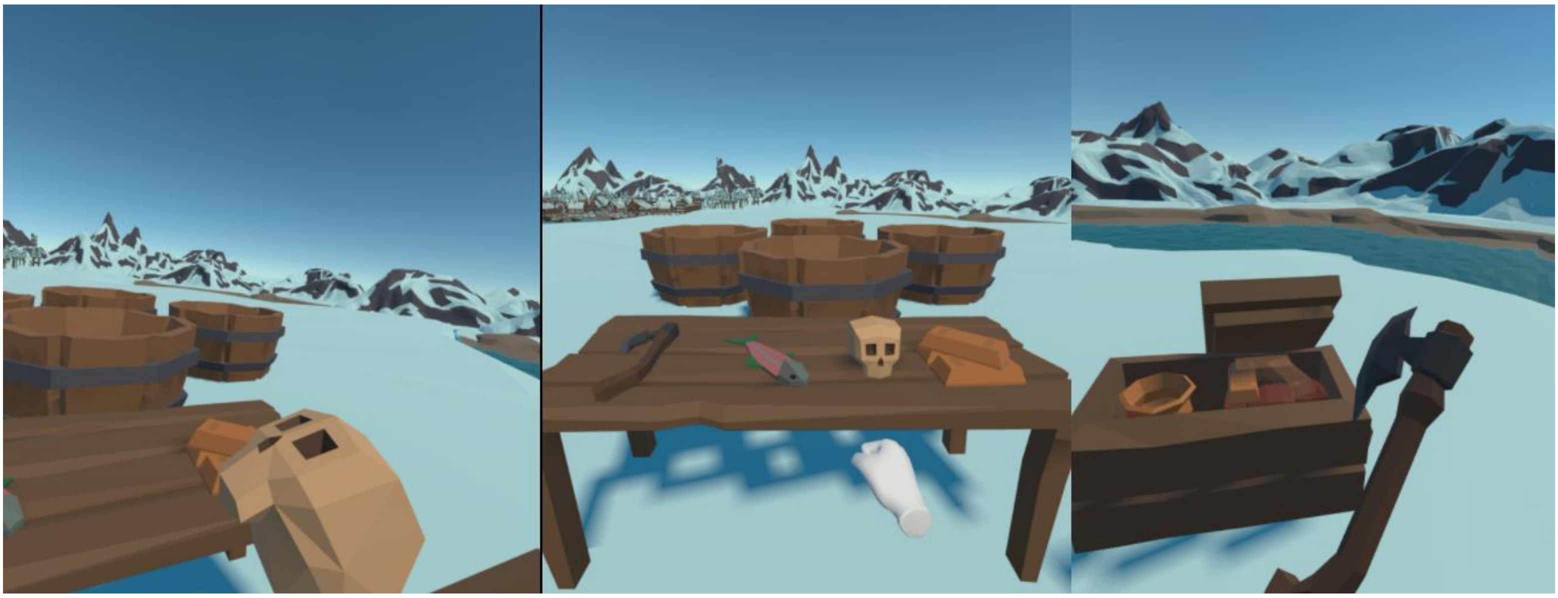

Figure 8 – Object Interaction Tutorial

TUTORIAL TELEPORTATION

This scene is the first of the three tutorials about locomotion techniques. In this tutorial, the players will move following a circuit in the Viking village using the teleportation technique. The path that the player must follow, has turns and obstacles to force the player to move in different directions.

For the teleportation to be performed, the players will need to hold the Index.Trigger of the right hand and a parabola will appear from their right hand to the floor. If the parabola is blue, it indicates that the teleportation can be performed, if it is red, the teleportation is blocked by some obstacle and the player can't be teleported at that position. When the Index.Trigger is released, if the parabola is blue, the player will be instantly teleported to the end of the parabola. The end of the parabola is clearly identified by a blue circle at the floor.

The player can also use the snap turn to turn 45º to the right or the left using the right controller joystick and he or she can also turn physically. The player can use both options at all times.

It is important to say that this tutorial only has the teleportation system available, no other controls rather than the right Index.Trigger and the right joystick are used in this scenario.

In order to advance to the next tutorial, there is a golden cross at the end of the circuit that must be picked up. Whenever it is picked up, the player will move to the next scene: the walk-in-place tutorial.

Figure 9 – Teleportation Parabola

TUTORIAL WALK-IN-PLACE

The following scene is the tutorial for the most common physical locomotion technique, the walk-in-place method. The idea behind it is the same as the teleportation tutorial with some differences in the obstacles that appear in the circuit. For example, there is a low ceiling where the players must crouch physically in order to walk under it.

In order to trigger the walk-in-place locomotion the player must press the Button.One of both controllers (buttons A and X) and swing both hands to move forward. The direction of the movement for the walk-in-place technique is the forward direction of the HMD. During this scene, the player also has the snap turn method available. The mechanic of grabbing objects and teleportation is disabled.

In order to advance to the next tutorial, there is a golden cross at the end of the circuit that must be picked up. Whenever it is picked up, the player will move to the next scene: the free locomotion tutorial.

TUTORIAL FREE LOCOMOTION

This scene is the last tutorial of the prototype. The tutorial is about the free locomotion technique where the player must use the left hand joystick to move himself or herself in any direction in the environment. The snap turn is available to use while the rest of mechanics (pick up objects, teleportation and walk-in-place) are disabled.

The circuit the player must follow is exactly the same as the walk-in-place tutorial.

In order to advance to the next tutorial, there is a golden cross at the end of the circuit that must be picked up. Whenever it is picked up, the player will move to the next scene: the slow paced scenario.

SLOW PACED SCENARIO

This scene is the first experimental scenario after all the necessary tutorials that the players need to follow to understand the control schema and to get introduced in the game.

This scenario consists in a series of tasks that each user must complete in the same order using locomotion and the mechanic of grabbing objects.

Now, each player has available all three locomotion systems explained before: teleportation, walk-in-place and free locomotion. Also, there is the possibility to snap turn and to pick-up objects during this scenario. All controls and mechanics explained in the tutorial are available now.

The scene starts with a written UI panel of instructions that the player must follow. The players will start the scene with an altar that contains four semi-transparent objects: a fish, a beer, a skull and a chalice, that they have to find in the village and bring them back to the starting point, to the altar.

The player must raise his or her hands to start the scene (this is the point when we start recording how many times the player uses a given locomotion system) and a list of objects will appear. The first object is the chalice but the other three are written in an intelligible language and they will transform to the English language whenever the player has brought the previous item to the altar. The order of the objects is the following ones:

1. Chalice
2. Skull
3. Beer
4. Fish

This scene talks about the incoming battle that the Vikings will face. That's why they need to bring some offerings to the Gods that will protect them in combat. The player has the responsibility to bring the different items to the altar.

To clarify the process that the players must do, we will explain an example. First, the chalice will be the only word that can be understood from the list, meaning that the chalice is the only object that can be picked up. If the player tries to pick up the beer, the game will not let him or her do it. Then, when the player has brought the chalice to the altar, the skull will change the language that is written in and it will be available to be picked up. This is a design decision to force all players to do the same path and to not have different objects to be picked up in a different order. We won't let the players grab two different objects at the same time to avoid that some players could exploit this method while others may go for one object at a time. We force the players to pick up one object at the time to have the same experience in order to have less noise in the results of the study. The first two objects, the chalice and the skull are really easy to find, they are in the same area as the altar and they can be found just by looking around without moving from the starting point. The other two objects are a bit more difficult because we want the player to move and explore the village at his or her own pace. The beer is really close to the fish, and the fish is obviously next to the sea.

The main goal of the scenario is to have different types of locomotion systems available for the player to use at the same time, while having the option to pick up and release objects, to observe how the players use the different locomotion techniques, in which frequencies and in which cases they prefer one system or another and why that is happening. For the goal of the whole study, we wanted to compare the different locomotion systems commonly used in narrative and action games and why they use different locomotion techniques. Then, this scene has been designed as a narrative game scene, having a slow paced rhythm and motivating the exploration of the village.

Figure 10 – Images from the slow paced scenario

FAST PACED SCENARIO

This is the last scene of the study and it follows the same pattern as the previous scene. The player can use all available locomotion systems, snap turning and can grab and release objects. The goal of this scene is the same as the slow paced scenario, the player must pick up four different objects and leave in different locations that are close to one another, just next to the panel that indicates which objects must be picked up. The objects are the following ones with the given order:

1. War Hatchet: it must be brought to a Viking that does not have a war axe (it appears in the hand but with a semi-transparent material).
2. Viking Shield: it must be brought to a Viking that does not have a shield (it appears in the hand but with a semi-transparent material).
3. Saw: it must be brought to a tool hanger next to some other tools like a pickaxe, a hammer and a shovel.
4. A red bag: it must be brought to a cart that already has two red bags on it.

The narrative of this scene follows the previous scene. Now the Vikings must go to the sea and the battle after obtaining the favours of the Gods. The player must bring different items needed for the trip to the harbour.

These objects are a bit more difficult to find since the player now knows how the village is structured and how to navigate in it. The hatchet and the shield are next to each other and close to the starting point but the player must move a bit to find it. Then, the saw is close to the sea but can be a bit difficult to find. Moreover, it is in a zone where the player can jump over a fence to pick it up, or the player can just go around the house that is next to it, but the shortest movement is to teleport to that position jumping over the fence. Finally, the red bag is quite easy to find, it can be seen from the starting position but it is far away, at the entrance of the village.

Of course, these four objects were not present in the slow paced scenario, so no one could have any advantage in case they saw the items in the previous scene. Moreover, the altar and the items from the previous scene are not present on this one. Again, we want to reduce the distractions from the player and just let them use only what is needed at each time. We want the players to do the same process as the rest to obtain comparable results.

Although this scene has the same mechanics and patterns as the previous one, the main difference here is the pace of the scene. Now, the players have a challenge:

- If the player beats the level (bring the four items to the harbour) in under 2 minutes, he or she will receive a gold Viking badge,
- if the player beats the level (bring the four items to the harbour) in under 4 minutes, he or she will receive a silver Viking badge, and
- if the player beats the level (bring the four items to the harbour) taking over 4 minutes, he or she will receive a bronze Viking badge.

During the whole scene, a timer appears showing at all times how much time the player is taking to complete the level.

The reasoning behind this design decision is that we want the player to feel that he or she is in an action game, in a fast paced environment and in a tense situation that they need to solve quickly. We wanted to have the same feeling that we obtain playing action games without adding enemies, combat or other mechanics that could add noise to the study. We wanted to keep the mechanics and control systems as easy and simple as possible because at the end, we are just interested in comparing locomotion systems in narrative and action games.

When the player beats the level, the instructions panel now shows how much time the player has taken to bring the four items to the harbour and the badge that has been obtained. At this point, the prototype is finished.

Figure 11 – Images from the fast paced scenario

4.3 Process of the Study with Users

In this subchapter we will explain the process that we followed with each user in the study, from the beginning where we explain the goals of the study and why they are doing it, until the end, where we finish having a conversation with each participant.

At the beginning of the study, we welcome and thank all the participants that helped us in this project and then we introduce them to the Oculus Quest 2 HMD and Oculus Touch controllers explaining that they are going to test a VR prototype with a given set of tasks that they will know in detail later during the study. The study takes approximately 45 minutes per user, although it depends on how much the user may like to talk about the experience that he or she had.

We told them that this is not a test of their abilities but of the game and the different locomotion techniques so they should play as they would do at the comfort of their homes. Playing in a VR platform helps the player to feel less observed because he or she is more focused in the game in comparison to playing in a non-immersive platform such as a PC or console.

The participants also received information about the risk of suffering motion-sickness and how it could feel (as it is a similar feeling of getting sick while moving by car). They could stop at any point if they felt sick and finish the study earlier if they wanted.

There was a special characteristic about playing in VR with the Oculus Quest 2 setup that made the experience different from playing with a non-immersive setup. They had the computer and the screen in front of them and because of that, they could play without any cables and they were free to move around without any type of danger. Of course, there was the possibility of colliding against some obstacles in the real world outside the play area, but Oculus has a technology that prevents them from getting hurt: the Oculus Guardian. This system needs to be set up before playing and it consists in marking on the floor with a virtual pencil the play area that is free of obstacles where the player can move safely. We explain how the system works to the user when he or she puts the HMD on. If the player is not close to the borders of the limits that we defined, nothing is shown and they see the virtual environment as it is. In case they get close to the limits, red lines, like a cage, will appear indicating where the limit is, and if they step out of the limit, the screens will no longer show the virtual environment and they will show the real world with the cameras that the HMD has.

Before starting the study, we explain the structure of it and we ask them to please share their impressions and feelings as much as possible while they play. As we previously said, we couldn't see what was happening in the game so we needed the player's help.

After this introduction to the study, we ask them a series of questions (see Annex – 8.1 Initial Questionnaire) about their experience playing games, which platforms of gaming they are more used to and if they had experience with motion controllers (Wii or PSMove controllers) and VR. We are interested in their gaming habits to see if that could affect the player behaviour in the study.

It is important to say that all the questionnaires of the study are oral and the participant must take off the HMD from his or her head to answer. We try to use the questionnaires not only to obtain information from the participants and their experiences but also to reduce screen time and exposure to VR that could be harmful for them. We want them to spend as little time as possible in VR because the participants do not have a lot of experience and high exposure could be a problem for their experience and performance. It is a great moment for them to take a rest for a few minutes.

Also, a field called "Player Reference" will be seen in all questionnaires. This field exists to keep the privacy of the users. We decided to implement an id generator for each time the game is executed and then it is saved in Firebase. Because Firebase is a Realtime Database, we can see the player id whenever he or she starts the game and then we introduce this value into the questionnaires. The format is "REAL-" followed by 20 random letters and digits combined. In the database we could also see the id starting by "DEV-" if the debug mode is active for development purposes. Using this id, we can create different questionnaires without personal data and keep track easily which questionnaires are from the same person.

After finishing the initial questionnaire, we will explain all the controls with the Touch controllers, because we want them to see the handheld controllers and interact with them before going to the prototype. Then, they will put the HMD on their heads and the player will start the prototype. They will go through the introduction and the object interaction tutorial. In the first tutorial, we will explain to them what they can do with each object but we will let them explore the possibilities first. In this scene, we remind them that the controls needed to pick up and release objects are the Hand.Trigger of each controller.

After finishing the first tutorial, we go to the teleportation tutorial. Whenever it is complete, we will ask the participants to take off the HMD and answer a series of questions for the teleportation system to find out some data about the user experience they had with the teleportation system. After finishing the questionnaire, the participants will put the HMD on again, and will complete the tutorial for the walk-in-place locomotion technique and the specific questionnaire. The same process applies for the free locomotion tutorial. The questionnaire is always the same for each one of the systems and it is an adaptation of the Games Experience Questionnaire [14] and the System Usability Scale [15] questionnaire.

The questionnaire (see Annex – 8.2 Locomotion Questionnaire) consists of 13 sentences that are presented to the participants using a Likert scale. For each one of them the participant must answer a number in the range of 1-5. If the participant says 1, it means that he or she totally disagrees with the sentence while 5 means that the participant totally agrees.

The first six sentences are some sentences obtained from the System Usability Scale (SUS) questionnaire. We selected the sentences that are relevant to the study. With the six sentences that we have, we can obtain a score between 0 and 60 to compare each one of the locomotion systems at a usability level. The score is computed in the following way:

$$Total\ Score = 2.5 * ((scoreQ2 - 1) + (scoreQ4 - 1) + (scoreQ5 - 1) + (5 - scoreQ3) + (5 - scoreQ6) + (5 - scoreQ7))$$

As we can see, what the formula really does is to get the positive questions and removes 1 to the score, while with the negative questions it computes 5 – score of the question to obtain the result. At the end, we end up getting the SUS modified score between 0 and 60 points.

The next four sentences are extracted from the Games Experience Questionnaire (GEQ) core module. We think that these sentences are relevant to compare each one of the locomotion techniques and add value to the modified SUS questionnaire.

Moreover, the last three sentences have been created for this specific study in order to extract data related to the VR experiences since the rest of the questionnaire do not consider that the game is being played on a VR platform.

Of course, the fact that we are not using a full questionnaire that has been used in other studies means that we can’t compare other systems or games although we are using parts of the SUS or GEQ questionnaires but it allows us to compare the three locomotion systems that we have implemented for our study.

Since the players had to answer the same questionnaire three times (one per locomotion tutorial), we decided to shuffle the questions so they were not answering the same questions in the same order.

Asking the same questions for each tutorial let us compare the results for each one of the locomotion systems and the user experience that each participant has had. These scenes not only work as a tutorial for the players, but for us, it gives a lot of information on each one of the locomotion systems as an individual technique. The great thing about these scenes is that the locomotion technique is the only mechanic available, then there is no noise from other mechanics that can affect the results. For each one of the tutorials, the previously mentioned user metrics were saved in the Firebase database.

After finishing with all tutorials, the player will put the HMD on for the final time until the end of the study. Now the participants will go through the slow paced and the fast paced scenario and at the end we will take some minutes to recover from the experience and start a semi-structured interview (see Annex – 8.3 Semi-structured interview). The idea of the interview is to ask some key questions but also to drive a conversation about their experience, we want the participants to share as much information as possible. This is a great opportunity for us to ask some questions depending on their behaviour or to clarify some ideas that they shared with us during the study.

This set of questions has different goals. First of all, it is meant to work as a structure to start a conversation and talk about interesting topics for the study rather than just asking questions to the participants. These questions are more focused in the last two scenarios of the prototype rather than the tutorials, for which we already have information from the locomotion questionnaires. With this conversation we try to ask for what is the preferred locomotion technique and under which conditions, if the participants felt dizzy or tired at any point and if they had any type of problems with external factors like personal safety, or problems with the combination of mechanics.

As a complement to the interviews and the questionnaire, we also wrote down what the participants were saying at all times during the study to better understand their behaviour. The results of the interviews were also supported by the metrics of each user's gameplay in each of the two scenes that we saved in Firebase. The observations of the players' behaviour and the locomotion metrics was important for the semi-structured interview since we could talk about their experience knowing how they interacted with the game and we were able to ask them about that behaviour with more detail.

The prototype that the participants played did not have a lot of information on how to play it or UI panels to explain the controls. We decided to not overload the player with a UI that can be a bit confusing when used in VR. Implementing UI in the prototype also means more developing time and we decided to explain all the information ourselves during the experiment. Another reason that helped us to take this decision, is that during the first days of starting the project, we invited some colleagues to try some popular and successful VR games and we realized that they were so immersed in the environment that they forgot about the goals and the missions of each level, they were more interested in explore the possibilities of VR and how they could interact with the world than what the game was telling them. That's why we preferred to interact directly with the user to draw their attention. Nevertheless, there is still some UI in the game to help the user remember the mission and how to beat the level.

Because explaining what the player must do took some extra time at the beginning of each scene, it affected how we record data in Firebase. We were interested in the game time that each player was taking for each scene but since we were losing some time explaining the mechanics we needed to start the time counter later. In the tutorial, the player started on a harbour pier so we started counting the time whenever he or she touched dry land, and eventually stopped the counter when the player was close to the cross that would teleport him or her to the next tutorial. In the case of the experimental scenarios of the slow and fast paced tasks, we decided to start the counter when the players raised their hands (it is indicated by a UI panel) and stop the timer when the last item has been brought to the correct position.

We also added one special functionality for rare cases in which the prototype may have a game breaking bug. If the player pressed the Button.Start from the left handheld controller, the scene would reload from the beginning. This was helpful in some cases during the study. We wanted to be able to play from the beginning of the scene if some bug happened but without having to go through all the tutorials again. All bugs that appeared during the study were at the beginning of the scene, so the player did not have a bad experience by restarting the game after advancing a lot in the level.

Another decision that we made was to put more than one of the objects that must be picked up in each scene. That was done to avoid any type of bug that could appear with an item, if that was the case, the player would just grab another object. We placed multiple items one next to another to solve this issue.

4.4 Selection of Participants

In order to select the participants of the study the first thing that came into our minds was the limitations that we had. Working with users in this Covid-19 times is a bit difficult because of the restrictions, travel bans and the conditions in which we have to perform the study. So, we were looking for people between 18 and 30 years old with different ranges of experience playing video games and without distinction in genre that were physically and mentally able to play in VR platforms while standing up. One thing in common that we were looking for was that the participants should have little to no experience in VR. The participants accepted to be part of the study and were informed about the process that we would follow and the restrictions that we had to have because of Covid-19. In total, we did a study with 23 different people.

4.5 Pilot Study

Before starting the study with the selected participants, we decided to do a pilot study with one person to test for the first time the prototype with someone that has not developed it. From this pilot test, we wanted to find out some game bugs but specially compute how much time was taking to do the study, if there were any problems with the process or if we could find some improvements to be done. We wanted to do it first as an isolated study and then apply the obtained knowledge to improve over it. We did not want to do changes after, for example, five people were tested needing to do significant changes that would have meant that the first studies were not valid for the results of the work.

From the pilot study, we found several areas of improvements and we decided to take a list of actions to improve the user experience. We also found some critical bugs that were solved.

These are the observations extracted from the pilot study and the actions that we took for the real study:

- **Time**
    - **Observation:** The study took a bit more than an hour to be completed. The introduction was too long, with too much detail and the conversation that we had later also was longer than expected.
    - **Action:** Do not explain the whole work in detail and what we are working on, it is not relevant for the user. Keep it simple and explain what the study is about.
- **Tasks to perform**
    - **Observation:** It was difficult to understand the task that needed to be performed at the last two scenarios.

    - **Action:** We did not change anything in the game, but now we explain in detail what is the set of tasks that the player must do and we make sure that they understand the assignment.
- **Disorientation**
    - **Observation:** First person camera was disorienting. The player would like to have other camera options or a mini map.
    - **Action:** We don't think this must change. The prototype tries to be as close as possible to the popular games in the market and they do not use other types of cameras than the first person point-of-view and the player rarely has a map available. Having as little UI as possible is beneficial for the user experience and having different cameras that are not first person collides with the immersion levels that VR wants to achieve.
- **Motion-sickness**
    - **Observation:** The player felt sick and needed to stop two times. He used the free locomotion technique during 50 seconds per minute while he just teleported 3 times per minute and did not even use walk-in-place locomotion.
    - **Action:** Inform the participants that the best locomotion systems to avoid motion-sickness are teleportation and walk-in-place and that one of the solutions to avoid it is to move the full arms and legs to trick the body to think that the player is moving in the virtual environment.
- **Tutorial time**
    - **Observation:** The tutorials and the questionnaire after each one of them were not long and the player did not feel uncomfortable.
    - **Action:** We were afraid that the tutorials and the questionnaire for each one of them could be repetitive and too long. It looked like there was no problem with the questions and the time so we decided to keep the questionnaires and the tutorials as they were.
- **Screen time**
    - **Observation:** The player did not take off the HMD at any point during the study.
    - **Action:** This could be another reason why the player got motion-sickness. With that in mind, we later asked for each participant to please take off the HMD when they were answering the questionnaire to reduce screen time.
- **Physical Security**
    - **Observation:** The player did not feel worried about his physical integrity or the surroundings and possible obstacles.
    - **Action:** One of the main concerns of the study is to avoid any type of collision and injuries while playing in the VR platform and we wanted to make sure that every player was comfortable in the real world environment. Although for the pilot user he did not worry about the surroundings, we decided to show how the Oculus Guardian system works to the users as the first thing to do whenever they put the HMD on to learn about what security system they have available to prevent injuries.

Once the pilot study was finished, we started doing the study with real users applying all these actions. The results presented in the next chapter do not include the pilot study.

5. RESULTS AND DISCUSSION OF THE STUDY

In this chapter we will be showing all the results obtained from the study about locomotion systems that we have presented in Chapter 4. We will talk about the results from the demographics questionnaire, then about the three locomotion systems questionnaires, next we will talk about the behaviour of the players in the slow paced and fast paced scenarios, and finally the results from the semi-structured interview.

The JSON generated saved in Firebase with the tracking of all the user data is in this JSONBin link if anyone is interested. For an explanation of the terms used in the JSON we can refer to the part of the thesis where we explain the used technologies for the work.

The number of participants that finished the study were 21 people. We also did the study to a participant as a pilot to test the procedure and iterate over it so this person is not going to be counted as a participant for the study since there were some changes between the experience of the pilot and the rest of participants. In addition, one person did not finish the whole study because he did not have enough time to finish the last scenario because of personal reasons. For this reason, we will count him towards the results for the locomotion tutorials but not for the slow/fast paced scenario results since we cannot compare the results between the last two scenarios.

The full results of all questionnaires and player metrics can be found in this Google Drive link. For the specific results of each questionnaire you can refer to the following Google Drive links:

- Initial questionnaire,
- Teleportation questionnaire,
- Walk-in-Place questionnaire, and
- Free locomotion questionnaire.

Figure 12 – Participants doing the study in the UPF facilities

5.1 Demographics

For this subchapter, we will talk about the results obtained from each one of the participants of the study (N = 22) that answered the Initial Questionnaire (see Annex – 8.1 Initial Questionnaire).

The age of the participants is 22.36 years old as an average with a standard deviation of 1.65 years. 10 people identified themselves as women while 12 participants identified themselves as men.

15 of the participants said that they usually play video games while 7 do not. 7 participants play video games more than once a week, 12 participants play games weekly or monthly while 3 participants rarely play any games.

The most commonly used platform to play is the console with 16 participants that use it, 14 participants said that they used to play on PC and 10 of the participants played with mobile games. Also, one participant said that she had a VR headset to play at home.

12 of the participants did not try any VR experience, 7 of them just tried it once and 3 of the participants have played in VR games several times. Also, 21 of the 22 participants have played with the Wii, PSMove or a similar system that had motion tracking systems and 9 out of the 22 participants also had experience playing with full body interaction experiences such as Eye Toy or Kinect.

5.2 Locomotion Tutorials

This subchapter presents the results from the three locomotion tutorials. We will divide it in two parts: the results from the player interaction with the locomotion systems that are being tracked and saved in Firebase, and the questionnaires that each one of the participants answered after each one of the tutorials. As a reminder, the data has been extracted from 22 participants. For the player interaction results, we are interested more in the ratio of use of the locomotion systems than the totals, so we will plot the ratio values.

The results will be represented in box plots or whisker plots. The values appearing in the image will be, in order, minimum sample, first quartile (Q1), median or average, third quartile (Q3) and maximum value.

a) Teleportation Tutorial Player Interaction

We will now present the player interaction results of the study for the Teleportation tutorial. The following box plots represent the results for how much time the player has been playing the teleportation tutorial, the frequency of use of teleportation per minute and frequency of use of snap turning per minute.

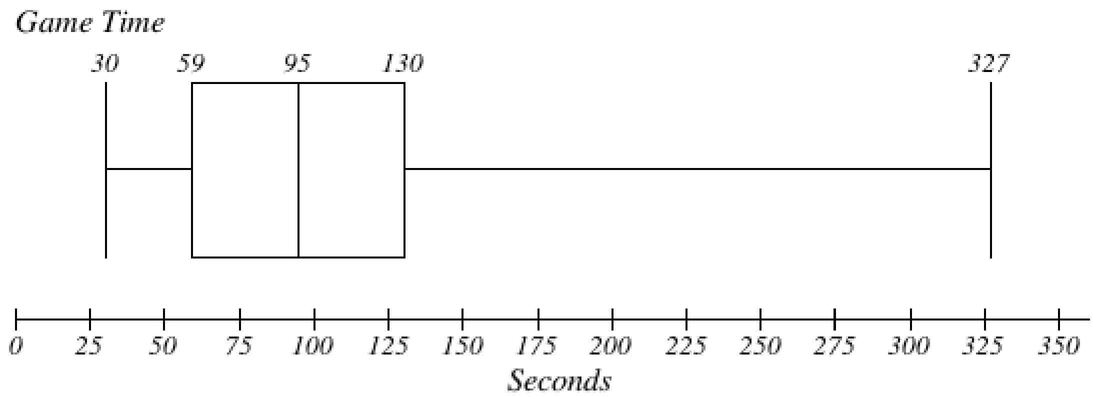

Figure 13 – Game time in Teleportation Tutorial

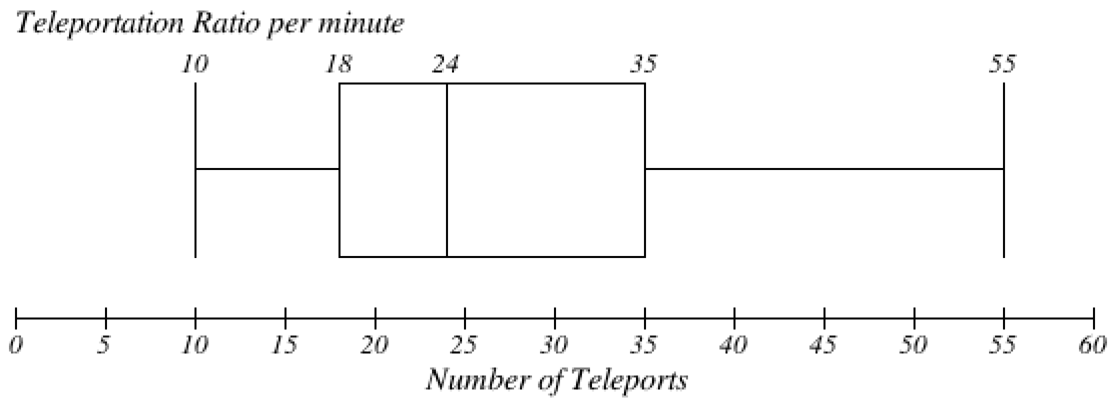

Figure 14 – Teleportation Ratio per minute in the Teleportation Tutorial

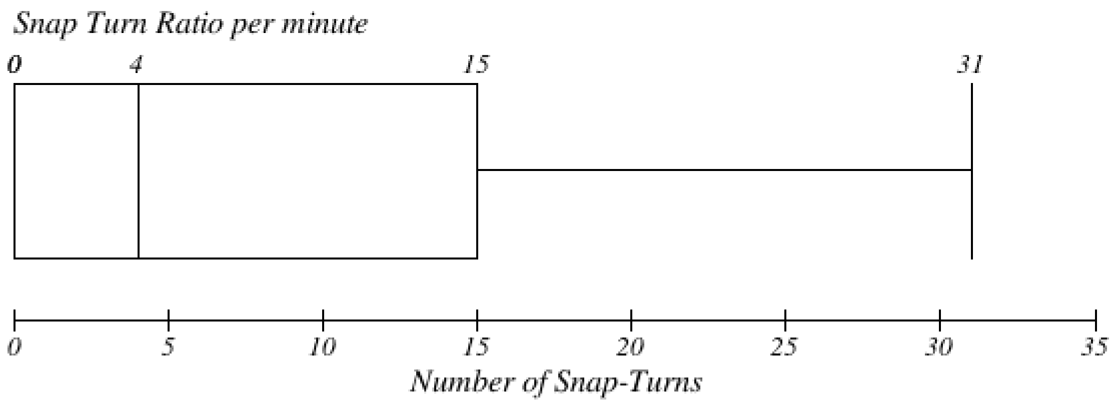

Figure 15 – Snap Turn Ratio in the Teleportation Tutorial

b) Walk-in-Place Tutorial Player Interaction

We will now present the player interaction results of the study for the Walk-in-Place tutorial. The following box plots represent the results for how much time the player has been playing the walk-in-place tutorial, the frequency of use of walk-in-place per minute and frequency of use of snap turning per minute.

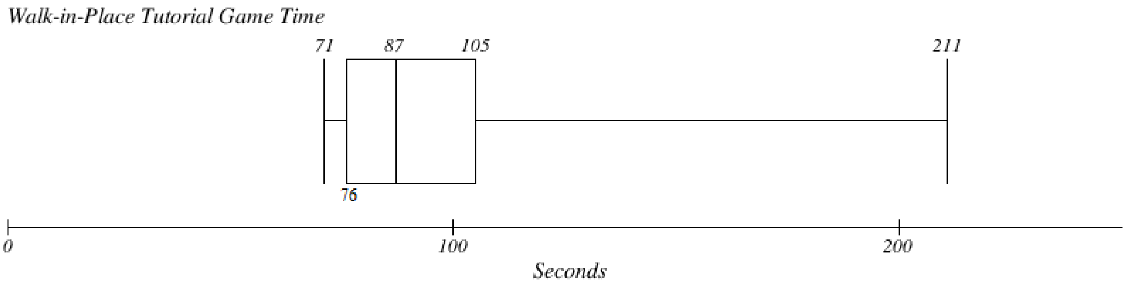

Figure 16 – Game time in Walk-in-Place Tutorial

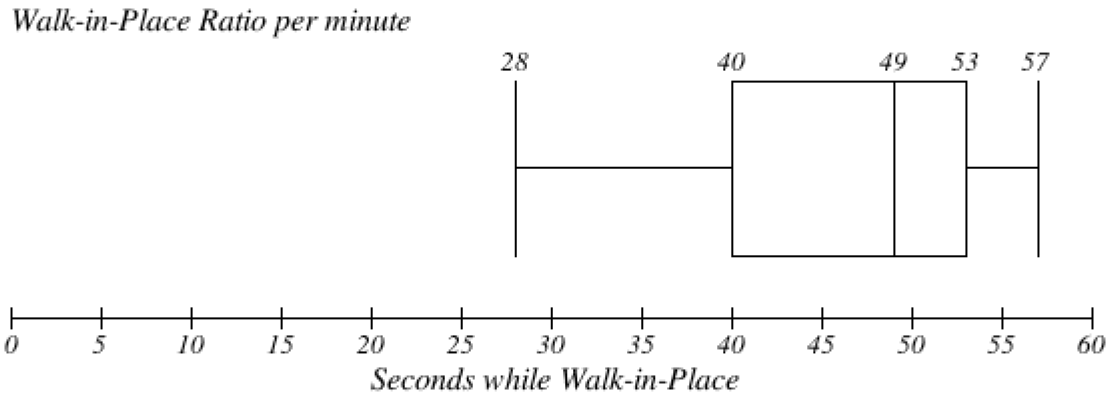

Figure 17 – Walk-in-Place Ratio per minute in the Walk-in-Place Tutorial

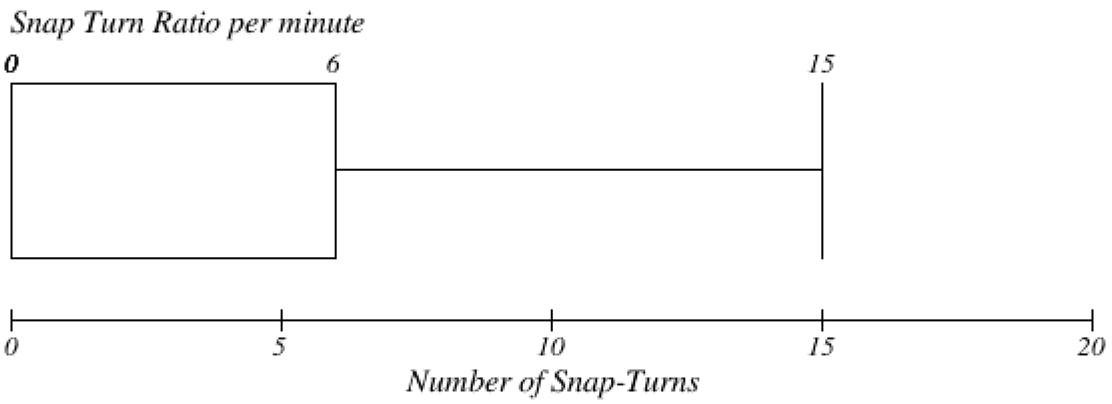

Figure 18 – Snap Turn Ratio in the Walk-in-Place Tutorial

c) Free Locomotion Tutorial Player Interaction

We will now present the player interaction results of the study for the Free Locomotion tutorial. The following box plots represent the results for how much time the player has been playing the free locomotion tutorial, the frequency of use of free locomotion per minute and frequency of use of snap turning per minute.

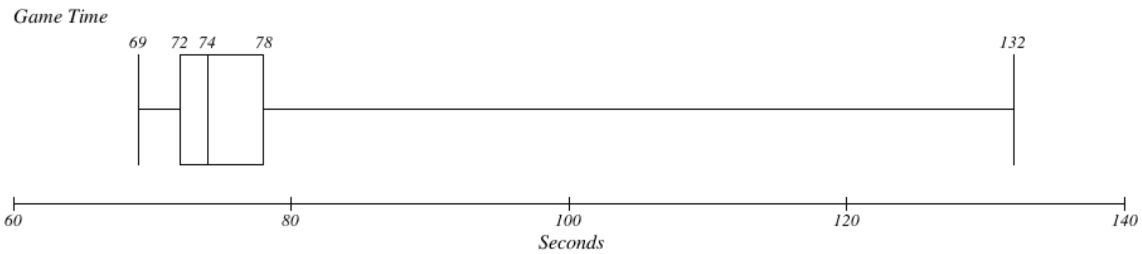

Figure 19 – Game time in Free Locomotion Tutorial

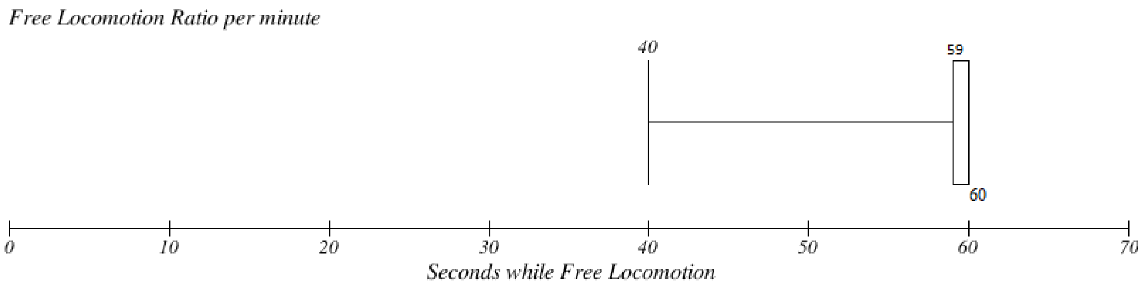

Figure 20 – Free Locomotion Ratio per minute in the Free Locomotion Tutorial

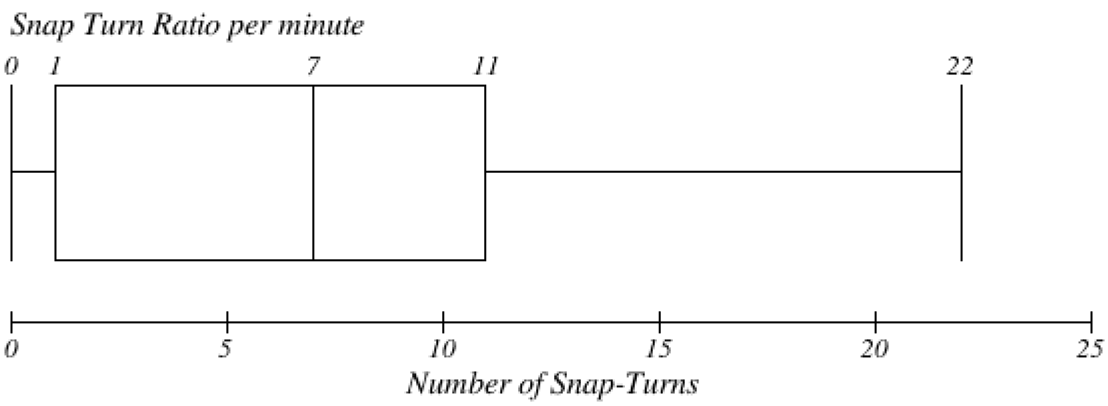

Figure 21 – Snap Turn Ratio in the Free Locomotion Tutorial

d) Locomotion Systems' Questionnaire Comparison

Next, we will talk about the questionnaire results of the three locomotion systems in comparison. We will show the results for the modified SUS questions, the modified GEQ questions and the VR related questions.

MODIFIED SUS

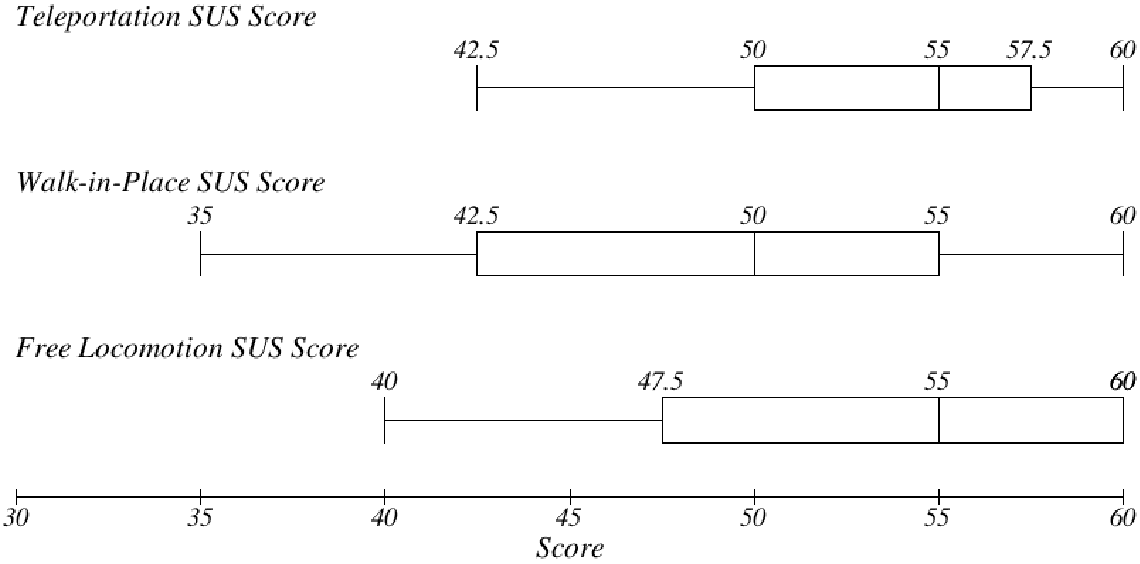

Figure 22 – SUS score comparison for each Locomotion System

The following tables show the results of each question of the modified SUS questionnaire. A green colour indicates the locomotion system that got the best score on average where the red colour indicates the worst score.

I think I would like to use this system frequently

	Average	Standard Deviation
Teleportation	4.18	0.73
Walk-in-Place	3.23	1.27
Free Locomotion	4.05	1.09

Table 4 – Statistics of the answers to "I think I would like to use this system frequently"

I found the system unnecessarily complex

	Average	Standard Deviation
Teleportation	1.18	0.50
Walk-in-Place	1.36	0.73
Free Locomotion	1.32	0.72

Table 5 – Statistics of the answers to "I found the system unnecessarily complex"

I would imagine that most people would learn to use this system very quickly

	Average	Standard Deviation
Teleportation	4.64	0.58
Walk-in-Place	4.41	0.91
Free Locomotion	4.68	0.48

Table 6 – Statistics of the answers to "I found it tiresome"

I thought the system was easy to use

	Average	Standard Deviation
Teleportation	4.64	0.49
Walk-in-Place	4.55	0.91
Free Locomotion	4.64	0.58

Table 7 – Statistics of the answers to "I found it tiresome"

I needed to learn a lot of things before I could get going with this system

	Average	Standard Deviation
Teleportation	1.27	0.46
Walk-in-Place	1.27	0.46
Free Locomotion	1.09	0.29

Table 8 – Statistics of the answers to "I found it tiresome"

I found the system very cumbersome to use

	Average	Standard Deviation
Teleportation	1.18	0.39
Walk-in-Place	1.86	1.08
Free Locomotion	1.50	0.80

Table 9 – Statistics of the answers to "I found it tiresome"

MODIFIED GEQ

Now, we will see the results from the study about the 4 questions that have been obtained from the GEQ for each locomotion system.

I found it tiresome

	Average	Standard Deviation
Teleportation	1.36	0.79
Walk-in-Place	1.64	1.00
Free Locomotion	1.50	1.01

Table 10 – Statistics of the answers to "I found it tiresome"

I forgot everything around me

	Average	Standard Deviation
Teleportation	3.64	1.47
Walk-in-Place	3.86	1.17
Free Locomotion	3.50	1.57

Table 11 – Statistics of the answers to "I forgot everything around me"

I lost track of time

	Average	Standard Deviation
Teleportation	2.36	1.43
Walk-in-Place	2.64	1.56
Free Locomotion	2.59	1.68

Table 12 – Statistics of the answers to "I lost track of time"

I felt frustrated

	Average	Standard Deviation
Teleportation	1.45	0.67
Walk-in-Place	1.55	0.67
Free Locomotion	1.27	0.55

Table 13 – Statistics of the answers to "I felt frustrated"

VR RELATED QUESTIONS

Same process as before, now taking a look to the results of the three VR related questions of the study:

I felt dizzy

	Average	Standard Deviation
Teleportation	1.45	0.67
Walk-in-Place	2.59	1.10
Free Locomotion	2.18	1.14

Table 14 - Statistics of the answers to "I felt dizzy"

I felt confused

	Average	Standard Deviation
Teleportation	1.82	0.85
Walk-in-Place	2.27	1.16
Free Locomotion	1.64	1.00

Table 15 - Statistics of the answers to "I felt confused"

I felt immersed into the world

	Average	Standard Deviation
Teleportation	4.64	0.66
Walk-in-Place	4.45	0.74
Free Locomotion	4.41	0.91

Table 16 - Statistics of the answers to "I felt immersed into the world"

5.3 Study Scenarios

We will present the results from the study for the slow paced scenario (Calm) and the fast paced scenario (Stress). In this case, there is no questionnaire for either of these scenarios but we have tracked the locomotion actions of the participants. We will show each one of the metrics in comparison one next to each other by scene type.

As a note, the number of participants for this part of the study is N = 21, because of a participant that could not complete the last scenario.

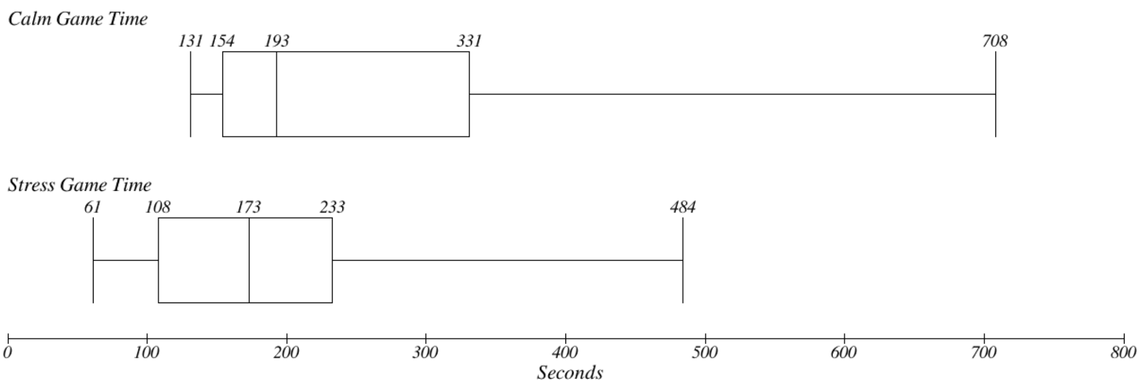

Figure 23 – Game time comparison for scenes "Calm" and "Stress"

Out of the 21 participants, 5 of them obtained the gold medal during the Stress scenario, meaning that they needed 2 or less minutes to finish the scenario. 11 people obtained the silver medal because they used 4 or less minutes to finish it and 5 participants obtained the bronze medal since they needed more than 4 minutes to finish.

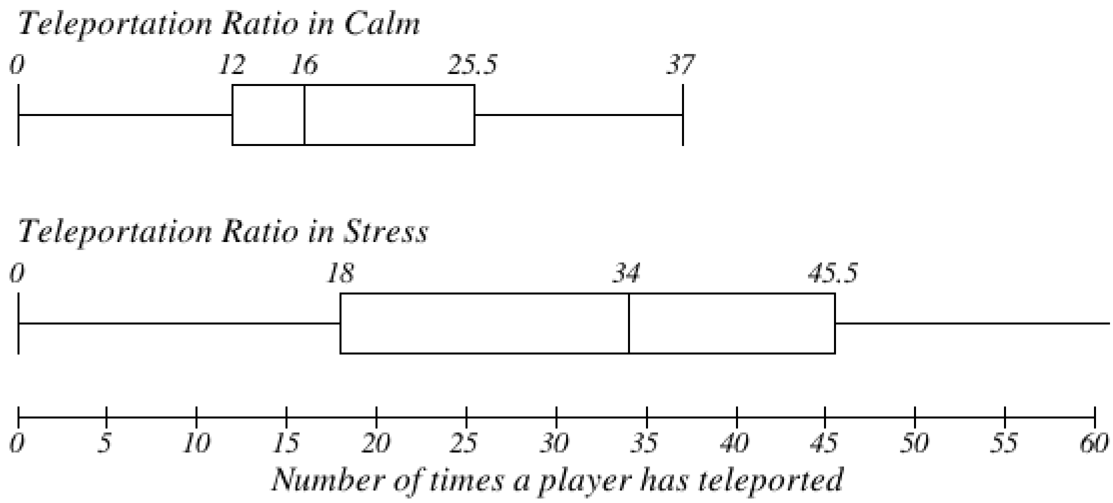

Figure 24 – Teleportation Ratio comparison for scenes "Calm" and "Stress"

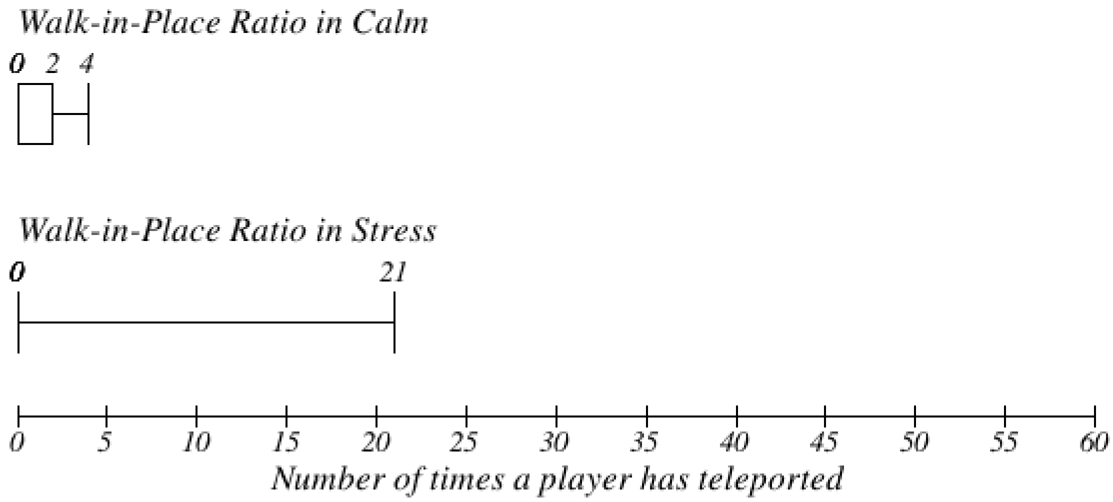

Figure 25 – Walk-in-Place Ratio comparison for scenes "Calm" and "Stress"

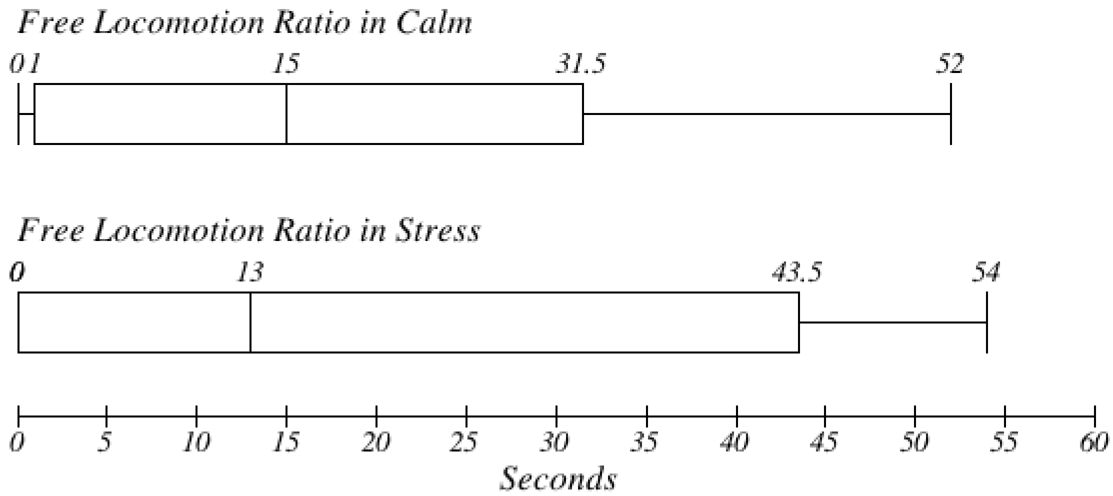

Figure 26 – Free Locomotion Ratio comparison for scenes "Calm" and "Stress"

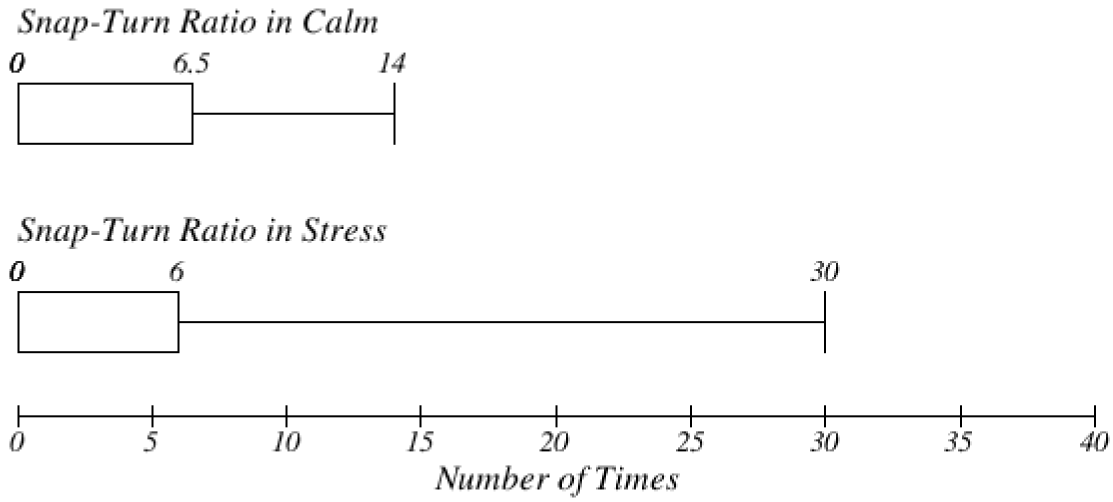

Figure 27 – Snap Turn Ratio comparison for scenes "Calm" and "Stress"

5.4 Interviews

To finish with the results section of the thesis, we collected all the relevant information that the 21 participants that finished the study answered during the semi-structured interview. The detailed answers for each participant can be found in this Google Drive link.

1. **Between the slow and fast paced scenario, which one did you like the most, felt more comfortable or would you like to play again?**

From 21 participants that answered this question, 15 of them indicated that they felt more comfortable with the fast paced scenario. They told us that they preferred the competition and wanted to have a challenge. Also, playing the "Calm" scenario before helped them to combine all the mechanics and to know the environment. The Calm scenario worked as a final tutorial for them. On the other hand, the 6 participants that preferred the Calm scenario said that the experience that they had was better in the first scene, it was less stressful and the tasks were easier to complete.

2. **Which locomotion system did you prefer to use during the slow paced scenario and why?**

Out of 21 participants, 13 of them had a preference to use a combination of Teleportation and Free locomotion. The usage was a bit different depending on the person but overall they used teleportation for covering large distances and free locomotion to do small adjustments in their position because Teleportation let them move faster than any other system. Some participants used less teleportation in favour of free locomotion when they were looking for objects since teleportation could cause a bit of disorientation and the player could miss things because it was a faster movement, non-continuous and it was difficult to look around while moving. Whenever they got an object, these players rapidly changed to use teleportation to get back to the starting position. A few people used the best possible strategy: keep moving forward with free locomotion while you are teleporting. This combination let the player always move since teleportation had a small cooldown that did not let do two back-to-back teleportations instantly. It could be a bit dangerous because the player may miss some objects while moving this fast.

5 of the participants used only teleportation because it was easier to use and more efficient and effective, they had more control and it was more comfortable than the other systems. In addition, it caused no motion-sickness, not like free or walk-in-place locomotion techniques.

3 participants used only free locomotion, since they felt it was the most natural mechanic and they were familiar with it from the experience of playing games with controllers before.

Most of the participants tried to use walk-in-place locomotion at the beginning of the scene but they did not use it in a consistent manner.

Only a minority of players tried to finish this scene as fast as possible. During the study, we encouraged the player to take his or her time and most of the players took advantage of the purpose of the scene to get used to all the mechanics and took their time to explore the village.

3. **Which locomotion system did you prefer to use during the fast paced scenario and why?**

In the fast paced scenario, the situation is different. 12 people opted for using a combination of free locomotion and teleportation while 8 of them used only teleportation and a single participant used only free locomotion.

The reasons to use the combination of free locomotion is pretty similar to the answers of the previous question: people use teleportation to move faster and cover large distances while free locomotion is used when the participant needs to find an object and when he or she needs to do small adjustments to the position. The main difference now, is that overall, teleportation is used in a higher frequency than in the Calm scenario although some people had troubles with the orientation in the scene.

Some people only used teleportation to move, because of the same reasons as the previous answers but they also felt that no other locomotion technique was necessary in order to have success in this scene.

As we said, one participant decided to only use free locomotion because teleportation was too disorienting and did not know where she was at some points if she was using it.

4. **Did you use all locomotion systems, if not or if there is one system that is rarely used, why did you choose one over the other?**

The primary locomotion system that was not used is the walk-in-place technique. Some words that described why they didn't use it were that the system was the most complex one, and felt unnatural and uncomfortable. Also, it caused dizziness and a bit of tiredness and it was difficult to use with other mechanics like snapping or grabbing objects. At the end, the feeling was similar to the free locomotion technique but it was more difficult to use than free locomotion, that was feeling the same but with less effort.

Nevertheless, some of the participants said that it was the most immersive experience and it felt natural to use when they were moving their feet at the same time.

5. **Did you feel dizzy at any point during the experiment? Did you want to stop playing?**

Most of the participants had some issues related to motion-sickness, usually they had short periods of nausea and dizziness that went away while playing, some describe it more as a "weird feeling" more than feeling sick. They experienced more motion-sickness in the walk-in-place tutorial, in comparison to free locomotion. Two of the participants needed to rest for a couple minutes between the Calm and Stress scene to recover from motion-sickness but they could continue with the study without any major problem.

The situations on which the participants felt motion-sickness were diverse. Some of them had problems while doing physical movements like fast physical turning or crouching and three of the participants get this same feeling while doing snap turning. Two participants also stated that they felt weird and a bit confused after playing.

6. **Did you feel tired at any point during the experiment? Did you want to stop playing?**

5 out of 21 participants said that they felt a bit tired during or after the experiment. The main reasons were because of standing up for 45 minutes and the sweat on their faces while playing. But overall, no major issues happened during the experiment.

One participant had more problems with the experience since she felt that the HMD was too tight and was pulling her head down. She also got fatigued when forcing the sight because she had some vision problems.

7. **Did you use the snap turn and why?**

15 participants of the study did only use their own movement to turn around the scenario. For them it was more natural, immersive and precise, and it also was more useful than snap turning since they could see the scene better while if they snap turned, the player may miss interesting objects because of the non-continuous movement of the snap turn. On the other hand, some participants had issues with the physical demands of the movement and it caused a bit of dizziness for them.

Only one participant used snap turn as the only technique to turn around while 4 participants combined both snap and physical turning. The snap turn had some advantages since it was faster and easier to not get disoriented in the real world, the player could be in a safe spot because they did not need to move their body to turn. On the other hand, snapping was disorienting in the virtual world for some participants, abrupt and unreal. Moreover, a minority of participants said that they felt dizzy while using snap turn.

The players that used snapping and physical turns in combination, usually did it in a given set of conditions. They used snapping for large turns or to turn around 180º while the physical turn was used for precise turning and when they were looking for objects since it helped to find them when looking at the environment with attention.

8. Did you feel confused or disoriented at any point?

10 out of the 21 participants felt disoriented or confused at some point during the study. They usually related the confusion to disorientation on the map, because of the use of teleportation and snap turning. A minority had minor problems remembering the control schema and had issues finding objects in the scene. Some did not realise that they could do certain movements like jump over obstacles using teleportation or crouch physically when they needed to get under a building. Moreover, playing the Stress scenario caused more disorientation than playing in the Calm scenario because the players felt more stressed and it was difficult for some of them to stay focused on the task when they had difficulties finding objects in a timed scenario.

9. Did you find any kind of difficulty in moving while holding any object with your hand?

Three participants had some difficulties combining the mechanic of grabbing objects and the different locomotion techniques. One of them, at some point, did not remember what trigger was needed for picking up objects and the other two had issues with picking up objects while using the teleportation and walk-in-place locomotion systems because more than one button had to be pressed at the same time.

10. Did you lose track of time?

8 of the participants stated that they lost track of time significantly, 5 of them said that they lost a bit the track of time while the last 8 participants said that they did not lose track of time during the study.

11. Were you afraid about your physical security?

5 out of the 21 participants answered this question saying that they were a bit afraid about their physical security and the surroundings, although the Guardian System of the Oculus HMD was explained and shown to them. Their reaction to this fear was avoiding physical movement of their position and hands, if possible, and focus on knowing where they were located in the real world because they were afraid of hitting some obstacle in their surroundings. Some people needed help to get into the centre of the play area when they saw the Guardian system appearing and others were a bit afraid of moving while having the HMD on because of the possibility that it may fall down.

5.5 Discussion of the Results

Starting with the discussion of the results we must first talk about the participants. As a reminder, the set of participants of the study were 21 people all between 20 and 26 years old and without any disabilities to play standing up with two handheld controllers. The majority of them played video games regularly a few times a month and had little or no experience with VR games. Only three of the participants had previous experience with full VR games and some others had experience in events with small demos and simple mechanics where no locomotion was needed. Others had some VR experiences thanks to the stereoscopic devices developed for mobile phones. Overall, the participants had a lack of experience in the topics of the study. 21 out of the 22 participants also had some experience with motion controllers or full body interactions because they have played games on the Wii platform or have used the EyeToy or the Kinect cameras. This previous experience helped them to be more familiar with the demands of VR controllers.

Now, we will talk about the results from the locomotion tutorials. The first metric that we take into account is the game time for each one of the scenes. We can see that the teleportation tutorial was the slowest one to complete while the free locomotion tutorial was the fastest one. This data makes sense since the circuit of the tutorial was the same for each one of the scenarios so in the first one, the players were moving slower, taking their time and exploring the village and the locomotion system. Moreover, the free locomotion system was the most familiar technique of all because of the previous experience of the participants playing with joysticks so they did not need a lot of learning time in this tutorial. Although teleportation is the fastest technique to move, the teleportation tutorial was the first one that they played so they used it to get familiar to play in VR and that's why it took more time to be completed.

We have also seen that a higher teleportation ratio implied a faster game time in the tutorials and that the free locomotion ratio was higher than the walk-in-place ratio. This can be explained because the participants stated that it was more difficult to physically turn using the walk-in-place technique and even to use snap turn, the player should stop moving to do a turn. On the free locomotion system, it was easier to use the left joystick to move and the right joystick to snap turn. This was translated to the snap turn ratio results: snap turning was more used in the free locomotion tutorial where in walk-in-place, the ratio was the lowest of the three. The majority of participants preferred to turn physically rather than using snap turn because some said that it was causing dizziness and disorientation, also players said that they had more control using physical turning. This makes sense since they could turn any given angle and not necessarily 45º as it was implemented in the prototype. The fact that some of the players said that it was causing motion-sickness to it was a bit surprising since the state of the art talks about snapping as a comfort mode to reduce motion-sickness but on the other hand, there were also players that had motion-sickness from turning physically, so it seems that this study will not be able to conclude the performance of the snap turning because of the divided opinions of the participants. Really high snap turn ratios were a rare exception of the study.

If we analyse the SUS score for each of the different locomotion techniques, we can see that teleportation and free locomotion had similar performances with the best average of all three with 55/60 but with less deviation in teleportation than in free locomotion. Walk-in-place performed the worst with a SUS score of 50/60 and it also had the lowest individual score of all three with a 35/60 score. All three locomotion techniques had at least one participant scoring a 60/60. These results are confirmed by the behaviour of the participants in both Calm and Stress scenarios where most of the participants combined the use of free locomotion and teleportation but rarely used walk-in-place locomotion to move around the prototype.

Now, we will discuss some of the most interesting questions of the tutorial questionnaires individually. In the sentence "I think I would like to use this system frequently" the best score goes for the teleportation system, followed closely by free locomotion and the worst score was for walk-in-place. This result makes sense with the behaviour of the player later on in the study where teleportation was the main locomotion system used, sometimes in combination with free locomotion. It was also more common to have players using only teleportation as they play than to only use free locomotion, reinforcing the obtained scores.

The participants also said that in the area of complexity of the systems, the walk-in-place system was the most complex one and the most difficult to use where teleportation and free locomotion got very similar scores in this area. Walk-in-place is the most complex system of all three because it needs more user interaction than the other two locomotion systems. Two buttons and hand motion are needed to work while in teleportation pressing and releasing a trigger is enough and in free locomotion, moving the joystick is the only necessary interaction to move.

When we asked the participants about how difficult it was to learn how to use each one of the locomotion systems, the best performance was for the free locomotion and the worst was for walk-in-place. Walk-in-place is classified as the worst performing because it needs more information to learn than the other two and the gesture of the player is really different from what he or she is used to do while playing non-immersive video games. On the other hand, free locomotion was the easiest to learn probably because the participants were already familiar to use a joystick to move around and they did not take a lot of time to get used to it, they were feeling that they were controlling better the movement when using free locomotion rather than any other locomotion system.

Walk-in-place has also been scored as the most tiresome system and it totally makes sense, it is the only that requires constant motion of the hands while the body gestures in free locomotion or teleportation are not as needed. Moreover, using walk-in-place locomotion also caused the most motion-sickness to the participants while teleportation did not cause it at all. It was expected for the participants to feel dizzy using free locomotion, but it was not that common. The motion-sickness, for almost all participants, was a short period of time where they could recover while they were playing although two participants needed to stop and take out the HMD from their heads between scenes because of motion-sickness. Some people that decided to move their legs while moving using the walk-in-place technique did not have motion-sickness during the study. The participants may not have had the experience of motion-sickness during free locomotion because it was the last tutorial and they were more familiar with the VR prototype and had already felt temporarily sick during the walk-in-place tutorial, the experience was not new for them.

If we talk in terms of the confusion and frustration of the participants, they said that the locomotion system that caused less confusion and frustration was free locomotion. This is related to the previous experience of the participants since they already were familiar to how the relation joystick-movement works as it is present in non-immersive games. That’s why the participants did feel in control using free locomotion and they did not make errors while playing. On the other hand, most of the participants during the study were a bit surprised or disoriented using teleportation or collided with the environment using walk-in-place locomotion. They were not used to these two locomotion systems and they did not have more than 5 minutes to learn to use it, so the difference in the control that the participants had in the free locomotion tutorial was significantly better than in the other two tutorials. Teleportation caused some participants to get disoriented and confused because of the non-continuous movement and when they teleported sometimes did not expect what they were going to see once the teleportation had finished, sometimes they teleported further or closer than what they expected. This was especially problematic when the player wanted to do several teleports one after the other to move as fast as possible in the Calm and Stress scenarios and then they needed to get to the starting point but did not remember how to get back.

As per the last interesting topic of the questionnaire, we have the immersion. When we asked the participants how they felt about their perception of time and if they were aware of their surroundings in the real world, the best score went for the walk-in-place method but later in the questionnaire we did a direct question about if they felt immersed in the world and the best score there was for the teleportation. Then, if we go to the semi-structured interviews, the participants said that one of the benefits of walk-in-place is that it is the most immersive locomotion technique. These results are a bit difficult to understand because of the diversity but some works related to this topic [6] state that walk-in-place is the most immersive method. The results for the question “I felt immersed into the world” were really close, with just 0.23 points of difference with a maximum score of 5 and we have to remember that the player did not answer the same question for each locomotion system one after the other but some minutes afterwards causing the participants not remembering the score of the previous locomotion system to have a reference. Overall, we could say that walk-in-place was the most immersive system, followed by free locomotion because we should give more weight to the semi-structured interview where this topic was discussed with more detail with the participant after finishing the whole study.

Now, we must talk about the main part of the study, the comparison between an action game and a narrative game in VR. Of course, as we mentioned, it is difficult to compare two different games of different genres so we decided to develop our own scenarios trying to get the main difference between each genre, the game pace. So we will compare the results of the participants’ behaviour with locomotion systems in a fast paced scenario (Stress) and a slow paced scenario (Calm) that want to feel like an action game and a narrative game, respectively. If we compare the amount of time each player needed to complete both scenarios, we can see that the averages are close but the fast pace scenario was faster overall. Stress scenario had the lowest game time, while Calm had the higher game time. It makes sense since the game encouraged the player to complete the Calm scenario slowly, inviting the participant to get used to the locomotion systems in combination and explore the Viking village while in the Stress scenario, moving as fast as possible was encouraged by the game. There were some cases of people in the Stress scenario that needed more time in comparison to Calm and the main reason was the stress and that the users were nervous so they did not perform as well as in the first scenario. These people also said during the interview that the slow paced scenario worked better for them and was more enjoyable and it was easier to complete. The fact that the Calm scenario was easier to complete is right, it is designed to be easy since two of the items can be easily found from the starting point (the chalice and the skull) and for the last item of the scenario (the fish) the player could use the logic and think that it was near the harbour. On the other hand, in the Stress scenario, the objects were a bit difficult to find. In general, some people needed help at some point, so we gave them guidance about where a given item could be. We wanted for them to find the objects by themselves but if they were taking a lot of time, we helped them because we did not want the player to feel frustrated and get a bad experience because they had problems navigating around the map. Orientation on VR experiences is not the topic of the work so if we needed to provide help on this aspect, we did it.

One relation that we detected was that the participants that used a lot of time in the Calm scenario and did the scenario slowly and getting used to all the mechanics, had a better time score in the Stress scenario. Those participants that rushed the first scenario did not obtain a great time in the second scenario. Overall, the results of the Stress scenario were quite balanced, indicating that we did a good job with the difficulty, not making the goals of the last scenario too difficult or too easy. 5 participants obtained a gold medal (less than 2 minutes), 11 a silver medal (less than 4 minutes) and 5 obtained a bronze medal (more than 4 minutes).

Teleportation results also had some differences comparing the last two scenarios. On average, the teleportation ratio was more than double in Stress, with 34 teleports per minute, than in Calm, with 16 teleports per minute. Players felt teleportation to be the most efficient and faster locomotion system, so it makes sense for them to use it this much in the last scenario. We can also see that some people did not use any teleportation in favour of free locomotion. This is totally related to the fact that teleportation was also the system that caused more disorientation because of the non-continuous movement, so some people used it less frequently because sometimes they did not know where they were. One common behaviour for some participants was to use the teleportation to cover large distances or to get back to the starting point of the scene, these participants did use more free locomotion and less teleportation when they were looking for objects since it was less disorienting and they had more vision than using teleportation.

Walk-in-place locomotion was rarely used in both scenarios and was even less used in Stress. Most of the players tried a bit of walk-in-place locomotion in the Calm scenario, but they agreed on the fact that there was not much difference in terms of efficiency and what you can do in comparison with free locomotion. Free locomotion is more familiar to the players, causes less fatigue and most of them said that they felt more motion-sickness with walk-in-place locomotion than with any other technique and those are the main reasons why the walk-in-place has not been used during both scenarios although it was highly scored in terms of immersion.

Free locomotion was a commonly used locomotion system in combination with teleportation. But, it was less used in average in Stress than in Calm because the players decided to use much more the teleportation in the Stress scenario and even some players that combined free locomotion and teleportation in Calm, then decided to just move with teleportation in the fast paced scenario. As we previously said, how it works is quite similar to walk-in-place but it is more familiar and easier to use for the players. The main situations where free locomotion was used were to pay more attention to the environment than teleportation and also to do small positional adjustments to get closer to the items.

As per the last metric of the snap-turn, in both scenarios the players preferred to use their bodies to turn around. Some players felt motion-sickness with snap-turn although others also had this feeling by turning physically. Snap turning was much more disorienting and the player lost field of view and attention to the environment and sometimes, the angle of snapping was too big. Physical turning is easier to control and move as much as the player wants. Snapping was used by some players to do big turns since it was faster doing a snap turn than a physical one.

Only 2 participants had major issues with motion-sickness and they needed to stop for some minutes between the Calm and the Stress scenario. For the rest of the participants, most of them felt short moments of motion-sickness, especially playing the walk-in-place tutorial at the beginning of the study. This is related to the low experience they had in VR games and that they needed to get used to what was happening in the real world. Most of them did not have any major issues and could recover quickly while playing.

Also, a low number of participants said that they felt a bit tired, some physically because of the demands of playing by standing up for the whole 45 minutes of the study and mentally because of the need of attention the player must pay to the game. Some of them said that they felt a bit of heat because of having the HMD on and that it felt a bit heavy. These comments are from some individuals and cannot be generalized for all the players. We think that the fact of telling the participants to take the HMD off while doing the questionnaires between scenes, was beneficial for them because they could take a rest during a couple of minutes and recompose. One more general comment that was mentioned is that the participants felt weird after playing the whole study and this can be related by the high levels of immersion they could experience and the disconnection with the real world.

One question that we did just to make sure that the experience was not negatively affected by the grabbing mechanic was to ask them if they had any type of difficulty moving while holding objects. 3 out of the 21 participants had small issues like not remembering what was the trigger to grab an object or that they released the object on the floor when they teleported because they picked up the object with the right hand that they also use to teleport. Since the triggers for teleporting and grabbing are the index trigger and the middle finger respectively, some participants find it a bit difficult to control which trigger they were using. But overall, no significant difficulties combining locomotion mechanics and pick up/release objects mechanics, so we can be sure that the results were not affected by this mechanic.

As per the last question of the semi-structured interview, 5 out of 21 participants said that they were a bit worried about the surroundings and their physical security. 2 of them did not know what to do when the Guardian System appeared although we explained them before the study what could happen if they stepped out of the play zone and how to get back to a safe location but they needed help to get back to a point of the play area where they did not have any obstacle close to them. 3 of these 5 participants did rarely move physically in the area, if they needed to turn around they used the snapping mechanic or they turned themselves but they did not do steps in any direction or use the play area to move freely. They said that they were really afraid of crashing against any obstacle and that they wanted to be sure they were at the centre of the play area, in a safe position. For one participant, this was related to a previous experience with VR where he collided against an obstacle and he was trying to play as safe as possible. These participants had less immersion in the game because they were really focused on knowing their position in the real world.

6. CONCLUSIONS OF THE WORK

6.1 Conclusions

After analysing 25 of the most popular Virtual Reality games in the market of the few last years, we will talk about some of the main conclusions from their control systems and the study we performed about locomotion in VR games.

We found out that the main differences in control systems are determined by the genre of the game. For example, locomotion is commonly used in narrative and action games while rhythm games and simulators use static experiences. As another case, the use of the Index.Trigger button depends on the game genre. For an action game that involves shooting, the Index.Trigger is used to shoot a gun while in other genres the same trigger can be used to pick up or release objects from the scenario.

There are mechanics that have a standard control system such as picking up objects, free locomotion, shooting, opening the game menu and the activation of the walk-in-place locomotion technique. On the other hand, mechanics such as teleportation, inventories or snapping do not have a standardized control system.

Virtual Reality games in the market are doing a great job delivering immersive experiences to the players. One of the main characteristics are the interactive menus that are not present in non-immersive games. Not all games have them because of design and budget, but this type of menus improve the player experience and the immersion in the game. Immersion is also achieved by taking advantage of the body of the player, the motion-tracking and gestures thanks to the VR technology. Games try to be as realistic as possible in mechanics like shooting, reloading, healing and inventory systems in which they force the player to do movements as they would do them in real life like pulling the trigger of a gun or grabbing an object from the belt. Another common feature that games with combat have are the two handed weapons like rifles or big axes that the player must grab with both hands in order to be able to use them correctly, increasing the realism of the gameplay.

From the analysis we can conclude that the standard locomotion system for the action games is the free locomotion and the teleportation is the standard system for narrative games. Moreover, games including more than one locomotion technique force the player to select one of the available options at a time. From these conclusions, we decided to do a study with users between 20 and 26 years old with little to no experience in VR games presenting them a small game that we used as an experiment to research about locomotion in VR in narrative and action games. This study showed that the preferred locomotion system was a combination of teleportation and free locomotion although in the analysed games this possibility of combining both systems was not available. Teleportation was faster and more efficient for covering large distances while free locomotion was more immersive and less disorienting. Because of that in the action scene, the players opted for using teleportation more than free locomotion although in the analysed games, action games use free locomotion as the main locomotion system. Free locomotion was the fastest system to learn for the participants since they already had experience with non-immersive games that use the free locomotion technique to move, it was the most familiar control system. The participants felt that their movements were under their control using free locomotion. On the other hand, the walk-in-place technique was the least used in the study because the movement was really similar to free locomotion but it caused more motion-sickness, it was more complex and more difficult to control in comparison with free locomotion. In its favour, it was the most immersive method of the three. This technique is rarely used nowadays and it looks like it may disappear in favour of other locomotion techniques.

The games industry also wants the games to be as accessible as possible for every type of player and that is reflected in VR video games. The most commonly used comfort modes have two different goals: reduce motion-sickness and make the games accessible for disabled players. For reducing motion-sickness, action games with free locomotion add snap turning although from the study we made, there was no significant improvement in reducing motion-sickness. Snap turning is also an accessibility mode for disabled players or for people that do not have a large space to play or want to play seated, it is the best option to turn around without moving physically. Some VR games add the play seated mode that is meant to be a comfort mode and an accessibility feature although playing while standing up is encouraged by the game for a higher immersion. Some action games also have the possibility to grab objects from a distance, reducing motion-sickness.

As we have said at the beginning of the thesis, the VR industry is really young in comparison to the whole gaming industry and observing it is the best way to predict what the future of VR gaming can look like. Although the levels of standardization of control systems are far away from the ones in non-immersive games, there are some mechanics that already have standards and the popularity of VR that we have nowadays means that more companies and studios will invest and develop games, so different ideas, implementations and techniques will appear and some of them will start to be recurring in different games depending on the genre, eventually becoming a standard.

6.2 Future work

After this work, some ideas and projects appear to be interesting to work on in order to keep researching the topic of control systems in VR. One of the first ideas that could be interesting to develop is to do a similar study as we did here but for other control systems and mechanics in the analysed games in order to find the best options for a set of players.

It could be interesting also to expand the study to other types of players. Comparing the behaviour of non-experienced young players against experienced players in VR or even performing the same study with elderly people. In the end, we want to have a simple and easy to learn experience for everyone, and nowadays more people of advanced age know how to use a mobile phone and even play with them, so it could be a good idea to test how easy or difficult a control system is by testing it with elderly people.

Another work of research about control systems and VR could be to follow the hypothesis that we presented in this work that VR games will follow a similar evolution like the one that happened with the gaming industry, in relation to control systems. It could be interesting to observe how the early control systems of commercial VR games were and compare them to the current control systems with the goal of finding relations and patterns that could help to predict what will be the future of control systems for Virtual Reality games.

7. REFERENCES

[1] Clement, J. (2021, June 1). *Number of video gamers worldwide 2015–2023*. Statista. https://www.statista.com/statistics/748044/number-video-gamers-world/

[2] ESA. (2020, July 15). *2020 Essential Facts About the Video Game Industry*. Entertainment Software Association. https://www.theesa.com/resource/2020-essential-facts/

[3] Smith, N. (2021, February 4). *Virtual reality is starting to see actual gains in gaming*. Washington Post. https://www.washingtonpost.com/video-games/2021/02/04/virtual-reality-future-games/

[4] Steam. (2021, January 19). *Steamworks Development - Steam - 2020 Year in Review - Steam News*. https://store.steampowered.com/news/group/4145017/view/2961646623386540826

[5] Swinhart, D. (2021, February 20). *Virtual reality has real problems. Here's how game developers seek to delete them.* The Seattle Times. https://www.seattletimes.com/business/technology/virtual-reality-has-real-problems-heres-how-game-developers-seek-to-delete-them/#:%7E:text=Nausea%2C%20dizziness%2C%20disorientation%20and%20a,them%20that%20they%20are%20still.

[6] Boletsis, C., & Cedergren, J. E. (2019). VR Locomotion in the New Era of Virtual Reality: An Empirical Comparison of Prevalent Techniques. *Advances in Human-Computer Interaction*, *2019*, 1–15. https://doi.org/10.1155/2019/7420781

[7] Lang, B. (2021, January 4). *VR Comfort Settings Checklist & Glossary for Developers and Players Alike*. Road to VR. https://www.roadtovr.com/vr-comfort-settings-checklist-glossary-developers-players/

[8] Shelstad, W. J., Smith, D. C., & Chaparro, B. S. (2017). Gaming on the Rift: How Virtual Reality Affects Game User Satisfaction. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *61*(1), 2072–2076. https://doi.org/10.1177/1541931213602001

[9] Pallavicini, F., Pepe, A., & Minissi, M. E. (2019). Gaming in Virtual Reality: What Changes in Terms of Usability, Emotional Response and Sense of Presence Compared to Non-Immersive Video Games? *Simulation & Gaming*, *50*(2), 136–159. https://doi.org/10.1177/1046878119831420

[10] Yildirim, C., Carroll, M., Hufnal, D., Johnson, T., & Pericles, S. (2018). Video Game User Experience: To VR, or Not to VR? *2018 IEEE Games, Entertainment, Media Conference (GEM)*. Published. https://doi.org/10.1109/gem.2018.8516542

[11] Estupiñán, S., Rebelo, F., Noriega, P., Ferreira, C., & Duarte, E. (2014). Can Virtual Reality Increase Emotional Responses (Arousal and Valence)? A Pilot Study. *Design, User Experience, and Usability. User Experience Design for Diverse Interaction Platforms and Environments*, 541–549. https://doi.org/10.1007/978-3-319-07626-3_51

[12] Pirker, J., Pojer, M., Holzinger, A., & Gütl, C. (2017). Gesture-Based Interactions in Video Games with the Leap Motion Controller. *Human-Computer Interaction. User Interface Design, Development and Multimodality*, 620–633. https://doi.org/10.1007/978-3-319-58071-5_47

[13] Hufnal, D., Osborne, E., Johnson, T., & Yildirim, C. (2019). The Impact of Controller Type on Video Game User Experience in Virtual Reality. *2019 IEEE Games, Entertainment, Media Conference (GEM)*. Published. https://doi.org/10.1109/gem.2019.8811543

[14] IJsselsteijn, W. A., de Kort, Y. A. W., & Poels, K. (2013). *The Game Experience Questionnaire*. Technische Universiteit Eindhoven. https://research.tue.nl/en/publications/the-game-experience-questionnaire

[15] Brooke, J. (1995, November). *SUS: A quick and dirty usability scale*. Research Gate. https://www.researchgate.net/publication/228593520_SUS_A_quick_and_dirty_usability_scale

8. ANNEX

8.1 Initial Questionnaire

12/6/2021 Initial Questionnaire

Initial Questionnaire

1. Player Reference

____

2. Age

____

3. Do you play videogames?

   Mark only one oval.

   - ( ) Yes
   - ( ) No

4. Do you play videogames frequently?

   Mark only one oval.

   - ( ) Everyday
   - ( ) 3-4 days a week
   - ( ) Once a week
   - ( ) Once a month
   - ( ) Never

5. If you had played any games, which platforms do you use?

Tick all that apply.

- [ ] PC
- [ ] Consoles (Playstation, XBOX, Switch)
- [ ] Mobile
- [ ] Virtual Reality

Other: [ ] ____________________

6. Have you experienced Virtual Reality?

Mark only one oval.

- ( ) Never
- ( ) I have tried once
- ( ) I have played games for Virtual Reality several times
- ( ) I usually play video games for Virtual Reality

7. Have you ever played with the Wii/Wii U or Switch?

Mark only one oval.

- ( ) Yes
- ( ) No

8. Have you ever played with Eye Toy, Kinect or similar?

Mark only one oval.

- ( ) Yes
- ( ) No

8.2 Locomotion Questionnaire

Locomotion Questionnaire

1. Player Reference

___

2. I think I would like to use this system frequently

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

3. I found the system unnecessarily complex

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

4. I would imagine that most people would learn to use this system very quickly

Mark only one oval.

1	2	3	4	5
◯	◯	◯	◯	◯

5. I thought the system was easy to use

Mark only one oval.

1	2	3	4	5
⬭	⬭	⬭	⬭	⬭

6. I needed to learn a lot of things before I could get going with this system

Mark only one oval.

1	2	3	4	5
⬭	⬭	⬭	⬭	⬭

7. I found the system very cumbersome to use

Mark only one oval.

1	2	3	4	5
⬭	⬭	⬭	⬭	⬭

8. I forgot everything around me

Mark only one oval.

1	2	3	4	5
⬭	⬭	⬭	⬭	⬭

9. I lost track of time

Mark only one oval.

1	2	3	4	5
⬭	⬭	⬭	⬭	⬭

10. I felt frustrated

Mark only one oval.

1	2	3	4	5
⬭	⬭	⬭	⬭	⬭

11. I found it tiresome

Mark only one oval.

1	2	3	4	5
⬭	⬭	⬭	⬭	⬭

12. I felt dizzy

Mark only one oval.

1	2	3	4	5
⬭	⬭	⬭	⬭	⬭

13. I felt confused

Mark only one oval.

1	2	3	4	5
◯	◯	◯	◯	◯

14. I felt immersed into the world

Mark only one oval.

1	2	3	4	5
◯	◯	◯	◯	◯

8.3 Semi-structured Interview

1. Between the slow and fast paced scenario, which one did you like the most, felt more comfortable or would you like to play again?

2. Which locomotion system did you prefer to use during the slow paced scenario and why?

3. Which locomotion system did you prefer to use during the fast paced scenario and why?

4. Did you use all locomotion systems, if not or if there is one system that is rarely used, why did you choose one over the other?

5. Did you feel dizzy at any point during the experiment? Did you want to stop playing?

6. Did you feel tired at any point during the experiment? Did you want to stop playing?

7. Did you use the snap turn and why?

8. Did you feel confused or disoriented at any point?

9. Did you find any kind of difficulty in moving while holding any object with your hand?

10. Did you lose track of time?

11. Were you afraid about your physical security?