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# reGaze:

## Eye Tracking Assisted Superhuman Interactions in Virtual Reality Games

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**Abstract:**

Technological advancements in virtual reality (VR) headsets have enabled novel forms of VR interaction. Some of them, such as eye tracking, seem to be overlooked. Thus, the aim of this project is to introduce eye gaze based superhuman interactions, specifically when travelling and selecting and manipulating objects within the VR game. Dashing was utilised as a travel technique and telekinesis as an object selection and manipulation method. Via the proposed interaction methods the effect on game experience is compared between eye gaze based and traditional controller input. An iterative process of design and implementation was followed to develop a prototype in which the game experience could be measured. Each iteration had its own evaluation to gather data that would be used to improve the following iteration. The final experiment involved a within-group study ( $n=30$ ) where each participant tested the prototype twice in randomised order, one for each interaction method; eyes and controllers. The evaluation was done through the use of a refined version of the game experience questionnaire (GEQ). Based on the results, there are indications that eye tracking as a primary input method for travel and selection & manipulation in VR, can yield a comparable experience to the handheld controllers in an exploration and puzzle solving game scenario.

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# 1 Introduction

Virtual reality (VR) has been a widely researched topic for the last 50 years. It is a powerful technology, which induces a sense of presence in the user [66]. The research and development of VR has gone through a rather asperous process, by being labeled as a dead technology by figureheads of technological development in the 1990s. Since then, the scientific research community has persistently made progress to extend the possible applications of VR to the fields of telepresence, data visualisation, surgical simulation, education and remote collaboration [60]. However, the biggest area of VR utilisation is within the entertainment industry, including immersive film and gaming experiences. According to Mel Slater [66], in 2016 most of the first interactions that people will have with VR would be through a game or a cinematic experience. VR affords various novel interaction techniques which can be utilised by games to make the gameplay more engaging and enjoyable. This could also induce the aforementioned topic of presence, moreover, HMDs extend the technical boundaries of gaming due to their immersive nature.

Recently, VR has become more widely available, primarily due to the appearance of consumer-grade head-mounted displays (HMDs) [1]. The development of more accessible VR headsets opened up opportunities to more widespread home-based VR entertainment experiences. Still, most of the state of the art VR headsets utilise a rather uniform approach as input in the interaction process. Namely, through the use of two handheld controllers. These controllers utilise different interaction modalities including gesture and motion based interaction, aided by traditional forms of interaction like buttons and analog sticks.

Complex virtual environments with multiple objects afford a plethora of different interaction types via different modalities. It has been speculated that novel interaction types for VR experiences could offer more intuitive inputs. As an example, one currently emerging alternative is gesture-based interaction, where HMDs track the hand-position of users. This research direction has resulted in Oculus including hand-tracking in their Quest model, moving towards controller free interaction. The aim of this project is to explore similarly novel and emerging interaction types, as these could enhance the user experience by utilising more intuitive and fluid interaction in VR.

Eye tracking technologies have become more widely utilised in the field of human-computer interaction (HCI) in the recent years, and some argue that this will be the next interaction method for VR headsets in the coming years [20] [63]. Eye tracking techniques have been used to study human cognition as early as the 1900s [32]. Lately, it has seen a surge in possible use cases, partly aided by development in camera technology and computer-vision algorithms [13]. Eye tracking has also spread into the realm of VR, by enabling a more hands-free interaction with virtual interfaces. Specifically allowing users to interact with systems only using eye movements or controller-based interaction being aided by eye tracking [2]. The latest technological advancements have also allowed to make eye tracking more cost-efficient and versatile [13], and Clay et al. argues that eye tracking in VR is a burgeoning research topic. Thus, there should be room for exploration within this topic for this project. Especially within the realm of VR gaming - as it is currently the most widespread application for VR headsets. Therefore, this project will research whether the novel technology of eye tracking can be used as an input method in VR gaming experiences to enhance user experience. Based on this, the Initial Problem Statement can be formulated as follows:

## 1.1 Initial Problem Statement (IPS)

*"How can eye tracking technology be used in virtual reality games as a novel form of human-computer interaction to enhance user experience?"*

## 2 Analysis

The primary goal of this chapter is to provide a thorough analysis of the topics presented in the IPS [Section 1.1]. Through expanding on each initial research topic, a more narrow and specific direction of this project will be defined. At the end of this chapter, a final problem statement (FPS) will be formulated based on the conclusion [Section 2.4] of the analysis. The FPS [Section 2.4.1] together with the analysis will be used as a foundation to define a hypothesis, which in turn will guide the development of a research prototype. The prototype will be designed, implemented and evaluated through an iterative process. The methodology behind this process will be detailed in the Methods [Chapter 3].

To begin with, the growing field of eye tracking and what it is used for will be explored [Section 2.1]. This section will discuss in detail what are the main advantages and disadvantages of eye tracking when used as a novel interaction technique [Section 2.1.1] and how it could be utilised within HMDs [Section 2.1.2]. As the last part of the investigation of eye tracking in VR, a state of the art (SOTA) review will present the already existing games, or prototypes which apply eye tracking as an interaction technique in a VR gaming context [Section 2.1.3].

In order to propose appropriate applications for eye tracking, the core characteristics of 3D interaction techniques will be scrutinised [Section 2.2]. By getting down to the gist of 3D interactions in a virtual environment, a bottom-up approach will be followed in order to determine how and where could eye tracking be implemented as a novel form of input. This section will also take a look at the related works implementing eye tracking based interactions in virtual environments (VEs) [Section 2.2.3].

To further understand how to construct a relevant eye tracking based interaction, VR games and the gaming experience will be analysed [Section 2.3]. The gaming experience will be broken down into its building blocks, and how a novel interaction could affect certain blocks or the whole experience [Section 2.3.1]. Furthermore, how the experience of users could be measured will be investigated so that the future prototype can be evaluated properly [Section 2.3.2]. Finally, a conclusion will be presented that will summarise all the important findings, based on which a final problem statement will be formulated [Section 2.4 & 2.4.1].

### 2.1 Eye Tracking

Eye tracking technology is a set of techniques and methods in which a person's eye movements are detected, measured and recorded. Using this technology the exact location of where the gaze of the user is fixated can be determined, along with how it shifts from one place to another and in what sequence [44] [57]. As well as observing pupil dilation and the blinking of an eyelid. Eye movements give insight into a multitude of human behaviors and several aspects of cognition, such as problem solving, reasoning, mental imagery and search strategies [34]. Thus, it allows researchers to collect information about a test participant in a new and precise manner, which has led eye tracking devices to be deployed in many psychological research studies [44].

This technology has also provided researchers with an objective source of data on how people process visual information coming from a display which makes this technology exceedingly useful in evaluating usability. Based on the data gathered from eye tracking, factors influencing usability can be identified and more informed design decisions can be made on how to construct system interfaces [57]. It has also been used to understand how the audio in movies affect and direct the gaze of film viewers [12].

### 2.1.1 Eye Tracking as Input

Besides applying eye tracking technology as a passive sensor for research purposes, the detected gaze location and eye movements can also be used in a more active way, such as input to control a system interface. Enabling people to interact this way with an interface can be very beneficial for disabled users, who can't use traditional input devices such as mouse and keyboard. In these cases, as an example, the cursor of the mouse can be attached to the gaze point of a person, enabling a hands-free use [57]. Non-disabled users can also gain from using a system like this. Eyes are the fastest muscle in the human body, therefore it could potentially unlock extremely rapid interactions. However, the eye primarily evolved for perception of the environment, rather than manipulating it, thus incorporating it as a sole input modality can pose some challenges.

A central issue in systems that are based on eye tracking and gaze-control is the so called "Midas touch problem" [76]. This problem entails that when an interface is realised solely on gaze-control, each focused gaze of the user will result in the interaction with the observed component. The problem is named after the Greek mythos of King Midas, who asked from the god by the name of Dionysus that everything he touched would turn into gold. His wish was granted, but soon he realized that this is not as much of a blessing as he thought, since even the food and the loved ones he touched would turn into gold [46].

Similar to the fable, in a gaze-controlled system, every "touch", or in this case the gaze of the user will afford some form of interaction. Thus, might make the system difficult and problematic to use. As mentioned earlier, the human eye has developed to observe the environment, and not to manipulate it, and in a gaze-controlled system both is necessary. For such a system to function efficiently it should be able to differentiate between a gaze that is only for perception, and a gaze that's purpose is to interact with the interface [76].

A way to tackle this issue, is to use something called a dwell time. This method involves introducing a delay to discern between just observing and gaze-controlling. Basically, the user would look at the element of the interface they want to interact with, and after a short delay, the element would activate. The threshold of when the element activates should be tailored to the user, and to the task. There should be enough time for users to observe, confirm or cancel their actions, but it should not be too long to make the use of the interface too sluggish. Other ways to get around the Midas touch issue and implement gaze-controlling successfully is to use gaze gestures, or to create a specially designated selection area next to the interface elements. A blink or a wink can be used as a confirmation of intention [43].

These solutions are not necessarily the most advantageous, as they are error-prone. Gaze gestures can be misinterpreted by the system. Humans blink around 10 times a minute, therefore, the system might register a blink as a confirmation of intention, when in reality it was just a normal bodily function unrelated to the interaction. Furthermore, constantly winking and performing gestures will result in fatigue of the eyes, which is an unwanted side effect for users [4].

Introducing an additional modality can be a more effective way to find a solution for the Midas touch problem. This method can result in less error prone solution than the aforementioned ones, and it could be the most efficient way to prevent unintentional selections [43]. To put in layman's terms in the form of an example, the user could use a simple physical button to confirm the intention of interaction.

Next, the role of the visual system will be discussed, in order to derive the most meaningful modality to compliment gaze-control. It is imperative that the chosen modality together with eye tracking should feel intuitive for the users to make the interaction simple to master and easy to control. The eye plays a crucial role in the coordination of our limbs. Specifically eye-hand coordination is the ability to coordinate the movement of the hands based on the processed incoming visual information to fulfill precision tasks

[77]. Without good eye-hand coordination even the simplest of everyday tasks, such as grabbing a door handle or throwing a ball, may become challenging. Due to this close relationship between the eye and the hand, and the fact that most commercially available HMDs come with handheld controllers it would be logical to select an additional modality to aid eye gaze assisted interaction involving the hands.

### 2.1.2 Eye Tracking in VR

Recently, the emergence of efficient and precise event detection algorithms, have made the use of consumer-friendly eye tracking techniques more available. This trend seems to also be continuing in the coming years, with the incorporation of machine learning, to make a generalised event detection algorithms that would cross several different platforms [83]. This software based development is in turn aided by the invention of small high quality camera lenses, making it possible to integrate eye tracking into HMDs such as VR headsets [13]. The integration of eye tracking in HMDs has opened up a series of opportunities within experimental research in VR and human cognition in VEs. It has now become easier to define points of interest in 3D environments, and to draw visual patterns from these points. Furthermore these points can be used for interaction within VR. Eye tracking has the potential for creating a smoother and more intuitive interaction within VR applications, such as interactions with virtual objects or menu selections [38].

Because eye tracking technology has only recently been advanced enough to be embedded into commercially available VR headsets there are only a few available on the market for purchase. Some of these headsets are made possible by the help of the current world leader in eye tracking technology, a company called Tobii. According to Tobii, eye tracking in VR has a great deal of possible applications [69].

For example, eye tracking can be used to identify different individuals using the VR headset, thereby removing the need for manually switching between user profiles. Since users can be distinguished by unique eye characteristics, the need for authentication is also fulfilled. These characteristics result in easier and faster multi-user management and improved security [69].

User attention is another field where VR eye tracking can provide valuable input. As earlier discussed, data from eye activity in VEs can provide developers, designers and researchers with valuable information to improve usability and to facilitate a broad spectrum of analytical use cases. For social uses of VR, such as conferencing or VR chat, embedded eye tracking can enable realistic eye movements of user avatars, making interactions between users feel more enriched and real [69]. An example of the employment of this technology is Eyemotion, a research prototype that infers facial expressions in VR using eye tracking camera data. The facial expressions than can be used in social engagements in the forms of dynamic avatars, that would accurately convey the expressions of the user [28].

As for using it as an input modality for interaction, eye gaze can be utilised for things like navigating a menu, more intuitive experience of aiming or selection of an object [69]. Previously the "Midas Touch" problem was discussed, and possible ways to tackle it [Section 2.1.1]. Using an additional modality, also called a 2-step interaction is an easy way to circumvent the issue. This way users only need to look at a menu item, and then confirm through the additional modality, which in this case can be the VR controller [69].

Similarly, when wanting to interact with an object the user only needs to rest their point of eye gaze on the object, and initiate the interaction with the press of a button on the controller. This 2-step interaction can capitalise on and improve hand-eye coordination, an important coordinated control mechanism that allows the completion of a range of tasks, starting from simple things such as grabbing a mug from the table, all the way to complex activities like playing VR games. Combining the precise information from

our visual system with the movements of the controller to interact with a VR environment can result in a more natural user experience [69].

Eye tracking is currently not a widely adopted form of interaction within most VR systems. Especially, within games there have not been a significant amount of applications released as of this date. Therefore, a review on the current state of the art of eye tracking in VR games, will be made in the next section.

### 2.1.3 State of the Art - Eye Tracking in VR games

As aforementioned, eye tracking has gained substantial interest as a novel input form in VR. In this section, it will be examined how eye tracking technology has been used in VR games, and what are the recent contributions of the research community in this topic.

First of all, eye tracking is mostly used with an additional modality in VR games. As it was examined previously [Section 2.1.2], utilising an additional modality to overcome the Midas effect and other inconvenient usability issues is beneficial for eye tracking as a input method for VR games. As it has been detailed earlier, these additional input modalities often utilise hand controller or hand gesture related technologies in the interest of hand-eye coordination [Section 2.1.2].

This is a plausible notion in VR games as well, as there are examples of research in the given field. A study carried out in 2019 investigates hands-free interactions in VR using eye gaze and electromyography (EMG) [49]. In this comparative study focusing on selection tasks in VR, five different interaction types are presented.

1. Gamepad
2. Dwell time
3. Dwell time with eye gaze
4. Motion controllers
5. Eye gaze with EMG

The study comprehensively reviews the different input methods, and also introduces the results of accurately selecting and aiming at targets in a VR point and shoot gun-game. Based on the presented research in the paper, it becomes apparent that eye gaze combined with EMG was not the most accurate, but the most enjoyable input method. When interacting with the gun-game, users stated that aiming with the eyes feels natural and intuitive [49].

Another relevant study conducted in 2019 compares eye tracking with hand controllers for aiming tasks in VR [42]. This study uses a similar aim and shoot task experience with targets with different speeds and trajectories. The qualitative data gathered from the study focuses on the usability via the system usability scale (SUS) [3]. The achieved results indicate that the perceived cognitive load is lower whilst using gaze aiming, and there is no significant difference in the SUS. Rather interestingly, the study concludes that the overall accuracy of the gaze aiming was considerably lower than the results on via the controllers [42].

A paper titled "*Understanding User Attention In VR Using Gaze Controlled Games*" was also published in 2019, however rather than scrutinising eye tracking as an input method; it explores a distinct use-case for eye tracking in VR games [18]. The game prototype created in this research project utilises eye tracking as a research tool to understand user's attention in gaming experiences. The game itself is gaze controlled and offers a simple gameplay: In a given environment there are three cubes representing targets, and the users need to fixate their attention on them in order to gain points. Additionally, there

are distracting characters to make the users split their attention, therefore, it can be studied how players' attention can be affected by non-target objects.

The results of this experiment are not necessarily important to detail here, as it covers a slightly different aspect than this project's research goal. Nonetheless, it is interesting to look at the qualitative user feedback provided in this study. All of the 16 participants in the experiment found their game experience positive, and they were generally intrigued by gaze-control according to Dohan et al. [18].

To further understand the possibilities and limitations of what eye tracking in VR poses, an overview of the different kind of interaction modalities in a 3D environment will be made in the next section 2.2. These will be described by using the theory presented in the book of "3D User Interfaces: Theory and Practice" by LaViola et al. [38].

## 2.2 3D Interaction Techniques for Eye Tracking

This chapter will investigate the three particular 3D interaction types – **selection & manipulation**, **travel** and **system control** – from the perspective of eye tracking technology. It is crucial to understand and investigate these interaction types, to see how and where eye tracking technology could yield meaningful novel interactions. Thus, the aim of this section is to provide a comprehensive analysis of the aforementioned 3D interaction techniques; and offer viable suggestions on how could eye tracking technology enhance each particular 3D interaction type.

Additionally, related work to eye tracking-based interaction techniques will be presented and reviewed at the end of the chapter [Section 2.2.3]. Thus, the significant advancements can be acknowledged in this particular field, and they could be used as a foundation to further specify this project's research topic.

According to the work of LaViola et al., 3D interaction techniques are methods to accomplish various 3D interaction tasks, via a specific interface [38]. The different types of 3D interaction tasks can be sorted into three categories. These are the following:

- **Selection & manipulation:** Covers interaction tasks closely associated with choosing, controlling and modifying properties of objects in 3D environments. These tasks have been extensively analysed by the research community, since they are fundamental building blocks of 3D interaction. Selection & manipulation also acts as a foundation for various other 3D interaction techniques, as well [38].
- **Travel:** Is connected to the task of navigation, i.e. moving in and around a virtual environment. This task is significant, since navigation is a quintessential human effort, thus, providing appropriate metaphors for it is equally important. Navigation can be broken down to two big components: travel and wayfinding, where the former refers to the core motor component of navigation and the latter examines the cognitive aspect of route-planning in navigation [38].
- **System control:** Deals with managing the change of mode or state within the 3D system. This topic is slightly less researched compared to the previous two, however they are equally essential for 3D user interfaces. System control tasks often implement command-based interactions or graphical menus [38].

It has to be addressed at this point that this research will not focus on system control as an interaction technique. It has been decided that the scope of the project will be limited to *travel* and *selection & manipulation*, so that an achievable research prototype may be constructed, tested and evaluated in the designated research period.

### 2.2.1 Selection & Manipulation

Within a virtual environment (VE), different methods for selecting objects can be applied. Manipulating the selected objects can also be carried out various ways. Hence, structuring selection & manipulation is fundamental to narrow down and filter specific use-cases, interactions, and metaphors. Before detailing this 3D interaction technique, it is important to point out that most of the selection & manipulation tasks in a 3D environment remarkably depend on their specific use-case. According to LaViola et al., the techniques required to quickly rearrange objects in an immersive 3D modelling application can highly differ from the selection & manipulation techniques needed to perform surgical operations in a medical simulator [38].

In 3D interactions, manipulation can be limited to so called *spatial rigid object manipulation*, which are manipulations that preserve the shape of the objects. However, manipulation can be narrowed down more, via identifying the four canonical manipulation tasks: **selection**, **positioning**, **rotation** and **scaling**. These four core manipulation tasks can be observed in most VEs, where manipulation interaction type is apparent, regardless exact use-cases. These canonical tasks also comprehend particular task parameters, as seen in figure 1, which have a possible impact on the user's performance whilst carrying out a specific task.

| Task        | Parameters   |
|-------------|--|
| Selection   | Distance and direction to target, target size, density of objects around the target, number of targets to be selected, target occlusion        |
| Positioning | Distance and direction to initial position, distance and direction to target position, translation distance, required precision of positioning |
| Rotation    | Distance to target, initial orientation, final orientation, amount of rotation, required precision of rotation                                 |
| Scaling     | Distance to target, initial scale, final scale, amount of scale, required precision of scale   |

Figure 1: Canonical tasks and their parameters [38]

Another significant viewpoint regarding selection & manipulation techniques is connected to isomorphism. The two main approaches are **isomorphic** and **non-isomorphic** views. The former concept proposes a realistic and geometric comparison between input methods and actions in a VE, with direct, one-to-one mapping [38]. Isomorphism, hence, has the advantage of providing the users a natural way of interacting in 3D environments resulting in a more realistic experience.

On the contrary, the **non-isomorphic** way of thinking about selection & manipulation proposes supernatural or "magical" interactions to users. This approach notably diverges from realistic interactions in 3D environments, allowing users to cut the constraints of natural concepts. Manipulating objects via non-isomorphic manners differs from manipulations in the physical world, which can result in more engaging interaction techniques in specific scenarios where strict realism is not the main objective [38].

As stated by LaViola et al., most of the selection & manipulation tasks can be decomposed to the same essential components [38]. Taking the example of selection, the main building blocks are **indication of object**, **confirmation of selection** and **feedback**. As it can be seen from figure 2, each of these components can be broken down into smaller building blocks. The main advantage of this methodology is that even though there are distinct input techniques – metaphors – in selection & manipulation, these

can be structured in the same manner. Additionally, new metaphors in selection & manipulation can be constructed out of existing building blocks of 3D interaction.

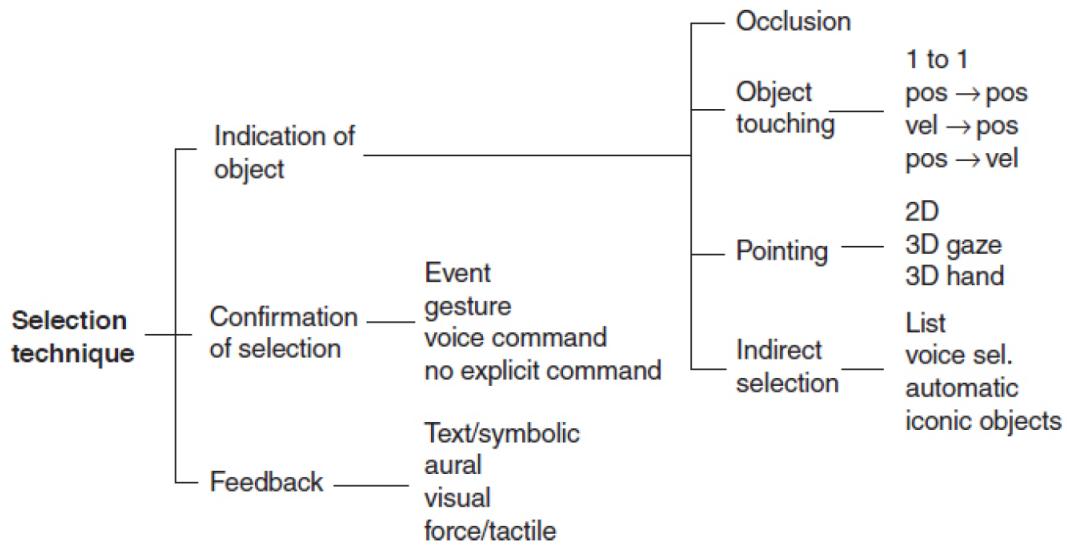


Figure 2: Classifying and decomposing selection techniques [38]

Most of the discussed 3D interaction techniques can be decompounded into various metaphors and combinations of these metaphors. Most of them are based on mental models of real-world interaction techniques, which prompt users on their cognitive level to perform specific actions by providing **affordances**, or dissuade them by providing **constraints**. In this manner, there are six common metaphors:

- Grasping
- Pointing
- Interacting with a surface
- Indirectly manipulating objects
- Bimanual interactions
- Combining metaphors to create hybrid techniques

### 2.2.1.1 Selection & Manipulation for Eye Tracking

As mentioned before, this section will detail the possible applications of eye tracking technology within selection & manipulation. After reviewing the previously discussed six common interaction metaphors, several observations will be presented here, which will presumably influence the direction of the project research.

First of all, it needs to be addressed that eye tracking was found to be more suitable for selection rather than for manipulation. More particularly, **pointing** metaphors could utilise eye tracking as a possible improvement. The concept of pointing can be broken down to two parts: a vector coming from a specific input (controller, hand) pointing and converging with a virtual object, and via a trigger event selecting this object. Pointing metaphors perform better in selection tasks than grasping metaphors due to their significantly less physical impact on hand movements.

As eye tracking could offer a pointing metaphor which is completely "hands-free", it could possibly be a feasible alternative for selection. Moreover, using only the eyes for selecting virtual objects could further

ease the cognitive load of the users. From sensing and perceiving the object on the visual and cognitive level to actually point at it, users need to translate and direct their attention from recognising the object to actually selecting it. However, via utilising eye tracking this process could be faster and less cognitively demanding, since the pointing itself would utilise the same input modality that is used as the main sensory input, the eyes.

Pointing, however is generally not a precise metaphor for the other canonical manipulation techniques [Section 2.2.1]. As LaViola et al. [38] argues, for positioning, pointing is less suitable, as in itself cannot provide sufficiently enough degrees of freedom (6-DOF), thus an additional input method shall be incorporated to achieve enhanced pointing techniques [38]. Rotation, however, can be accomplished sufficiently on one axis, defined by the pointing vector.

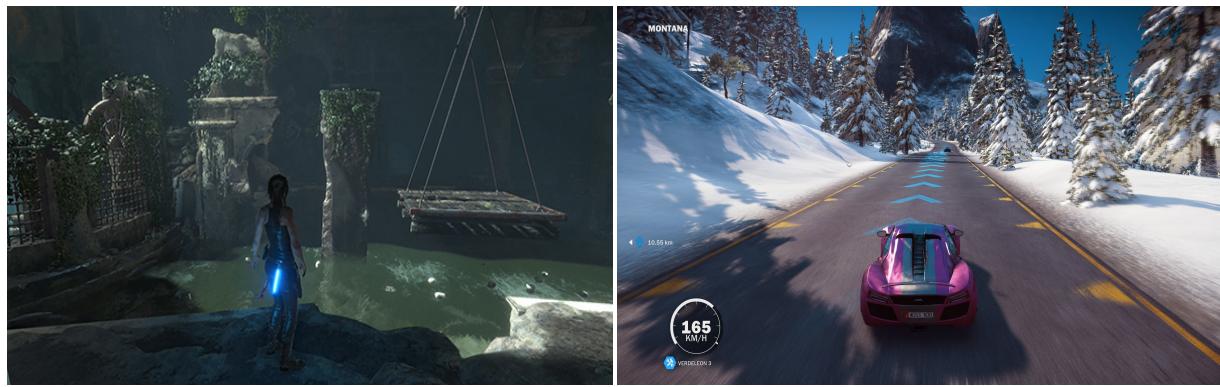
In conclusion, a viable approach will be presented for a meaningful interaction technique, incorporating the essence of selection & manipulation and the advantages of eye tracking technology. Using the eye as a direct input could result in a highly accurate, long-distance and agile object selection. Positioning, rotating and scaling objects could also benefit from the implementation of an additional input modality such as eye tracking to achieve a less cognitively demanding interaction. Manipulating objects with the aid of eye tracking could presumably result in a more definite positioning due to its precise and fast ray casting technology. Additionally, this technology could enable and enhance non-isomorphic manipulation, a technique that can result in more engaging interaction.

### 2.2.2 Travel

Navigation in a VE can be broken down into two aspects, namely "travel" and "wayfinding" [38]. Wayfinding can be seen as the cognitive aspect of navigation, while travel is the task of moving to a new location or in a certain direction. The act of travelling in a virtual world is often discussed in terms of real life metaphors. This results in more easily relating an unfamiliar way of travel in the VE to a familiar way of travelling in the real world. To move shorter distances the leg muscles would be used, but to travel longer distances and with more speed, some type of vehicle is often utilised. Vehicles in the real world involve certain interfaces such as pressing a pedal and turning a wheel to control speed and direction of travel. In a 3D environment metaphors are used, like a vehicle, to travel as well as to create novel ways of travel that are not feasible in the real world [38]. One major distinction between real world travel and VE travel is that 3D UIs only provide visual motion cues and not vestibular cues which can lead to visually induced motion sickness or "cybersickness" [38].

**Wayfinding** describes how a user will find their way from point A to point B. This is arguably done through building a mental map of the environment and planning a route [38]. Wayfinding can therefore be defined as something that only occurs within the user's mind and is not necessarily a task to be performed by systems creating the VE. Nevertheless, certain wayfinding cues can be put into a VE to guide the user to a desired location or in a desired direction. These, environment-centered wayfinding cues are put into the VE as a choice of design, to support the users in finding the correct way [38].

In figure 3 (a), the wayfinding technique that the developers have included are somewhat subtle. Here, the lighting is used to indicate a point of interest of the column to the left of the character. The users' eyes are immediately drawn to that location, thus they will deduce that that is their goal location. From this point, the user will arguably begin to plan their mind map on how to reach the cued location. This technique is called a natural environmental cue, and is widely used in the design of virtual worlds to support wayfinding [38]. While in figure 3 (b) the user is given an artificial landmark wayfinding cue that clearly indicate which direction the user should proceed in to reach the desired goal location [38].



(a) A natural wayfinding cue using light [61]

(b) An artificial landmark wayfinding cue [36]

Figure 3: Examples to environmental-centered wayfinding

After the user figures out possibly how and where to proceed in a VE via wayfinding, the actual travel to the desired location occurs. The act of travel can be categorised in various ways. LaViola et al. [38] propose that it can be decomposed into three sequential subcategories:

- **Direction or target selection**, where users decide on their final destination or direction to travel,
- **Velocity or acceleration selection**, where users select the specific speed and time for their travel,
- **Conditions for input**, which enables users with different controls to start, pause or finish their travel.

Nilsson et al. presents a comprehensive taxonomy for virtual travel techniques in VEs. [47]. In this paper, travel is analysed from three key aspects: *mobile and stationary travel techniques*, *mundane and magical travel techniques*, *vehicular and body-centric travel techniques*, as it can be seen in figure 4.

**Mobile and stationary** differs from the aspect of whether there is involvement of physical body movement by the users in the real world. Whilst the contrast between **Mundane** and **Magical** interaction metaphors is based on the level of limitation provided by physical constraints, such as gravity or the laws of physics. Finally, **Vehicular and Body-Centric Travel Techniques** can be distinguished based on the involvement of a virtual vehicle to simulate travel or utilising techniques which make the user's body apply forces to the environment, such as walking or running [47].

Additionally, looking at travel based on the distance covered is compelling for this research topic.

- **Short range** distance travelling can be executed using natural physical motion in VR, such as redirected walking [48] as well as maneuvering, which is the fine tuning of the position of the player character or camera.
- **Medium range** travel requires some form of virtual travel technique like a vehicle metaphor or the ability to jump between different locations [38].

To control position and movement in a 3D environment a steering metaphor can be used. Specifically spatial steering metaphors provide some of the easier methods of travel for a user. Steering essentially involves a tracking device that is manipulated by the user. One form of steering is gaze directed steering. In simple terms the user can manipulate the vector that they move along via head tracking. Essentially the user would control this vector by turning to different directions and can initiate their movement through a discrete event, like a button press [38]. Some issues arise with this method. If the user can only move towards where their head is pointed it will not be possible for them to strafe. This could

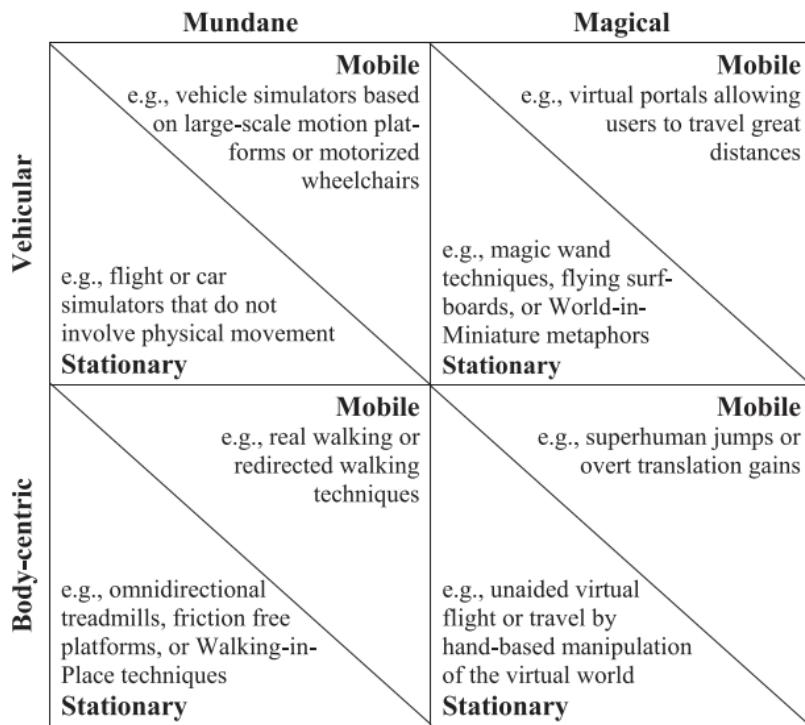


Figure 4: Taxonomy for virtual travel techniques [47]

make it difficult for the user to make short range fine tuning of their position [38]. Additionally, too much movement can induce "cybersickness" as discussed in [Section 2.1.2]. The steering metaphor could utilise eye gaze as an input instead of head gaze, which would grant the user more accuracy, however the aforementioned problems would still arise [38].

### 2.2.2.1 Target Based Travel Techniques & Eye Tracking

A major category within travel is target based travel. This metaphor simplifies travel, in the sense that the user does not need to think about the details of traveling. In this metaphor the user designates desired target location parameters and lets the system handle the actual movement. An empirical study [9] concluded that if the user is teleported instantaneously to a point, they would lose spatial awareness and therefore, continuous movement is recommended when spatial awareness is important. On the other hand if the user moves to the target location at a relatively slow speed, then it can induce *cybersickness*.

Therefore a compromise can be used where the user is moved to a location very quickly, then the user would retain some spatial awareness and because it happens so quickly it will reduce the chance of experiencing *cybersickness*. This method of travel is referred to by different names, some call it a "blink" [38] while others call it a "dash" [5]. Since this project will utilise eye tracking as an interaction method, the project group has decided to stick with the phrasing of "dash", as "blink" easily can be confused with an eye blink.

Dash is a **medium to short range** rapid movement to a target location. As stated above it is important for the user to retain some spatial orientation when traveling, therefore this travel technique seems like a promising option for a VR game. [5].

There have been several studies investigating virtual teleportation, as a target-based travel technique. It has been found that the point & teleport locomotion technique in VR is a fun and user friendly method

according to Bozgeyikli et al. [10]. Participants in the study preferred the point & travel metaphor compared to joystick input and walk-in-place travel techniques.

For room-scale VEs Langbehn et al. evaluates three travel methods: joystick, teleportation, and redirected walking [37]. The findings support that teleportation is a preferred travel technique, however this experiment suggests that redirected walking is the most natural and preferred for room-scale experiences. It is worth noting that the joystick method induces motion sickness, whereas the other two do not.

Coomer et al. also presents a comparative study on VR locomotion, but for large-scale VEs [14]. It analyses joystick input, teleportation, arm-cycling and point-tugging, the two latter are novel interaction methods presented by the authors. This research also confirms that it was easier for participants to travel longer distances with teleportation, furthermore participants looked around the most in the VE when travelling via teleportation without being motion-sick. However, this paper suggests that the arm-cycling metaphor is the best overall travel technique, based on their results.

A significant concept to include here is the so called *jumper metaphor*. This combines redirected walking with magical locomotion for large-scale VEs [7]. An interesting takeaway from here, is that Bolte et al. uses a smooth ease-in & ease-out jump animation to restrain motion sickness and disorientation of the users. They also presented a motion blur animation to further enhance the magical travel metaphor. These findings correlate with the aforementioned concept of dash.

Target based travel techniques usually involve another interaction technique, to select the desired travel destination [Section 2.2.1]. Dash for travel often uses a target signifier. It usually happens via putting an object into 3D space that would signify the target of the specific travel. This relates to object manipulation since the user is creating an object in 3D space and manipulating its position [Section 2.2.1].



(a) Dashing up on a ledge [6]

(b) Dashing forwards [15]

Figure 5: Example of how a user creates an object in the environment that signifies where the target position is

As can be seen in figure 5 (a), the dash target has an arrow on it, this signifies that the user will jump up on the ledge if they dash to it. This makes it possible for the user to reach places above them [6]. In figure 5 (b) the dash target also projects light on the ground beneath it. This signifies where the user will land if they dash into the air.

To actually trigger the teleportation or dash, an additional input condition is required. Nilsson et al. evaluates three different input conditions for teleportation: button clicking, physical jumping and fist clenching [29]. From this study it becomes apparent that a button click required less attention from the user and it also felt more enjoyable and less disorienting.

To conclude this section on how eye tracking could improve travel, it can be argued that teleportation as

a selection based travel might stand to gain additional value with eye tracking applied as an interaction method. Especially long range travel could benefit from applying eye tracking while navigating in large-scale VEs. The presented related work carried out on teleportation proposes that it is a preferred travel method by users compared to other locomotion techniques. It has also been found that teleportation significantly reduces motion sickness, but could intensify motion sickness. Finally, it has been identified that the most preferred input condition to trigger teleportation is the button click. Referring back to Nilsson et al., the proposed travel technique with eye tracking falls into the category Mobile, Body-centric, Magical travel technique.

### 2.2.3 Related Work to Eye Tracking as an Interaction Technique

This section will present related work where eye tracking has been utilised as an input in VR interaction. The section will follow the same structure as the previous one, it will group related work based on its interaction techniques: **selection & manipulation** and **travel**.

Incorporating eye tracking in **travel** has been carried out in various ways over the last few years by the research community. Zank et al. investigated whether eye tracking could augment redirected walking via locomotion prediction [82]. Eye gaze was applied to predict users' locomotion target whilst performing goal-directed locomotion tasks in a VE. The implemented eye gaze-based method was compared to existing position-based methods in prediction time and accuracy. The findings of the experiment indicate that in some cases the eye tracking based approach performs better in prediction time, however there was no significant difference compared to state of the art object-based prediction methods.

As it was suggested before, target-based travel techniques could possibly benefit more from the implementation of eye tracking [Section 2.2.2.1]. In a study carried out by Linn in 2017, eye gaze based teleportation was compared to a hand tracking method [40]. The research involved 12 participants in two groups for the two conditions (eye gaze, hand-tracking). Linn measured the participant's enjoyment, frustration, effort, distance, occlusion, immersion, and motion sickness via Likert questions. The results indicate that eye gaze based teleportation is: *"enjoyable, fast, intuitive, and natural locomotion method that performs similarly to hand-tracked teleportation but is preferred by users when they are given a choice"*[40]. It is also important to note that the eye gaze based teleportation made participants significantly less motion sick.

Finally, in 2018 Qian et al. proposed an empirical evaluation of eye-based travel in VR [58]. The main goal of this research was to measure and compare the effectiveness of eye tracking as an input for travel. There were two experiments conducted in this study, the first one evaluating seven methods for controlling direction while flying in a VE; whereas the second one included travelling on a terrain while avoiding obstacles. From the second experiment of this study Quian et al. concludes that the performance of the different methods were close, but eye tracking was cumbersome to calibrate and provoked motion sickness. However, this study's goal was to evaluate performance and effectiveness, there has been some qualitative data gathered on the participant's subjective preference. There has been positive indication that participants enjoyed interacting via eye tracking, despite the fact it was not as effective as other methods. It is also crucial to mention, that Qian et al. had critical issues with calibrating eye tracking, mostly due to using the FOVE HMD. They mention that presumably the calibration issues resulted in the increased level of cybersickness and via better VR displays and more quality eye tracking integration this could be avoided [58].

Moving on to **selection & manipulation**, there has been several implementations of eye gaze based selection due to its rapid and effective characteristics, which were also introduced previously [Section 2.2.1.1]. Nonetheless, **manipulation** has gained less interest thus far, there is therefore no significant

research to present.

Qian et al. also conducted an empirical evaluation on comparing eye gaze and head-gaze for selection tasks [59]. The experiment was modelled after the ISO 9241-9 reciprocal selection task with selection targets placed in different depths. The study compared eye-only, head + eye, and head-only conditions for selection. Similarly to the other research carried out by Qian et al. the performance and effectiveness of eye tracking compared to the other selection techniques was worse in most of the analysed factors [59]. However, looking at subjective qualitative data from interviews, users suggested that head + eye and eye-only input was enjoyable to use, however it was not sufficiently precise. Some participants also suggested that the combined method would suit first-person shooter games as the input for aiming. It needs to be addressed again that - similarly to the previous experiment by Qian et al. - the FOVE HMD with eye tracking sensor was used. The possible calibration issues of this eye tracking integration, conceivably had an impact on the results of the experiment.

Referring back to the classification and decomposition of selection [Section 2.2.1], the confirmation of selection is a crucial aspect of eye tracking interaction [Section 2.1.1]. Piumsomboon et al. presented an exploratory research of the topic, where natural eye gaze based interaction techniques are introduced as a form of novel interaction [53]. The research argues that dwell-time is a rather ponderous way of confirmation of selection, hence it introduces methods based on natural eye-movements: Duo-Reticles, based on eye gaze and inertial reticles, Radial Pursuit which takes advantage of smooth pursuit and Nod and Roll, a head-gesture-based interaction built upon the vestibulo-ocular reflex. All of the aforementioned novel eye-interactions performed better compared to the baseline condition. However, an important takeaway from this study is that using head gesture as a confirmation is fun and joyous, but it is tiring on the long run and could lead to the displacement of the headset which results in inappropriate eye tracking [53].

Finally, using an additional modality for manipulation to eye gaze based selection is implemented by Pfeuffer et al. [52]. Pinching is utilised as a manipulation technique after selecting objects via eye tracking. This ego-centric, bimanual manipulation technique offers a hands-free interaction in VR, and eye tracking makes it possible to manipulate objects from a large distance in a VE. It is worth noting that the research prototype was made to manipulate objects from a distance, thus emphasising on a 'magical' sense of interaction [52]. As it was mentioned earlier, there were no direct examples of object manipulation found in VEs. Qian et al. proposed that after reviewing travel and selection by eye tracking, it could also be a fascinating topic to investigate manipulation by eyes [59].

To briefly summarise this section, there has been several studies supplementing eye tracking aided target-based travel - teleporting via selecting targets with eye gaze. Selection tasks in general in VEs alleviated by eye gaze are also commonly used. Based on the evaluations of these interaction methods it can be concluded that their rapid manner does not result in superior precision and effectiveness. However, users do find this way of interaction more enjoyable and amusing compared to traditional interactions. It has also been addressed that the learnability of eye gaze based interactions should be taken into consideration when running user studies. Lastly, there has not been any studies found which utilise explicit eye gaze-based manipulation.

### 2.3 Gaming in Virtual Reality

What does it take for a technology to become considered as essential? In the final pages of the 3D User interfaces: theory and practice book [38] the authors reflect over the future of 3D user interfaces and use the term "killer application". They argue that for a technology to become an industry standard it needs an application that sets it apart from every other current technology and allows for a whole new way for the user to interact. For personal computers, this application was the spreadsheet, which made the

complex handling of accounting tasks simple and visual. Another new technique for interaction for PC was the mouse. This made a significant difference in the possible interaction methods a user could have with the technology compared to the typewriter [38].

So, what will the "killer application" be for VR? Well, LaViola et al. [38] argues that the current trends in the VR market indicate that the answer to that question is essentially gaming [38]. Although, this statement dates back to 2017, and in 2020 there are definitely other areas of VR trends apart from gaming that stand out, such as virtual desktops for home office [22] and VR simulations for a range of professions. It seems that as of today, a broader consumer market is still led by gaming applications and still stand as the one trend with the most potential to disrupt the industry. To further support this claim, the global VR gaming market size was estimated at 11.56 billion USD in 2019 and is predicted to grow up to 92.31 billion USD by the end of 2027 [78]..

Where VR gaming stands out from the traditional set-up such as desktop or console gaming is the whole new range of different possible interaction inputs and outputs that is presented to the user. These new input methods allow for new game features, which can have a significant impact on the user experience and on how a game is played [39]. Because any game is limited to its technical features, such as "display sizes, viewing angles, fidelity and synchrony" [50] and these boundaries are significantly extended for a user in a VR. It is the extension of these boundaries that also seem to make VR appealing for future prospects within the gaming industry [51].

### 2.3.1 VR Gaming Experience

Virtual reality gaming is one that is considerably different from traditional video games played on desktop displays. The most apparent distinguishing factor between the two gaming experiences is the level of immersion achievable [50]. According to Mel Slater et al. immersion can be defined as "*quantifiable description of a technology, that includes the extent to which the computer displays are extensive, surrounding, inclusive, vivid and matching*" [64]. Based on this interpretation it can be deduced that VR displays that completely encompass the players visual field and allow them to enter the world of the game while blocking the outside world can be deemed more immersive compared to traditional computer screens. Building on this, traditional displays such as computer screens or handheld controller displays can be categorised as non-immersive modalities, while VR HMDs would fall into the class of immersive modalities [50].

Immersion is the more objective and technology related characteristics of a virtual environment. The consequence of immersion on the cognition and perception of an individual is called presence [45]. It means that the person being immersed in an environment, for example through a VR HMD, has the illusion that they are at the displayed environment, and the events shown to them are actually taking place. Because of these illusions the users react as if what is being presented through this highly immersive technology is real. Of course the individual is aware that it is not actually physically real and they are not really in the VE, but they deliberately surrender to the experience [41]. Basically, they "feel present" in the environment that is being mediated to them. "Being there" or being "present" is called place illusion by Mel Slater. The other illusion that occurs in an immersive VR system is the plausibility illusion (Psi). Slater defines this as "*the illusion that the scenario being depicted is actually occurring*" [65]. Because VR facilitates presence much more than non-immersive modalities, neurophysiological arousal becomes more affected hence the experiences of users can be much more intense [72].

Another factor that differentiates VR gaming from traditional experiences is how the player's body is being utilised. Gaming on desktop computers most of the time involve using a controller, a mouse or a keyboard. In a VR game the rest of the users' body is employed to a much higher degree. It becomes

the primary interface to interact with the virtual environment. Head rotation can be translated into the player looking around in their environment, while the controllers will accurately represent the position of the players' hands in the virtual world. The involvement of the body in this way combined with the immersive display that excludes the distractions of the outer world leads to an ingenious experience that has the potential to achieve much higher engagement of the players [50].

For video games to be successful the player must be provided with good user experience (UX) [24]. UX in the field of Human-Computer Interactions refer to the perception of the interaction process between the user and the computer and combines applicable aspects for the subjective evaluation of a product. Specifically in games, this interaction happens between the player and the game [50]. An integral element of UX is usability [27]. The International Organization for Standardization defines usability as "*the extent to which a product can be used, by specified users, to achieve specified goals with effectiveness, efficiency and satisfaction, in a specified context of use*" [33].

For computer software other than games, usability is about maximising the performance, productivity and efficiency while taking into consideration the aspects defined by Jakob Nielsen, namely, learnability, memorability, efficiency, satisfaction and errors [30] [74]. On the other hand usability in relation to games, can often be boiled down to eliminating unintended challenges and unneeded interruptions, while taking into consideration the above listed factors [30]. Quantitative data on the usability of a game can e.g. be obtained by recording metrics such as time of level completion or total time spent playing. While for qualitative data gathering, questionnaires can also provide valuable information on how players perceived the process of their interactions with the game [50].

If one wanted to break down the VR gaming experience into building blocks, it would not significantly differ from a game played on non-immersive modalities [51] [81]. However, VR games have the potential to elicit much stronger emotional and physiological responses from players due to their immersive nature [50]. According to Calvillo-Gámez et al. the core elements of a gaming experience, including the video-game itself, along with the interaction between the player and the game [11]. This is basically identical to the definition of UX discussed above, where the product is the video game, and the interaction between the user and computer happens between the player and the game. The paper breaks down video-games as a product into two elements, these being game-play and environment. The latter is the aesthetics of the game such as graphics and sound. Game-play on the other hand refers to the narrative, rules and mechanics of the game [11].

The second element of game experience, the interaction between the game and the player, is referred to as puppetry by Calvillo-Gámez et al. This process is influenced by control, ownership and facilitators. Control is facilitated by controllers as basic tools to command the game, and refers to the player manipulating the game [11]. For a non-immersive modality this would be a mouse or a keyboard, while for a VR HMD this would be the controllers and eye tracking, in this project's case. The paper defines six categories that influence the process of gaining control [11]:

- **Goal** - the general aim of the game that has to be grasped by the player
- **Small actions** - the basic activities that the player's character can perform
- **Controllers** - as mentioned above, the basic tools of control through which small actions can be executed
- **Memory** - is the capability of the player to connect controller and small action
- **Something to do** - is the notion that the player must be kept occupied
- **Point of View** - is the perspective from which the player observes the game

After gaining control, the player ventures into executing their own will in the game, making it their own. This element will eventually lead to an aspect of enjoyment within the game. This is called ownership, and can be broken down into 4 sub-categories [11]:

- **Big Actions** - executing a series of small actions to work towards the goal of the game
- **Personal Goals** - the player can also create their own goals, beyond the general goals of the game, and carry them out
- **Rewards** - the game provides rewards to the player when they complete goals of the game
- **You-but-not-you** - is the concept that the player is participating in activities that are foreign to their everyday actions

The last component influencing puppetry is facilitators. For players to achieve a positive gaming experience controls should be obtained to gain ownership. However the research paper argues that even though players have control they can fail at gaining ownership, and even if players fail to get control they can still conclude ownership and therefore an enjoyable game experience. These outcomes are attained through facilitators [11]:

- **Time** - the time the player devotes to the game
- **Aesthetic Values** - the visual and auditory characteristics of the game
- **Previous Experiences** - of similar games or even similar objectives

Rather than just evaluating the video game or the user independently this theory aims to assess experience objectively by looking at the interaction between the two. The above listed items should be considered the core elements of the gaming experience. A questionnaire based on these elements would serve as an appropriate metric to measure game experience from a more objective standpoint, while still considering subjective elements such as the facilitators. The paper concludes that if the core elements are missing from a game, the experience will be negative [11]. Therefore, these elements should be considered when constructing a VR game to successfully cater to the needs of players and achieve a positive experience.

Another more subjective way to deconstruct the experience of a game has been proposed by Poels et al. [55]. Their study concludes, based on the combined knowledge of pre-existing empirical and theoretical findings, along with focus group explorations, that the game experience can be split into 9 distinct dimensions.

**Enjoyment** is the very first dimension the study discusses. Various players are attracted for different reasons to the gaming experience, but it is argued that the common denominator is that they all get enticed to play for the sake of enjoyment. Some users may find enjoyment in the environment or narrative the game offers, while some get drawn in by the challenges of mastering a game [55]. Especially the suspense of a game has been shown to be an important driver of game enjoyment [80].

The next dimension defined by Poels et al. is **flow**. This dimension in their categorisation scheme is largely based on the intrinsic motivational theory of Csikszentmihalyi explaining that a state of total absorption is dependent on the challenge posed by the game [16]. If the challenge of the game does not meet the skill of the player, the state of flow can not be achieved, and thus the player will not get into the optimal state of concentration [55].

Following flow in a similar fashion partially based on existing theory is the dimension of **immersion**. Split into categories the research distinguishes between two types of immersion [55]. Sensory immersion

is that which relates to the senses, such as the visuals and the soundscapes of the game. Imaginative immersion on the other hand relates to the narrative of the game [19].

The dimension of **suspense** refers to the aspect of the game experience where players are in a state of feeling excitement or are experiencing uncertainty in regards to what is going to happen. Suspense can also encompass feelings of tension, pressure and relief. It also occurs when the level of the challenge of the game meets the skill level of the player [55].

When players complete a goal given to them by the game or they become experts in a certain skill a sense of achievement is felt. Perceived competence of players increases in such situations, which constitutes to the **competence** dimension of the game experience. If the player is unsuccessful in any of the above mentioned activities negative affects can be felt such as dissatisfaction and irritation. **Negative affect** is another dimension in the scheme of Poels et al. [55].

**Control** is the dimension concerning the ability of players to manipulate the world of the game. The last dimension of the categorisation is **social experiences**, which includes experiences of engaging with other social entities. These entities might be friends, or even non-player characters [55].

A questionnaire based on these dimensions would serve as subjective measure of game experience. Such a scale could potentially measure differences in game experiences when different interaction methods are used to control the game. The effects of these varying methods would particularly affect the dimensions of control and competence. Looking at all the above listed categories one can tell that many of them are overlapping and interconnected. A VR game that aspires to be entertaining and enjoyable would ideally grant experiences in all dimensions, however it is not an exclusive pre-requisite of good games [55]. To see how eye tracking specifically influences all dimensions, a VR game should be developed utilising this technique and evaluated based on the categories analysed in this section. Comparing the results from the eye tracking version to the same game implemented with a more widely adopted interaction technique for comparison may provide an answer whether it could enhance user experience. By paying special attention to control and competence, it could be discerned whether the improvement was due to the application of the novel interaction technique, or to some other factors.

### 2.3.2 Measuring Game Experience

A comprehensive study carried out also by Poels et al. in 2007 [54] provides a meticulous approach to conceptualise and evaluate game experience. This paper presents the Game Experience Questionnaire (GEQ), and provides an insight about how this questionnaire was constructed. The 9 dimensions discussed in the previous section are based on this prior study of Poels et al. The final prototype of the project could potentially be evaluated via this framework.

The GEQ is made to have a modular structure, as follows:

- The main questionnaire (GEQ), which is the heart of the Game Experience Questionnaire. This explores several aspects of the players' experience while gaming.
- The post-game questionnaire (PGQ), which explores the players' experience after finishing their gaming session, and also checks for effects on users caused by the game.
- The social presence module (SPGQ), explores players' experiences and involvement while gaming with others.

As the prototype is not aimed to be a social gaming experience at this stage, the last module will not be covered in this section.

To build this questionnaire robustly, various methods were utilised including empirical data gathering during focus group interviews and relevant scientific literature check. This also formed as a basis for creating the items, which followed a 5-point intensity-based, unipolar scale, being: not at all (0), slightly (1), moderately (2), fairly (3) and extremely (4).

There are total of 92 items for the GEQ questionnaire, which is broken down into 7 factors based on a preliminary test conducted on a representative sample of gamers. The 9 dimension deliberated earlier are extended versions of the 7 factors listed here. Each factor contains multiple items connected to its core topic. The 7 factors are, as follows:

1. Sensory and imaginative immersion
2. Tension
3. Competence
4. Flow
5. Negative affect
6. Positive affect
7. Challenge

From these 7 factors there are ones which put significant emphasis on the game's narrative and story, such as **negative** and **positive affect** and **sensory and imaginative immersion**. Undoubtedly, these play a crucial role in a game experience, however a novel interaction technique would have less direct impact on the factors primarily connected to the game's narrative. On the other hand, novel interactions could possibly have a significant influence on the game's controls. From the aforementioned factors, **Competence** is the one that provides items which encompass the topics of game controls the most:

- I felt strong
- I was good at it
- I felt successful
- I felt skillful
- I was fast at reaching the game's targets
- I felt competent

These items primarily deal with the player's abilities and skills in a game. Thus, if the game offers meaningful and intuitive interaction for the players to control the game, that could possibly elevate the perceived competence of the players. To see exactly how the players' experience is in connection with manipulating the world of the game, the dimension of control should be introduced from the extended 9 dimension. Questions concerning how the users would evaluate the interaction methods that the game utilised and how it affected their gameplay would provide appropriate data to asses whether their experiences were negative or positive. Furthermore, as speculated in the conclusion of the VR gaming experience section these dimensions could be used to compare different input types, such as eye tracking versus a VR controller.

## 2.4 Conclusion of Analysis

Through the presented analysis the goal was to research whether eye tracking technology can be used as a novel form of interaction in a VR game to enhance its experience [Section 1.1].

Firstly, eye tracking technology was presented in general [Section 2.1]. The main use-cases of eye tracking were detailed, narrowing down the scope towards eye tracking as an input for interaction [Section 2.1.1]. Midas touch was introduced as the main issue of eye tracking, thus it was found that an additional modality has to be introduced to ease the interaction [Section 2.1.1]. For this modality it was decided to involve the hand of the player, to utilise the ability of eye-hand coordination. The use-cases of eye tracking in VR have been presented [Section 2.1.2] and the current state of the art (SOTA) was examined on how eye tracking has been used in VR games within previously published research [Section 2.1.3].

To build a suitable VR experience for eye tracking interaction, a thorough analysis was presented on 3D interaction techniques [Section 2.2]. This bottom-up approach focused on **selection & manipulation** [Section 2.2.1] and **travel** [Section 2.2.2]. Each of these interaction techniques were inspected from the perspective on how could eye tracking be incorporated in them [Section 2.2.1.1] [Section 2.2.2.1]. As a preliminary outcome it was identified that **selection & manipulation** could highly benefit from eye tracking due to its rapid, agile and long-distance manner. These aforementioned characteristics solicit for an eye gaze based telekinetic interaction [Section 2.2.1.1].

These characteristics could aid travel in a similar way, particularly target based travel techniques. It was distinguished that eye tracking as an input could assist selection-based travel, more specifically, dashing. This is a travel technique similar to teleportation, but the user is swiftly moved to the desired target location instead of instantly reappearing there. This prevents the user from being spatially disoriented yet it does not induce motion sickness due to its fast fashion. Therefore, the proposed travel technique for eye tracking - dashing - is a mobile, body-centric and magical interaction [Section 2.2.2.1].

Even though these findings helped in the proposal of presumably sufficient eye tracking based interactions, a comprehensive overview of related research and work within these topics has been presented [Section 2.2.3]. This helped to validate or deny the ideas presented in the previous section. It was discovered that eye tracking aided target-based travel and selection tasks in VR have been researched thus far, with promising results. In spite of the previously presented theory, results indicate that eye tracking based selection is less precise but test participants did find it more enjoyable compared to traditional methods. Regarding eye gaze based telekinesis as a selection & manipulation technique, there has not been any particular study found [Section 2.2.3].

Next, differences between immersive and non-immersive modalities were established, to understand how does a VR gaming experience diverge from traditional set-ups like computers and consoles [Section 2.3.1]. It was found that introducing meaningful novel interactions in VR games has the potential to enhance the user experience. The core components of VR games has been analysed from the perspective of user experience and its building blocks explored. It was also discovered what components of the experience are influenced by interaction techniques.

A measurement scale called the GEQ has been introduced, that attempts to assess the experience of players based on the dimensions elaborated on in the VR gaming experience section [Section 2.3.2]. It was determined that from all the subscales of the GEQ, a novel interaction technique seemingly has the most impact on the user's **competence** in a VR game. While the GEQ does not include a **control** dimension, it was decided that this should be included to further grasp the effect of the interaction method on the player's experience. It was also mentioned that since the gaming experience is built up from closely interconnected parts, it should be evaluated as a whole, but paying particular attention to the competence and control score. It was also indicated in this section that to introduce eye tracking as an input in a VR game, bottom-up approach has to be followed based on the principles of interaction design. This will be further elaborated in the in the methods [Chapter 3]. Additionally, for precise evaluation, a comparison should be drawn between eye tracking based interaction and traditional inputs

for VR games [Section 2.3.2].

Throughout the analysis, eye tracking technology has been investigated as a form of novel interaction for a VR game - as presented in the IPS [Section 1.1] of this report. Based on the findings in the analysis, the project group suggests that to further investigate the formulated problem statement, a viable solution could be built as a prototype based on the presented theory of this chapter. The key elements for this prototype would revolve around a game play experience, that introduces a narrative to the user that would fit a non-isomorphic way of interaction, as the eyes in the real world cannot be used as a natural form of interaction. Thus, the project group, argues that a interaction method based on the input of an eye tracker in a VR HMD would feel superhuman (non-isomorphic). This would allow for a consistent and theory based approach to create a new and novel form of interaction with the eyes, and put into a context to be evaluated through the experience of a game.

Thus, a final problem statement can be presented to further manifest the direction of research within this topic:

#### **2.4.1 Final Problem Statement (FPS)**

*How does eye gaze assisted telekinesis and dash affect the game experience of virtual reality games compared to handheld controllers?*

### 3 Methods

This chapter will describe the methods and framework to be used to design, develop and evaluate this project's prototype. The approach of this research project will be based on the iterative process of interaction design [35]. Additionally, guidelines concerning the design and development for VR applications from the "3D User Interfaces: Theory and Practice" [2] book will be taken into consideration.

#### 3.1 Design and Implementation Methods

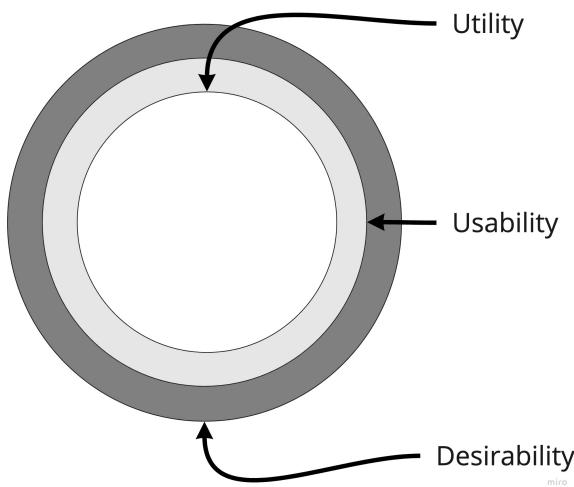


Figure 6: User experience circle, inspired by NNGroup [75]

The prototype will be developed through an iterative process that is based on the circle of user experience design. The slightly modified version of the circle can be viewed in figure 6 [75], where the outermost circle of "brand experience" has been removed, since this is out of the scope of this project. The three layers of the circles will form the basis of each iteration:

1. **Utility:** "It is useful to me. It meets my needs." [75]

This iteration will implement and test the basic functionality of the two eye tracking assisted interactions discussed in the analysis (dashing and telekinesis) in a simple VR environment, as a low-fidelity prototype. The testing of this section will be done with a small test sample utilizing the think-aloud method, to quickly extract relevant information from the test participants. Participants will be given instructions on what to do by the test conductor.

2. **Usability:** "I am able to use the product easily." [75]

This iteration will have a higher-fidelity prototype, adjusted based on the feedback from the first testing. Visuals will be implemented, to make the testing not only more aesthetically pleasing, but also granting it more clear affordance. Testing for this phase will be done in the form of a tutorial, where participants will be introduced to each of the two eye gaze assisted mechanics through the VR prototype, rather than getting commands and help from the test conductor. The test will seek to discover any needs for improvement on the tutorial for the game and if the graphics of the game provided accurate signifiers to clarify its affordances. The System Usability Scale (SUS) [3] will be used to collect quantitative data from the test participants. Besides the SUS, qualitative data will be gathered in the form of a follow-up interview.

### 3. Desirability: "I like the way the product looks and feels." [75]

The final prototype will test the experience of the game and the results gathered through the Game Experience Questionnaire (GEQ) [56] will be statistically evaluated and form the basis for discussion on the presented FPS [Section 2.4.1]. This testing will be comparing the traditional controller based interaction to the eye tracking assisted one. Besides comparing the two methods, it will be noted how it is for the participants to use the eye tracking assisted method developed in this project for multiple metaphors of interaction simultaneously, to gain insight if it feasible to implement it in games.

Each of these iterations will follow the following framework:

- **Concept Idea:** Each iteration will start with an explanation of what the iteration aims to develop.
- **Design Requirements:** A set of requirements will be established to make sure that all aspects are in place before implementation is started.
- **Design Process:** A walk-through of the flow of the design of the prototype aided by a selection of sketches and wire-frames.
- **Implementation:** Will showcase how the prototype was created through the use of the Unity3D game engine, with code snippets followed by explanations of functions. This section will describe the core aspects of the prototype.
- **Evaluation:** In this portion, the testing methods will be expanded upon, including concrete testing procedure, how the chosen scales are administered appropriately, and what are the requirements for them. The collected data will be presented. The results will be discussed, and if appropriate the concept idea for the next iteration will be refined accordingly.

The HTC Vive Pro Eye will be used as the hardware for this project. This HMD is one of few available headsets with integrated eye tracking technology available for the consumer market. The project group will be using the headset that is available for students that are affiliated with the Multisensory Experience Lab (ME-Lab) located at Aalborg University Copenhagen. Thus, this space will also be the location for the tests that are to be conducted throughout the project.

The prototype will be implemented using the Unity3D development platform. To be able to use the eye tracking technology within the HTC Vive Pro Eye, the Tobii XR SDK will be utilized to gain access to control of the eye tracking technology.

As was detailed in the conclusion of the analysis [Section 2.4], the prototype will be developed to have two different input methods, controller and eye tracking, which allows for two independent variables:

- **Controller:** the main input method for interaction with the prototype will be the hand held controllers of the HTC Vive Pro.
- **Eye tracking:** the main input method for interaction with the prototype will be the eye tracking technology within the HTC Vive Pro.

The two different input methods allow for an independent measured experimental design. The experiment will have the type of input method, the controller or eye tracking, as the independent variable and game experience as the dependant variable. Thus, a descriptive statistical analysis can be made on the gathered results of the test.

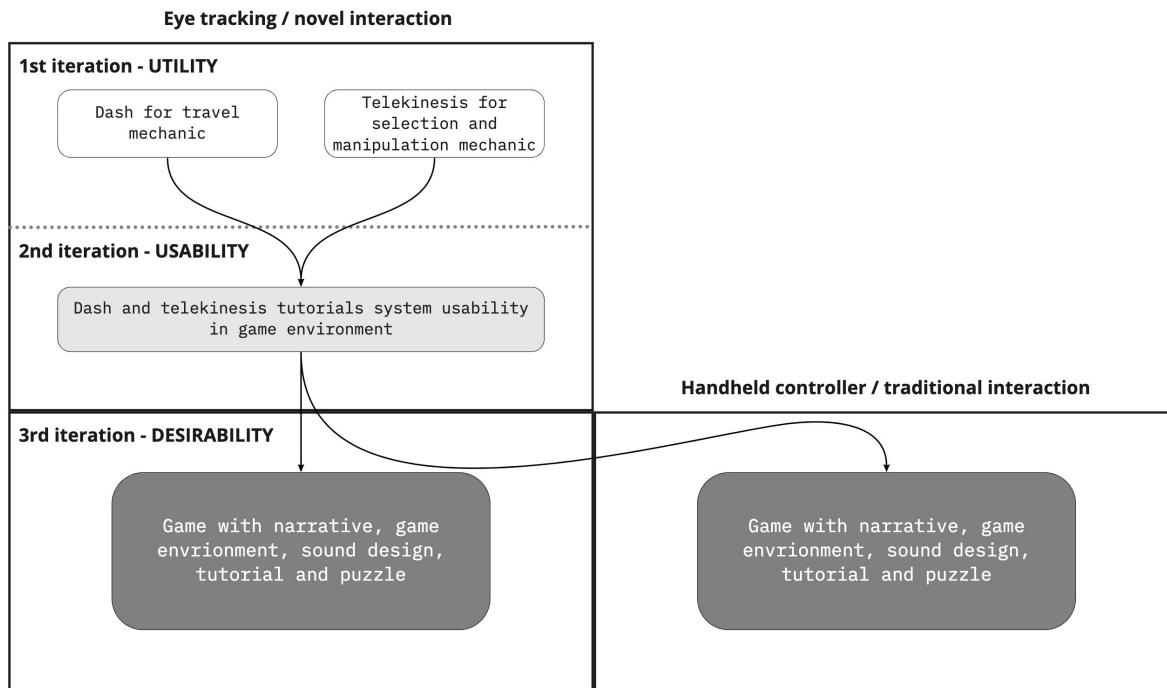


Figure 7: The experimental design for the evaluation of the prototype

### 3.2 Evaluation Methods

As was concretised in the FPS 2.4.1, the main goal of this project is to find out whether eye tracking can be used as an input method to enhance game experience for VR games. The chosen approach to give a validated answer to this question is going to be the following:

The first iteration will test the basic utility of the prototype. The goal will be to attain insight into how users, that have never interacted with the prototype before, feel about the chosen methods for interaction of telekinesis and dash for travel. Qualitative data will be gathered through the use of the think-aloud method and an unstructured interview.

The second iteration will be evaluated through the use of the System Usability Scale (SUS) [3]. Dating back all the way back from 1986, it is one of the most commonly adopted tools for measuring the usability. The SUS is known to be a simple and cost effective way to provide insight on the usability of any technological product. Also important to note, is that the SUS can provide reliable results, even with small sample sizes [3]. This allows for quantitative data to be obtained before the third iteration, which hopefully will prove to be a valuable contribution for the further development towards the final prototype to be tested in the third iteration.

For the third and final testing a modified version of the GEQ [56] will be used to evaluate both the traditional controller based version of the prototype, and the version that is eye tracking assisted. Based on the scores of the GEQ, a comparative discussion will be conducted, analysing which interaction type is preferred and why. This segment of the evaluation aims to answer if the game experience of participants is increased for the eye tracking assisted interaction, and if so what are the implications of it for the future.

## 4 First Iteration

### 4.1 Concept Idea

As discussed in the design and implementation methods section [Section 3.1] the first iteration will focus on **utility**. This is done to establish whether the introduced novel interaction's basic mechanics will make sense for the user. Furthermore, the user should be able to use these with relative ease to perform simple tasks. Therefore, the concept idea for this iteration is kept simple. The developed prototype for this iteration will implement eye tracking as the primary target selection mechanism for dashing, and the primary selection & manipulation method for telekinesis.

For dashing, the user should receive feedback regarding where their gaze is located at in the environment, in the form of a highlighted circle. Also, users should verify the intent of dashing to the highlighted area by pressing a button on the controller, upon which the action should be executed.

For telekinesis, objects on which the users' gaze rests on should be highlighted or outlined. To confirm the intent of interaction a button should be pressed and held. From here on, the object should follow the users' gaze, until the trigger is released. If the user wants to move the object closer or further away from themselves in depth, they will have to use an additional input. For this, the touch pad of the HTC Vive controller will be utilised. Resting the finger or touching on the top of the touch pad will move objects away from the user, while touching it down will move objects closer. In order for the users to be able to see what is behind the selected object, it should be made translucent while selected.

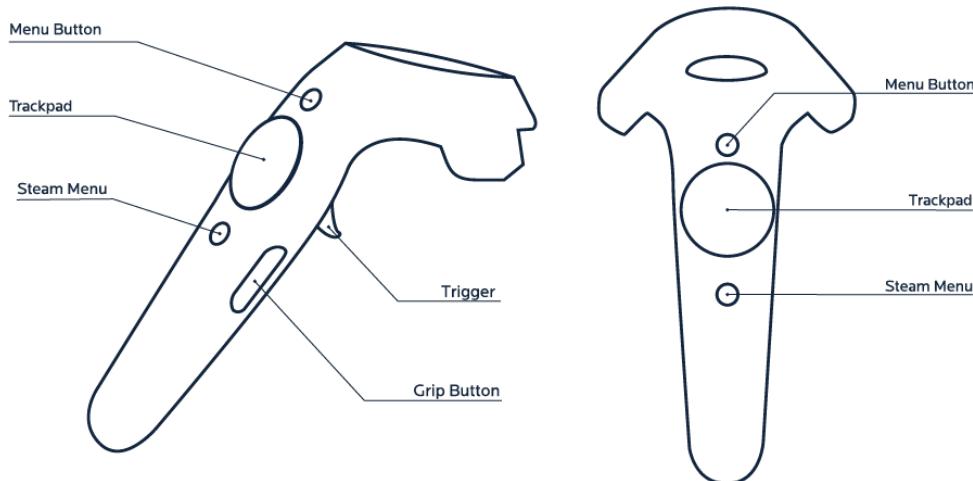


Figure 8: Sketch of the HTC Vive Pro controllers, with all of its buttons and controls [79]

There will be two separate environments. The first for dashing the player from one place to another, and the second enabling the telekinesis functionality. Each environment will have a simple set of playful tasks for the user to explore, perform and test the basic functionality of the prototype. These environments will be further elaborated in the design section of this chapter [Section 4.3].

### 4.2 Design Requirements

Here a list of design requirements will be presented that will need to be designed and implemented for the first iteration. These design requirements will serve as guidelines for how the scenes of the first iteration should look like, as well as the how the user's interactions will function. These requirements will be based on the analysis [Chapter 2] and methods [Chapter 3].

These requirements will be split into two parts. The first part will be the requirements for the functionality and user interaction. The second part will contain the design requirements of the testing scenes. Meaning what are the tasks for the user and what do they entail. Each part will address dashing and telekinesis separately.

#### **Functionality and interaction requirements for dash:**

- Users need to be able to dash to a target location based on where their eye gaze is directed
- A signifier should be made as reference point or feedback for where the user is looking at

#### **Functionality and interaction requirements for telekinesis:**

- The user needs to be able to manipulate objects in the environment with their eye gaze
- A visual feedback should be implemented to the user of what object is being looked at, and if it can be manipulated, or not
- A method should be implemented for telekinesis to control the object's position in all 3 dimensions
- The object needs to appear translucent when it is being manipulated so the user can orient themselves and see what is behind the object they are manipulating

#### **Test scenario requirements for dashing:**

- The user needs clear targets to dash to and a goal location
- The targets need to appear one after the other, and in an order that will compel the user forward to the goal location.

#### **Test scenario requirements telekinesis:**

- The user will need to manipulate the position of objects to various goal locations
- These various objects need goal positions of different sizes
- The objects need be moved in all 3 dimensions to get them to their goal location

### **4.3 Design**

The aforementioned design requirements were taken into consideration for the creation of the two different test scenarios, a travel test for dash and a selection & manipulation test for telekinesis. The design of these will be detailed in this section.

As can be seen in figure 9 the users are placed in the grey starting location. An in program screen shot of the dash test can be seen in figure 10. The closest blue circle will be a slightly raised platform. The next platform will appear when the user reaches the first location. The circles are placed at a slightly varying distance from each other. This has been done to make the user travel various distances to test the utility of the eye tracking assisted dashing. When the user reaches the goal, which has a green colour to distinguish it from the other locations, the travel test is finished.

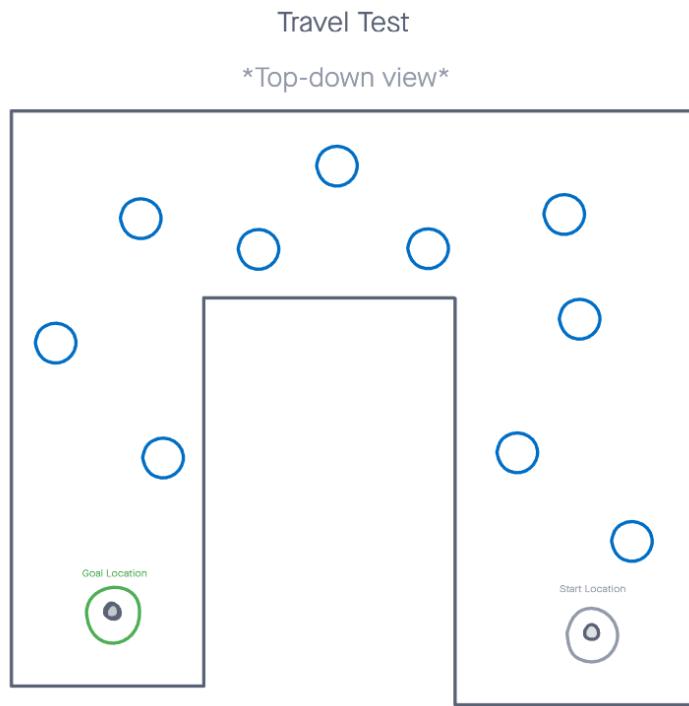
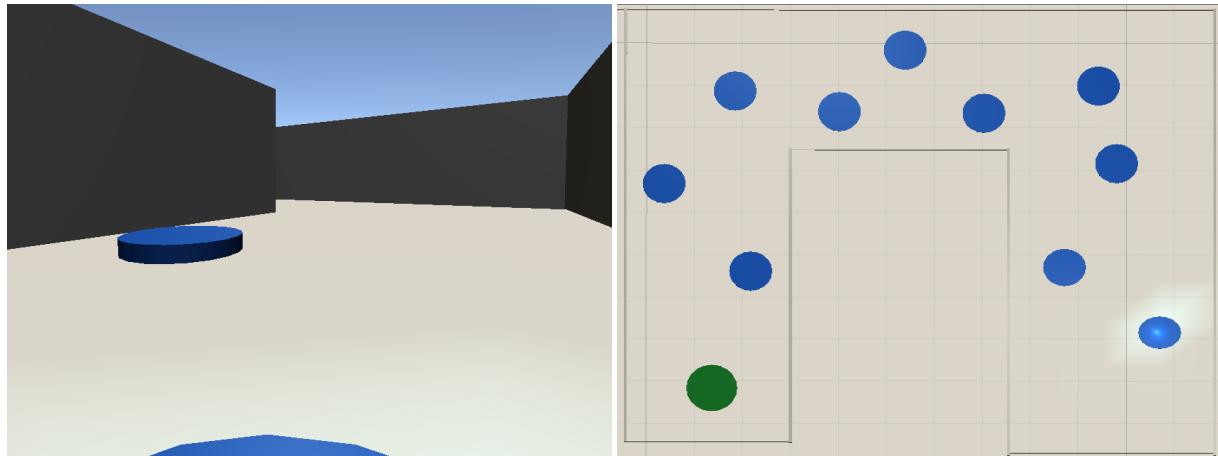


Figure 9: Dash test sketch

Eye tracking assisted dashing was designed according to Laviallo et. al. description of "blink" for travel which is also discussed in section 2.2.2. The user will have a signifier that pertains to the object that is hit by the eye gaze raycast. To initiate travel the user will press the trigger and then be moved by the system, speeding up quickly from a standstill until max velocity has been achieved and moving quickly at a continuous speed to their target destination. The mechanics of dashing will be further explained in section 4.4.



(a) Participant's point of view when starting the dash test (b) Top down view of the utility test dashing scene, with all dash targets shown

Figure 10: Dash test visual presentation

For the telekinesis scene it was important to take into account that the user needs to run through as many combinations of interactions as possible [Section 4.2]. Meaning that the user should be able to move objects in six degrees of freedom. Furthermore, the user will need to move objects with precision

in some cases, as well. In figure 11 a sketch of the telekinesis test can be seen and an in program screen shot of the scene can be seen in figure 14 & 13.

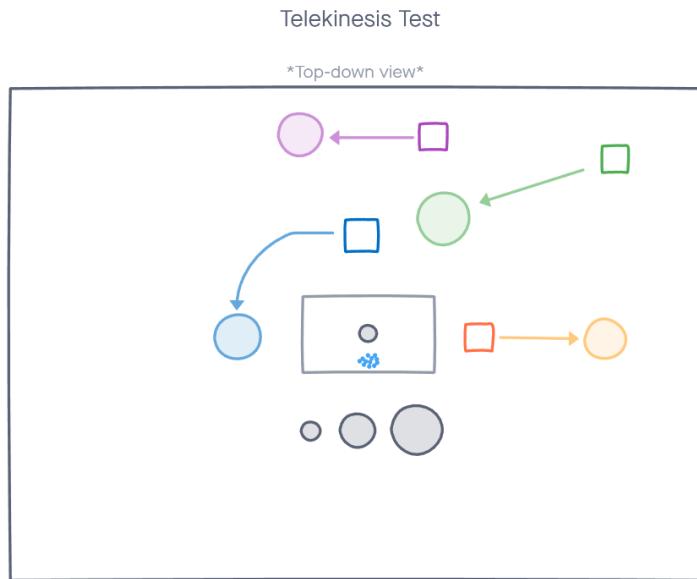
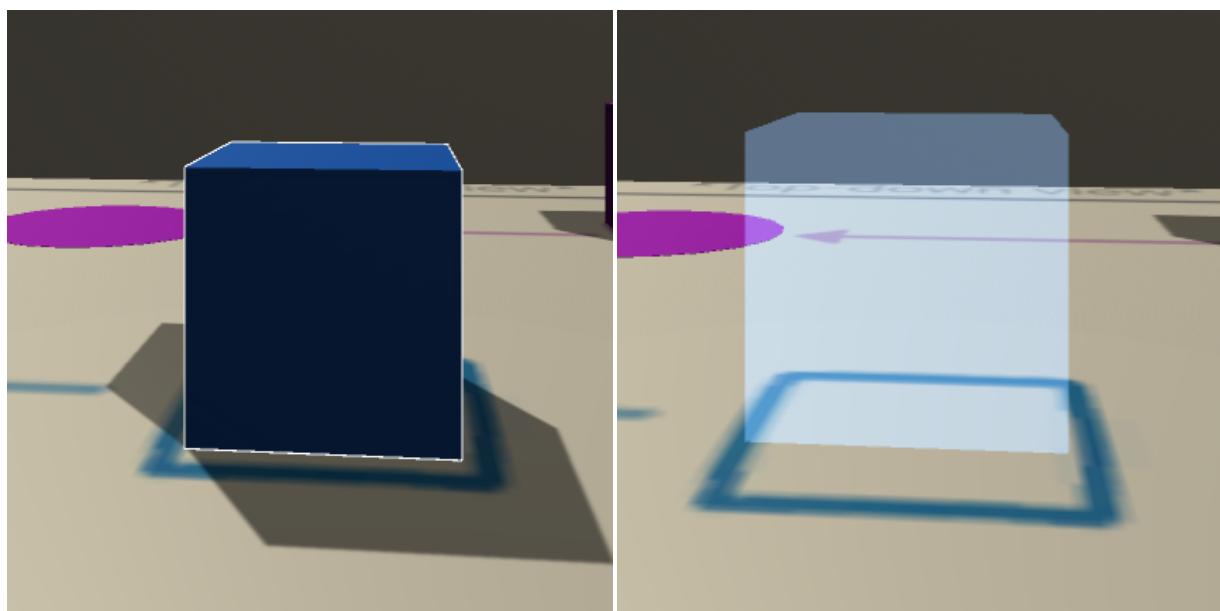


Figure 11: Telekinesis test sketch

The user will be able to see what object is being targeted by a blue outline appearing on the object when it is being focused on, also giving visual feedback to the user of which objects are interactable. Dashing will, for the telekinesis test, be disabled. When the user presses the trigger on the controller the object will become transparent also giving visual feedback to the user that the object is now being manipulated. Furthermore, the transparency gives the user the ability to orient themselves and see what is behind the object while they are manipulating it. A visual representation of the outline and transparent shader can be seen in figure 12.



(a) The outline of the object.

(b) Object being manipulated.

Figure 12: Visual representation of the outline and the transparent shader.

When the user is manipulating the object it will be fixed to the center of the eye raycast at the distance that the object was when it was picked up. The user will move the object in the X and Y axis by simply looking around. To manipulate the object in the Z axis the user will use the trackpad of the controller as a joystick. The precise mechanics of this interaction will be explained further in section 4.4.

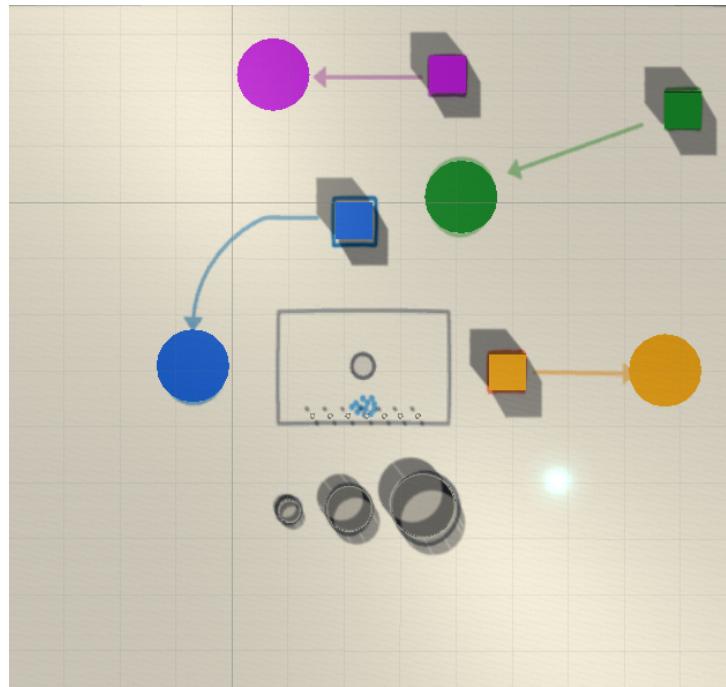
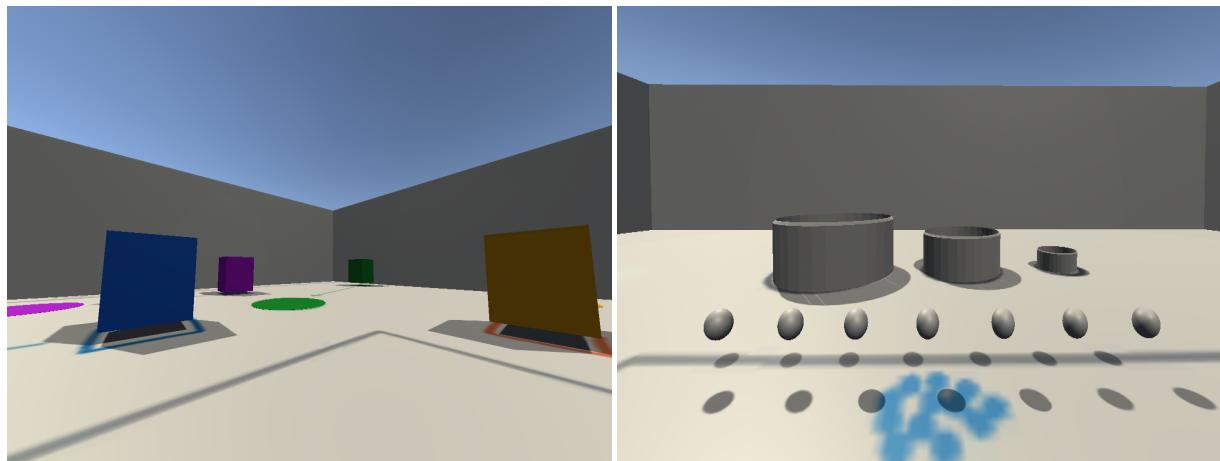


Figure 13: Telekinesis test top down view



(a) Participant's point of view all cubes enabled

(b) Participant's point of view, buckets and balls

Figure 14: Telekinesis test visual presentation

In this test the user will start in the small gray circle placed in the rectangle. For this test the user will be constrained to this location. Their task will be to move different colored cubes into specific locations. The cubes will appear one at a time just the same as the dash targets in the dash test. The cubes have also been given different bright colors to make them stand out from the environment's walls and background. Also, this way the user will not be confused about where each cube goes, as the matching colour indicates it.

The first cube to appear is the blue one. This cube needs to be moved into the blue circle. This movement is the simplest of the movements that the user will perform. It will only involve the user picking up the cube and moving it to the left with their eye gaze. Next the purple cube will appear. This cube is farther away and will test the capabilities of the user in movements that are relatively far away. Next the orange cube will appear, here the user only needs to move the cube away from them. This is to test the movement of objects only using the aforementioned depth controls. The last cube to appear is the green cube. The green cube needs to be moved in all three dimensions to reach its goal location. This will test the users ability to combine the controls in X, Y and Z axis position manipulation.

The last part of this test will involve the user picking up a sphere which will appear relatively close to them and place one in each bucket, depicted with the gray circles. The buckets are in three different sizes to test the ease of use in precision tasks as well as less precise movement tasks. The buckets will give visual feedback once a ball has been placed correctly in them, by turning green.

#### 4.4 Implementation

As mentioned in the Implementation methods [Section 3.1], the prototype is developed using the Unity3D game engine [73] in the C# programming language. All the eye tracking data is provided by the Tobii XR SDK [70], and all the visuals for the game are created using Blender. Git [25] and GitHub [26] are used in this project for version control of the code. The connection between Unity and the HMD is performed by loading SteamVR [67]. Steam VR creates the connection between the HMD and Unity.

The implementation of this iteration’s prototype has been developed so that it meets the design requirements set in the previous sections [Section 4.2]. It’s execution is explained as follows.

To begin with, the key component of this implementation is the handling of the user’s eye movements. For enabling this functionality, the Tobii XR SDK needs to be initialised. This is done by starting the SDK with the specified settings. The next step is to access the eye tracking data, to be able to understand where the users are looking at in the 3D environment. This is handled by the *EyeRaycast.cs* script, with the code in listing 1. Line 3 gets the eye tracking data in world space. Line 6 specifies that the eye’s gaze ray origin is at the current camera’s position. Lastly, line 9 assigns the direction of the gaze ray as a normalized direction vector.

```

1 // Get eye tracking data in world space
2 eyeTrackingData = TobiiXR.GetEyeTrackingData(TobiiXR_TrackingSpace.World);
3
4 // gaze ray origin is camera's position
5 eyeOrigin = Camera.main.transform.position;
6
7 // The direction of the gaze ray is a normalized direction vector
8 eyeDirection = Vector3.Normalize(eyeTrackingData.GazeRay.Direction);
9
10 // create a ray from the eye's origin following the eye's direction
11 GazeCast(eyeOrigin, eyeDirection);
12

```

Listing 1: Accessing the eye tracking data

The *GazeCast()* method in line 12 of Listing 1 creates a ray with a vector going from the previously explained eyes’ points of origin and direction. When this ray hits an object one of three different consequent actions will take place, briefly described as follows.

On the one hand, if the hit object pertains to the environment’s **ground**, then a signifier will be shown on the exact point of intersection between the object’s mesh and the eye’s cast ray. This would be the

target position where the users would dash to if they were to press the trigger button [Listing 2].

```

1 // send a ray of infinite length starting from startPoint with a certain direction. Only
2     check for collisions on objects that contain the 'Ground' layer
3     if (Physics.Raycast(startPoint, direction, out hit, Mathf.Infinity, LayerMask.GetMask
4         ("Ground")))
5     {
6         // update the player's target position to the new hit point in the ground
7         targetPos = hit.point;
8         // update the position of the eye signifier to the new hit point on the ground
9         lightObject.transform.position = hit.point + new Vector3(0, lightHeight, 0);
10        // ... rest of the code
11    }

```

Listing 2: Eye gaze Ray checking for ground object

On the other hand, if the hit object has been predefined as **selectable**, then if the users were to press the trigger at the same time as the intersection of the eye's ray and the selectable object is taking place, they will be able to grab it and move it around with the direction of their eye gaze [Listing 3].

```

1 // send a ray of infinite length starting from startPoint with a certain direction.
2     Only check for collisions on objects that contain the 'Selectable' layer
3     if (Physics.Raycast(startPoint, direction, out hit, Mathf.Infinity, LayerMask.GetMask
4         ("Selectable")))
5     {
6         // first check if this object had not been selected previously or if it's a new
7         one
8         if (hit.transform.gameObject != raycastHitObject)
9         {
10             // update the object the user has focus on
11             raycastHitObject = hit.transform.gameObject;
12             // enable the outline by setting it to focused
13             raycastHitObject.GetComponent<Grabbable>().focused = true;
14         }
15         // ... rest of the code

```

Listing 3: Eye gaze Ray checking for ground object

Lastly, if the ray hits any object other than the ground or selectable type, the users will just see the eyes' direction ray signifier without any further action, other than the deactivation of the eye light object signifier.

Once the eye movements are tracked, it is important to check for the users' input for confirmation of either selection of the objects they're looking at, or to move towards the point in space in which their eyes are fixated.

For both scenarios of dashing and telekinesis, the user confirms the desired action by pressing down on the trigger button of the Vive's controller. See figure 8 of the VIVE controller's buttons. For accessing the controller's trigger button via script there are multiple options. In this case, via the use of the Tobii XR examples package, which contains a controller manager and trigger button actions. Listing 4 contains the code responsible for accessing the controller's trigger button.

```

1 // make a reference for the controller's trigger button
2 private const ControllerButton TriggerButton = ControllerButton.Trigger;
3
4 // called every frame
5 private void Update()
6 {
7     // called when the trigger button has been pressed
8     ControllerManager.Instance.GetButtonPress(TriggerButton);
9
10    // called when the trigger button is held down
11    ControllerManager.Instance.GetButtonPressDown(TriggerButton);
12
13    // called when the trigger button has been released
14    ControllerManager.Instance.GetButtonPressUp(TriggerButton);
15 }

```

Listing 4: Accessing the eye tracking data

In the case of telekinesis, this would enable the users to confirm they want to move the object they're looking at. When this confirmation happens, the material of the selected object would change to a transparent one. However, how would they move it? Listing 5 demonstrates the code behind the movement of objects with the user's eye gaze and a VR controller.

First of all, the grabbed object should move towards where the eyes are looking at. For this, it is necessary to get the distance between the player and the object they want to grab, as can be seen in line 3 [Listing 5]. This distance will then be summed with the user's input on the trackpad in line 8, only if the player is touching the trackpad at the time. The target position of the grabbed object would then become the final point in the user's eye gaze ray, starting from the player's eyes and with a total length of the previously calculated distance, as shown in line 12. Finally, to not move the objects around in the VE as fast as the eyes do in real life, line 15 handles this by stating that the objects will move at a certain speed over time until they reach the eye's gaze target location.

```

1 // distance between the player and the grabbed object
2 distance = Vector3.Distance(Camera.main.transform.position, grabbedObject.transform.
3 position);
4
5 // if the users rest their finger on the y axis of the trackpad, they will increase
6 // or decrease the distance between the grabbed object and them
7 if (Input.GetAxis("right joystick vertical") != 0)
8 {
9     distance += Input.GetAxis("right joystick vertical") * depthMoveStrength;
10 }
11
12 // the target location for the grabbed object becomes the ray from the user's eye
13 // with a length of the distance to the user plus the trackpad's input
14 telekineticTransform.position = Camera.main.transform.position + eyeRaycast.
15 eyeDirection * distance;
16
17 // the grabbed object moves towards the target position with a certain speed (
18 moveStep) over time
19 grabbedObject.transform.position =
20     Vector3.MoveTowards(grabbedObject.transform.position, telekineticTransform.
21 position, moveStep);

```

Listing 5: Moving the objects with telekinesis. Eye position for x and y. The controller's trackpad for depth

Finally, in the case of the user dashing from one place to another, the eye raycast's hit on the ground is where the user would dash to. The code responsible for it is shown in listing 6.

```

1 // update the target position, so it is the eye's fixated location on the ground
2 target = eyeRaycast.targetPos;
3
4
5 // if the user pressed the trigger button
6 if(triggered)
7 {
8     // if the acceleration has not been calculated yet, calculate it
9     if (!accelerationCalculated)
10    {
11        acceleration = (Mathf.Pow(topSpeed, 2) / 2 * maxDistance);
12        accelerationCalculated = true;
13    }
14    // update the time value
15    timer += Time.fixedDeltaTime;
16    // increase the step
17    step += acceleration * Mathf.Pow(timer, 2);
18    // update the player's position by moving towards the new target position by the
19    // step amount every frame, until the distance to it is almost insignificant
20    transform.position = Vector3.MoveTowards((transform.position), target, step);
}

```

Listing 6: Dash formula and code

## 4.5 Utility Evaluation

The initial testing of the first low fidelity prototype took place in the ME-Lab at Aalborg University's Copenhagen Campus. As specified in the design and implementation methods [Section 3.1], this pilot testing was focused on the basic utility of the prototype. Issues regarding the utility which presented themselves throughout the testing will be discussed in this chapter, and rectified in the second iteration of the prototype.

### 4.5.1 Test Procedure

Test participants were asked to perform tasks in the two environments created for dashing and for telekinesis [Section 4.3]. The test followed the "think aloud" method, where participants were asked to continuously say out loud their tasks-related thoughts and comment on their own progress. If they have encountered any difficulties, or particular tasks felt easy to use participants simply verbalized these to the test conductor, who took notes. Additionally the test participants performance and actions were closely monitored and abnormal action or difficulties were noted.

Before conducting any of the tasks, the eye tracking was calibrated to each user using the Vive pro eye tracking calibration software. This step already gave a hint to the users that their eye gaze will be utilised in some way. Participants were also asked to rate how familiar they were with VR on a 4 point scale ranging from having never tried VR, to very experienced. After calibrating, the travel test environment was launched, and the test conductor explained what the task is. The explanation was done from a manuscript to ensure uniformity amongst all participants. Users followed the previously described concept and were exposed to the mechanics for testing the dashing [Section 4.3].

Once this section was completed, the telekinesis test environment was launched, and once again, the conductor explained what the tasks were. First users had to move cubes from a starting point to a

goal location, with the help of the eye tracking assisted telekinesis. Similarly, the users experience was orchestrated following the previously described concept and mechanics for testing the telekinesis [Section 4.3].

Once each test was completed, a semi-structured interview was conducted where participants were asked if there was anything they found particularly annoying or pleasing, and how their overall experience was using the eye tracking assisted interaction methods. The manuscript used for the introduction to the test along with the feedback received from participants can be seen in appendix A. The results of this testing phase will be presented and discussed in the next section.

#### 4.5.2 Results

In total, the test had 11 participants, mostly all of whom were students from Aalborg University from across various studies. Five participants were female, while the other were six male. Seven out of eleven participants were somewhat familiar, 1 was quite familiar, and three participants were very familiar with VR.

At first the results of the dashing experiment will be discussed, followed by the telekinesis tests. In general, all participants successfully completed the course in very little time and without too many issues. Some users found the feedback provided via the eye gaze signifier for the dash "flickering" and "jumpy", which they described as distracting and unpleasant. As an alternative, users remarked that a smoother moving indication was preferred. Many participants remarked that the selection for dashing felt intuitive, easy to use and fun. Predominantly, test participants preferred this way of travelling around in an environment regardless of the small aforementioned issues, therefore eye gaze assisted dash received affirmative feedback via this modest formative evaluation.

On the other hand, the telekinesis test resulted in more issues and more negative remarks. Almost all participants had difficulties grasping the mechanics, especially when the Z axis was introduced. In general, participants found it confusing to move objects around with their eye gaze while simultaneously figuring out where to place the selected object. They mentioned that it did feel counter-intuitive to have the selected object directly snapped to their eye gaze. Additionally, participants did find it hard to gauge the manipulated object's distance towards them, thus it was hard to control the object on the Z axis especially when placing the ball in the small bucket.

Overall, most of the participants enjoyed interacting in VR via their eye gaze and found the experience fun. Despite the minor highlighted issues, dash via eye gaze found to be a suitable interaction method, hence it will be revised and further implemented in the next iteration. Contrarily, telekinesis has received mixed feedback, thus it was decided that the interaction should be further analysed and a more meaningful interaction should be implemented.

### 4.6 Telekinesis Additional Input Modalities

#### 4.6.1 Redesign and implementation

Based on the feedback from the previous utility evaluation [Section 4.5.2], it was decided that telekinesis had to be revised. As a foundation for this, users' feedback has been taken into account in the redesign and implementation of it, as well as additional ideas have been developed by the research group. It is important to note that dashing was not altered for this test and will be reiterated upon in the second iteration, specifically the target signifier [Chapter 5].

First of all, as a notable amount of participants were confused about perceiving the manipulated object's

distance on the Z axis, a depth signifier was introduced. This signifier projects the object's position to the ground to provide an appropriate indication of its position [Figure 15].

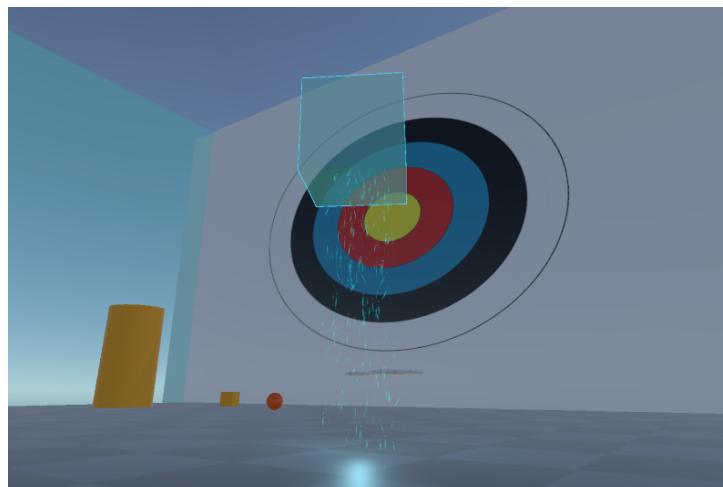


Figure 15: Depth signifier with particle system

In this reiteration of the utility test, the project group decided to have both dash and telekinesis abilities in the same environment. The ability to dash was given to the user so they would be able to move around in the environment. Furthermore, allowing people to use both techniques simultaneously could reveal bugs and flaws about the combination of the two interaction, rather than using them separately.

This required two different inputs: one for each ability. It should be noted, as mentioned in [Section 4.4], the input previously used was based on TobiiXR's prebuilt *ControllerManager*. This proved to be insufficient for this use case as it only allowed access to a limited number of buttons on the HTC vive controller. Therefore, the SteamVR package was imported into the project from the Unity's asset store. This allowed direct access to inputs such as the finger position on the trackpad, the grip and the trigger buttons.

As it was mentioned by some test participants, introducing a more natural input instead of the previously utilised trackpad for controlling depth would yield in a more intuitive interaction. For this reason, input based on hand gestures was implemented to control object's movement on the Z axis, as suggested by one of the participants. It was quickly discovered afterwards, that having the hand gestures not only help to move objects in depth, but it also provides a way of "fine-tuning" by gestures for the eye gaze based interaction. To find the most appropriate interaction method for eye gaze based telekinesis, it was decided to conduct another evaluation, solely for this manner. Since in this minor formative evaluation the main aim was to find out the most appropriate additional input modality for controlling depth, three different interaction methods were presented for eye gaze based telekinesis:

- **Trackpad** method: The original way of interaction, improved by adding a depth signifier below the selected objects as well as its shadows [Listing 7].

```

1  public SteamVR_Action_Vector2 trackpadPos;
2
3
4  // called every frame
5  private void Update()
6  {
7      // if the trackpad detects any touch input
8      if (trackpadPos.axis.y != 0)

```

```

9
10     {
11         // increase/decrease the distance from the selected object and the
12         player by the trackpad's input with a certain strength
13         distance += trackpadPos.axis.y * controllerMoveStrength;
14         // ... rest of the movement code
15     }
}

```

Listing 7: Trackpad using the Steam VR's input

- **Gesture** method: Gesture-only method for controlling depth of objects. This input modality for controlling depth also enabled to make small adjustments in each direction and provide 6-DOF manipulation, as well as rotation [Listing 8].

```

1
2     // called every frame
3     private void Update()
4     {
5         // increase/decrease the target position of the selected object by current
6         // position of the player's hand with a certain strength
7         telekineticTransform.position +=
8             (rightHand.transform.position - storedControllerPos) *
9                 controllerMoveStrength;
10
11         // linearly interpolate the the rotation of the selected object based on the
12         // rotation of the VR handheld controller over time
13         grabbedObject.transform.rotation = Quaternion.Lerp(grabbedObject.transform.
14             rotation, rightHand.transform.rotation * Quaternion.Inverse(storedControllerRot)
15             , Time.deltaTime);
16         // ... rest of the movement code
17     }
18

```

Listing 8: Gestures input allowing for 6-DOF

- **Combined** method: Since controlling depth only by gestures is limited to a specific length constrained by the user's arm reach, a combined method is introduced. This puts together the benefits of the two aforementioned methods resulting in a hybrid interaction. The more natural manner of the gesture-based control for small adjustments is aided by the trackpad's ability to cover infinite distances in depth [Listing 9].

```

1
2     // called every frame
3     private void Update()
4     {
5         // increase/decrease the target position of the selected object by current
6         // position of the player's hand with a certain strength
7         telekineticTransform.position +=
8             (rightHand.transform.position - storedControllerPos) *
9                 controllerMoveStrength;
10
11         // linearly interpolate the the rotation of the selected object based on the
12         // rotation of the VR handheld controller over time
13         grabbedObject.transform.rotation = Quaternion.Lerp(grabbedObject.transform.
14             rotation, rightHand.transform.rotation * Quaternion.Inverse(storedControllerRot)
15             , Time.deltaTime);
16
17         // if the trackpad detects any touch input

```

```

13     if (trackpadPos.axis.y != 0)
14     {
15         // increase/decrease the distance from the selected object and the
16         // player by the trackpad's input with a certain strength
17         distance += trackpadPos.axis.y * controllerMoveStrength;
18         // ... rest of the movement code
19     }
20 }
```

Listing 9: Trackpad and 6-DOF gestures inputs combined

#### 4.6.2 Test Procedure

Similarly to the first test, this one also took place in the Multisensory Experience Lab at Aalborg University’s Copenhagen Campus. A new testing environment was created as well as modified tasks that the participants had to perform.

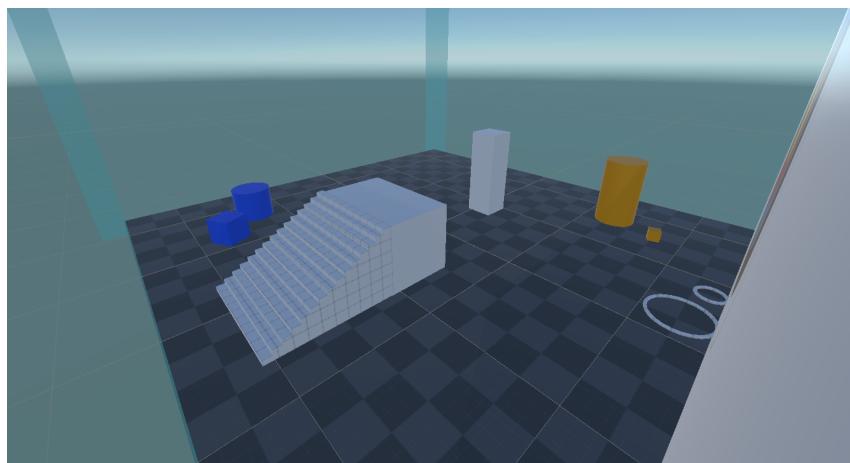


Figure 16: Birds eye view of the testing environment

There were two cylinders placed in the environment with corresponding cubes of the same color. The participants’ task was to place the cubes on top of its related cylinder. With this task the aim was to get an overview about their ability to manipulate the objects with 6-DOF, and encourage users to lift objects more with their eyes. For the same reasons, the previously incorporated buckets were changed to hoops and lifted higher in the environment. When the participant had completed the previously described tasks, they were then asked to interact with the Jenga tower in the middle of the room from the platform. With this particular element in the testing environment, the specific interaction type’s precision and accuracy was meant to be investigated. Furthermore, the participant was asked which interaction type they preferred and their interaction type was then changed to the preferred one. The participant was then asked if they were sure about their choice and if they would like to try any of the other interaction types while interacting with the Jenga tower.

This evaluation utilised the think aloud method again [Section 4.5]. The participants were introduced to all three aforementioned telekinesis types and they interacted with them in randomised order to reduce possible bias. The users were given specific instructions for how to use each interaction technique. After trying out all the three versions, the participants were asked which method they liked the most and least and why via a semi-structured follow-up interview. Just like in the previous test, participants were also asked again to rate their familiarity with VR.

The manuscript used for the testing along with the feedback received from participants can be seen in appendix B. The results of this testing phase will be presented and discussed in the next section.

#### 4.6.3 Evaluation Results

There were in total eight participants, students from Aalborg University Copenhagen. Three out of eight participants were somewhat familiar, three were quite familiar, and two participants were not familiar with VR at all [Appendix B].

From this evaluation phase it became apparent that the gesture-only input modality for telekinesis is the least suitable based on user feedback. 6 participants found this one the worst method. People highlighted that via this modality controlling object's depth is limited, which could be highly counter-intuitive. The movement of objects on the Z-axis was not efficient enough as users' could only move them according to their arm length. This efficiency issues was not inherent to the gesture based approach, but rather a problem arising in the implementation of it. Some participants did prefer this way of interaction in the sense that controlling the object by gestures felt natural. Participants expressed specifically that they liked that they could finely readjust the objects' positions in addition to the direct input coming from the eyes.

The trackpad has received the expected results, participants preferred this method due to its simple and more precise manner. They found it easy and quick to manipulate objects' position in VR via this method. Overall this was the most preferred way of interacting by four out of eight participants. An issue that users mentioned was the fact that they could not look away from the object to scan the surrounding environment for target locations once they started performing telekinesis. While in theory looking around and finding the target location while performing telekinesis should result in the completion of the task, in reality it appeared to bring about undesirable interactions. Objects would sometimes end up in unwanted places.

The combined method received positive feedback, as well. Here users highlighted that all the benefits from the previous two are combined yielding in a complex, yet precise and enjoyable interaction. It has also been mentioned that this way of telekinesis can be overwhelming to use. 3 out of 8 participants chose this one as their most preferred way of interacting.

To sum up the results and settle on the final additional input modalities for telekinesis, the combined method was chosen. Even though it was not the most preferred one by the participants based on the raw results, it has been decided that this interaction has the most potential to be further refined. It can be discussed that the reason that participants ranked the combined interaction type lower, was that the user did not have enough time to properly gauge the more complicated interaction type. As it was mentioned during the tests it blends together the best qualities from the other two interaction techniques, providing a simultaneously fun and efficient way of object manipulation. As it was also touched upon earlier, this way users could fine-tune the solely eye gaze based interaction via their gestures, thus the manipulated objects would not directly snap to their direction of eye gaze, which was an issue discovered in the previous testing phase [Section 4.5]. Overall, users' would have more freedom to select and manipulate objects in VR with the combined telekinesis method.

Nevertheless, it has to be addressed at this point that since some of the users did feel overwhelmed by the complexity of the combined method, where it further needs to be refined in the second iteration of the prototype. The goal of the second iteration will then be to enhance the overall usability of the game and its mechanics, including telekinesis.

## 5 Second Iteration

### 5.1 Concept Idea

Following the first iteration evaluation and telekinesis additional input modality evaluation a new design for the second iteration could be formed. It was clear that the users responded well to using eye tracking for travel, and telekinesis had, at least on a conceptual level, reached its final stage. The goal for this second iteration is twofold, the second iteration should be a test of usability first and foremost. The prototype should investigate the usability of telekinesis and dashing in a game environment. Secondly, the second iteration is an evaluation of the game environment itself, as well. Specifically, the game design choices will be evaluated that were made from a usability standpoint and they will be reiterated upon later. Following this formula it will be possible to create a usable game for evaluating the FPS in the final iteration [Chapter 6].

With this second iteration one of the goals was to make an environment and a narrative that the user could follow and at the same time be introduced to the mechanics and controls of the game. In game design this is referred to as a tutorial. It was decided that the user's superhuman powers would fit well in a science fiction environment and therefore the environment should reflect that. The setting that was agreed upon was an alien planet namely Europa, one of Jupiter's moons. The environment will be designed in such a way that the user will feel a sense of presence, taking advantage of the head start given by the inherent immersiveness of VR [Section 2.3.1]. It is also important to state that the game itself should also offer some resemblance or ambience of danger to heighten the sensation of suspense for the user.

The game itself should be designed as an immersive experience where the user is guided by clear instructions from a narrator. This narrator should appear in character as a commander of sorts giving the player orders. The narrator will give thorough instructions to the user about how the game mechanics work i.e. how telekinesis and dashing works. Furthermore, the narrator will give a brief overview of what the users' main task is which will be a reconnaissance and retrieval mission of an unidentified energy signature close to their location. On the route to this energy signature the user will have to navigate mostly by themselves. The route planning towards their goal location will be aided by wayfinding cues. These wayfinding cues should be subtle enough that the user is still engaged, but apparent enough that the user knows where to go i.e. natural wayfinding cues [Section 2.2.2].

Electronic games in general has a unique feature that the player of said games needs to overcome a challenge in order to progress. Therefore the tutorial of this prototype should also offer some impedance. The user will need to use telekinesis and dashing to overcome these obstacles and progress.

The visual feedback to the user should be updated. The target representing where the user is looking should be given a new visual that represents more clearly that the user will be dashing to that location. New visuals should also be given to the objects that can be selected and manipulated via telekinesis. Furthermore, the colouration of the visual feedback should be easily distinguishable and contrast to the environment.

Lastly the game should incorporate all the categories and sub-categories for puppetry. As specified in section 2.3.1 if a game does not incorporate the necessary components of puppetry it could result in a negative experience for the user. It should be noted that this iteration of the game will not incorporate all of the planned elements, those will be specified later in chapter 6.

## 5.2 Design Requirements

Based on the results from the previous utility test, new design requirements should be formulated. These requirements will summarise the overall design and dictate the future design process. The previous design requirements from section 4.2, will in most part be carried over. Therefore, the below list will reference only what needs to be changed and what needs to be updated. The list will be split into two parts, the first considering only functionality requirements, the second will regard environment requirements.

### Usability and Functionality requirements:

- The eye tracking signifier should be updated to convey its functions
- Moving the controller should displace the object in the same direction that the controller is moved
- When looking at an object the user should be given visual feedback that the object is interactable
- The object being manipulated should be transparent and have a shader applied to it when being manipulated
- When an object is being manipulated it should cast a signifier on the ground directly beneath it
- The user should be given an auditory introduction of their abilities by an in-game recording

### Environment and game requirements:

- The environment should convey a slight sense of danger
- The environment should serve as a tutorial for the user
- The game should incorporate all categories and subcategories of puppetry [Section 2.3.1]
- The user should be introduced to the interactions one by one
- The user should be given environmental wayfinding cues to their goal location
- The environment should challenge the user
- The user needs to overcome the challenges using their abilities in order to continue
- The user needs to at one point be challenged in their problem solving abilities in order to progress
- A voice-over recording should explain both dashing and telekinesis
- The environment should work together with the voice-over to properly introduce the user to their abilities

## 5.3 Design

The design for the second iteration of this prototype will be based on the previously mentioned design requirements. This section will describe the exact changes made to the prototype as well. Firstly the design of the environment will be laid out. The term environment pertains to the landscape geometry and the level design as a whole.

### 5.3.1 Environment and Game Design

The setting of the second iteration was agreed upon to be a science fiction setting as it would fit well with the user's superhuman abilities within the game. The setting should be one that would be exotic but still somewhat connected to the real world. It was therefore agreed upon to place the setting of the game on Jupiter's moon Europa. This decision was made from researching different settings and this particular

one had an interesting environment that gave the group the ability to implement some consistent features. Europa is slightly smaller than Earth's moon, has a surface primarily covered in silicate rock and has a water-ice crust. Furthermore, the ice covered surface has deep canyons in the ice and a thin oxygen atmosphere [31], which the design of the environment will be based upon. In figure 17 an overview of the entire environment can be seen.

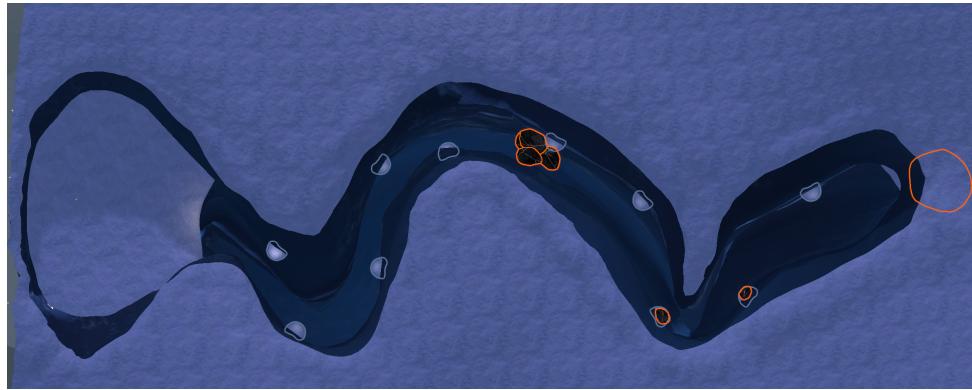


Figure 17: A top down view of the game environment

The user will start in the crater depicted on the left in figure 17. The user will progress through the environment from left to right through the canyon. The canyon features ledges on alternating sides highlighted with a gray outline. The user will progress through the level by dashing to each ledge in sequence. Along their path the user will encounter multiple boulders, highlighted with an orange outline. They will need to use telekinesis to remove the boulders in order to progress. The largest boulder which can be seen on the right in figure 17 has been placed within a cave that is depicted in figure 18.

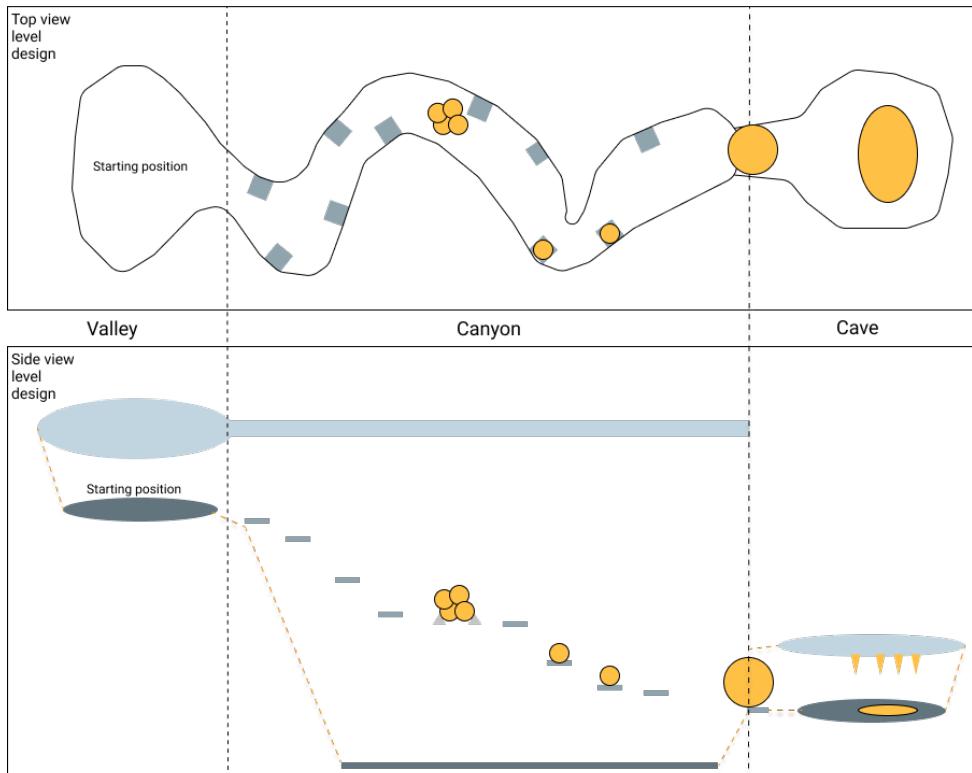


Figure 18: The level design of the prototype

Figure 18 was created to give a better overview of the level design and an additional side view. In the side view the verticality of the environment can also be seen. To promote ease of use for eye tracking and enable easier travel for the user, the ledges have been placed further down from each other. A secondary reason for this design choice is that to promote the user to progress down the canyon and not back towards the starting position. In figure 19, a screen shot can be seen of the user's starting position.



Figure 19: The point of view to the user's starting position

The user starts in a large crater in the surface, which is surrounded by high snow covered cliffs made of ice. In the sky the player can see Jupiter just above the horizon and the starry sky surrounding it. This scene serves also to inspire awe in the player with the grandness of the setting. The surface of the moon is lit in semi hard light which is realistic for a planet with no clouds to scatter the light. The sun in this scene is the main light source with a cool blue filter added to it. Some diffuse lighting has been added to the scene to not make shaded areas appear black and to replicate the scattering of light by the surface. Borrowing terms from mise-en-scene and stage lighting it could be seen as if the sun acts as a key light and the diffuse lighting added to all objects in the scene as a fill light [8]. The diffuse lighting has a very low intensity because of the aforementioned thin atmosphere. Here the lighting of the scene plays a role in creating a realistic environment.

When the user starts the game they immediately see a dust storm blowing on the surface which can be seen just above the canyon entrance in figure 19. The dust storm serves the purpose of inciting a slight sense of suspense [Section 2.3.1] for the user. Furthermore, they are deterred from trying to explore on top of the canyon and getting out of bounds.

When the game is started the user will look towards the canyon, a voice will play in the HMD's headphones giving them a short brief on where they are, who the player character is and what their overall goal is. A full transcript of the narrators voice over can be found in section 5.3.3.1, where the aforementioned voice line is depicted in item 1. The voice tells the user their goal is to recon an area and retrieve any important objects. Defining the overall goal is important for the user gaining control as specified in section 2.3.1. At this point in time and until the voice line is finished the player will be locked out of interactions. The user will then have time to orient themselves in the environment and not attempting any of the interactions until they have had time to get properly introduced to the environment plot and travel. The sound design of the prototype will be explained later in this section [Section 5.3.3].

The voice will introduce them to dashing and telling the user which button to press to initiate travel [Section 5.3.3.1 item 2]. When the user has dashed once, a new line will be triggered prompting them to

proceed to the edge of the canyon, once they are confident enough [Section 5.3.3.1 item 3]. The edge of the canyon has a wayfinding cue in the form of light [Section 2.2.2] so it can be more easily found when the user is searching for it. This first segment in the game introduces the first half of the **small actions** the user can perform, as well as the first part of **controllers** and **something to do** [Section 2.3.1] It should be noted that in a VR game the **point of view** in almost all cases is the first person point of view as it is what VR is specifically designed for.



Figure 20: The user's point of view when standing at the edge of the canyon

When the user gets to the mouth of the edge a new voice line will trigger reassuring the player that they can use dashing as a precise method of travel. The voice then urges the user to advance forward into the canyon [Section 5.3.3.1 item 4]. The lighting changes in the canyon segment to a darker mood building upon the realism requirement as stated in section 5.2. Light from the sun when it is at a shallow angle, as it is in this scene, would only light the canyon slightly. The lighting in the scene also creates a certain ambience of danger. As can be seen in figure 20 the ledges have slight highlights applied drawing the user's attention to them, similar to figure 3 (a) in section 2.2.2. The design of these platforms was also influenced for evaluating the user's ability to target small ledges and dash to them. The canyon walls are not targetable for dashing. This constraint was put in place to keep the user from accidentally dashing the canyon wall when they wanted to travel to the ledge. Dashing to the ledge would also break the users immersion because they will be suspended in the air. The user being suspended in the air might also frighten them or cause vertigo. Additionally the snow covering the surface of the ledges also serve as a wayfinding cue by the user creating an association that the snow are targetable for dashing.

When the user has progressed halfway through the canyon, telekinesis gets introduced. The user's path is blocked by several large boulders, as can be seen in figure 21.

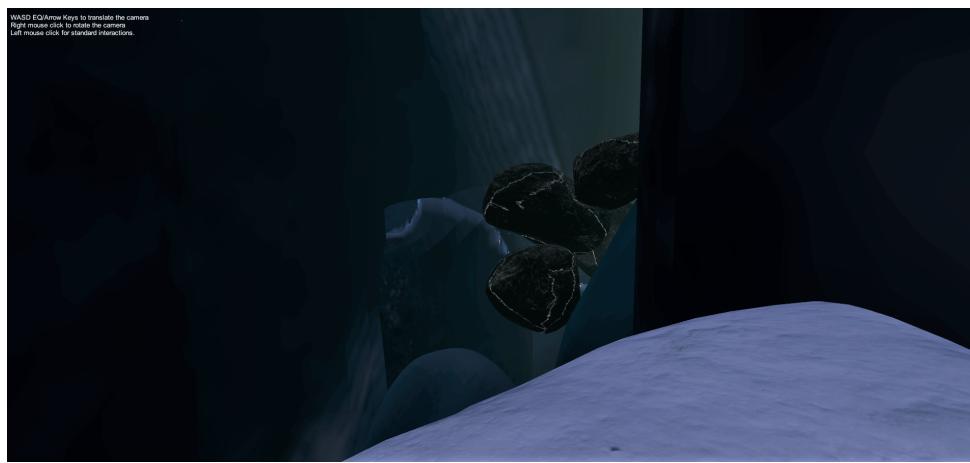


Figure 21: The user's path is blocked

The voice-over returns informing the user that they have the ability to use telekinesis to move objects. The voice-over also orders the user to look at the boulders and use their eyes to throw the boulders into the canyon [Section 5.3.3.1 item 5]. At this point the user can only move the boulders using their eyes and any movement of the controller will not move the object that is being manipulated. This event in the game defines the next part of establishing **controllers** and **memory**. This event also establishes the **something to do** category [Section 2.3.1]. When the boulders have been cleared, the next ledge will be visible [Figure 22]. Clearing the boulders also begins to establish ownership of the game. Dashing between the ledges and using telekinesis establishes the sub-category of **big actions** as well as the **you-but-not-you** sub-category by giving them the superhuman powers of dashing and telekinesis. This event also **rewards** the user with progress for completing the task.



Figure 22: After the user has removed the boulders

The next few ledges after the ledge visible in figure 22 will have boulders resting on them. Here the user will be introduced to the second interaction for telekinesis. After the telekinesis additional input modality test it was concluded that the **combined** input modality for telekinesis would be the most suitable [Section 4.6.3]. Here is where the hand movements are introduced and unlocked for telekinesis. The voice-over will tell the user to look at the boulder and use hand movements and eye movements **combined** to throw it over the edge [Section 5.3.3.1 item 6]. After removing several blocks from several ledges, the user will then encounter a cave opening blocked by an enormous boulder seen in figure 23.

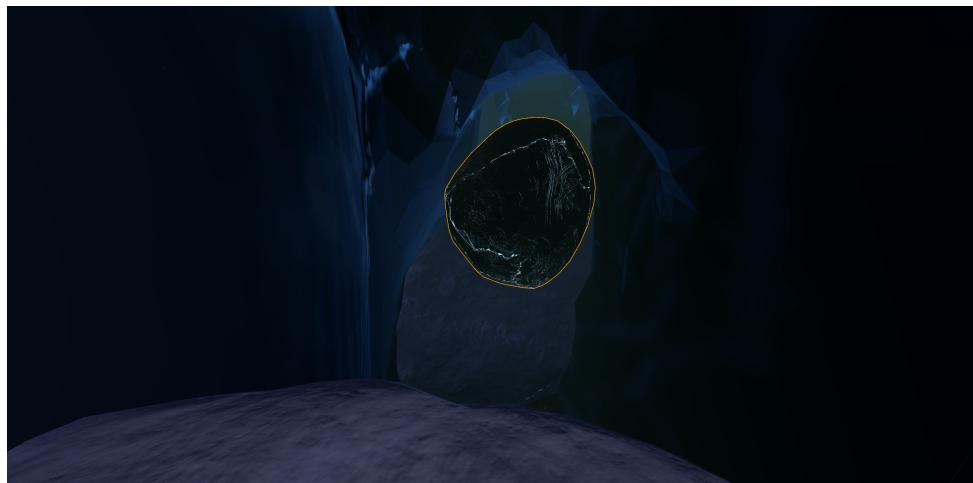


Figure 23: Cave boulder

When the user reaches the ledge before the canyon entrance the voice comes into contact with the user again, giving them instructions for how to move objects in the z-axis [Section 5.3.3.1 item 7 & 8]. When the user has removed the boulder they should have gained complete **control** over the game as well as having established **ownership** [Section 2.3.1]. Up until this point the user have been instructed during most of their interactions and should have a good understanding of their capabilities which is the goal for any tutorial. However when the user enters the cave they will not be given any further instructions. The sight that greets them upon entering the cave can be seen in figure 24.



Figure 24: The user's point of view upon entering the cave

The scene is lit from an unknown light source below the ice sheet covering the bottom of the cave. The ice that the light is penetrating would in the real world serve as a light blue filter and should act upon the light as such. The filter effect of the ice sheet will scatter the light covering the cave in this cool blue hue. The icicles on the roof of the cave are also given an intimidating and sharp look when the tips are lit from below as in this scene. It additionally serves as a wayfinding cue to the user that the icicles are important in some regard. Furthermore, the icicles have an indentation close to the base, indicating to the user that these are not solid objects that cannot be interacted with. Rather more obviously, when the user notices these icicles they would automatically look at them, triggering the outline to appear. The

user was told at the beginning of the game that their mission is to recon the area around an abnormal reading. It is intended that the user will be able to associate the abnormal reading with the light as well as they were told that the reading originated from deep below the ice. The user should be able to deduce that the icicles can be used to break the ice sheet and bringing them closer to their goal. Once they have broken the ice the tutorial will end.

The design of the environment has been laid out in sequences as seen in the figures within this section. The environment was designed to gradually introduce the user to how to interact and control the game. As stated by LaViola et al. travel is one of the most basic interactions that users perform in a VE [38]. Therefore, the user is first introduced to dashing and told that they should use it a few times to get confident in their abilities. The crater that the user starts in was specifically designed for this purpose. It was designed as a mostly flat and neutral space for the user to test out dashing before proceeding. When the user is comfortable with dashing they will need to use that ability in a precise manner.

In the next layer the user is introduced to telekinesis by having to move boulders out of the way. As stated previously the user can only use their eyes for telekinesis at this point. Next hand movements are unlocked for moving the boulders off of the ledges and finally the trackpad is unlocked when the user reaches the cave entrance. This design approach should improve learnability and memorability for both telekinesis and dashing which was necessary based on the input from the results of the telekinesis additional input modality evaluation [Section 4.6.3].

### 5.3.2 Usability and Functionality Design

Moving on from the environment, the usability and functionality requirements will be discussed. Color palettes were chosen for lighting in the environment and a contrasting color pertaining to usability and Graphical User Interfaces. The color palettes are shown in figure 25. The environment lighting color is a realistic gray with a teal tint, promoting that the snow and ice are manipulating the tone of the color when the light bounces off of the surfaces.

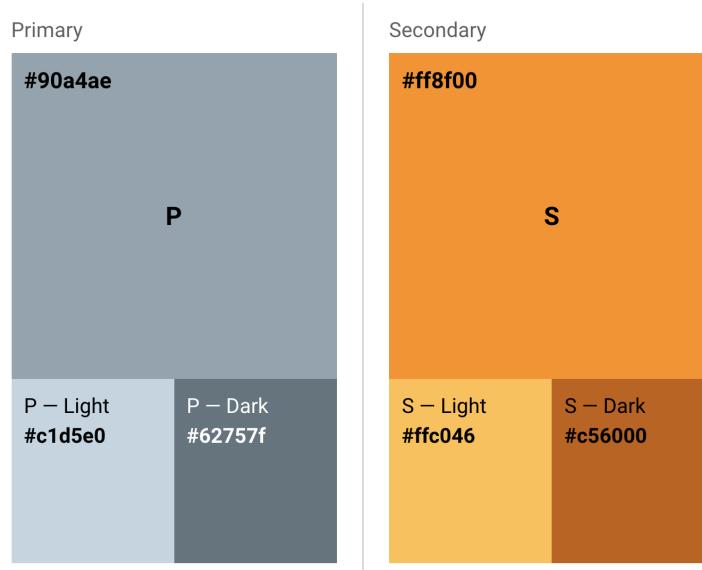


Figure 25: Color palette for environment lighting and functionality and interaction



Figure 26: To the left is the dash eye target signifier of this project, to the right is the one used in the game Dishonored [17].

It was previously stated that the eye target signifier was not noticeable enough. It should also provide the affordance that it is a target signifier for dashing. The signifier's design drew inspiration from the game Dishonored [17] where the player character possesses a similar dash ability to this prototype. A depiction of this effect can be seen in figure 5 [15] [6]. The target has rings that originate at the center of gravity relative to the player and drift up and down from that center. Also a flare has been placed at the center of gravity as well as particles that appear randomly and float downwards. These visual effects should make the user believe that the target possesses more functionality than just being a point where the user is looking. Additionally, the target has a science fiction aesthetic and should fit in the setting well.

From a usability perspective it is important that the user can easily distinguish between objects and terrain that serve a purpose within the game. Purpose pertains to what the user knows they can manipulate or travel to. The design of the different materials, textures and shaders should therefore convey to the user that they can be used, while still not be so different from the environment that they would feel artificial. But for telekinesis the user would have to manipulate different objects and within the cave scene [Figure 24] the user will need to use telekinesis on objects that look stationary and integrated with the environment. Therefore, the objects were given various states with specific visual feedback according to these states. An outline was therefore given to every object that can be manipulated when the user looks at them. The user should therefore quickly create an association that every object with an outline can be manipulated and additionally give feedback to the user of which object they are targeting.

It was specified in the design requirements of the first iteration [Section 4.2] that the object that the user is manipulating should be translucent so the user could orient themselves while performing telekinesis. This shader and material was updated for this iteration of the prototype, to have a more pleasing aesthetic. A screenshot can be seen in figure 27 of the updated telekinesis shader.

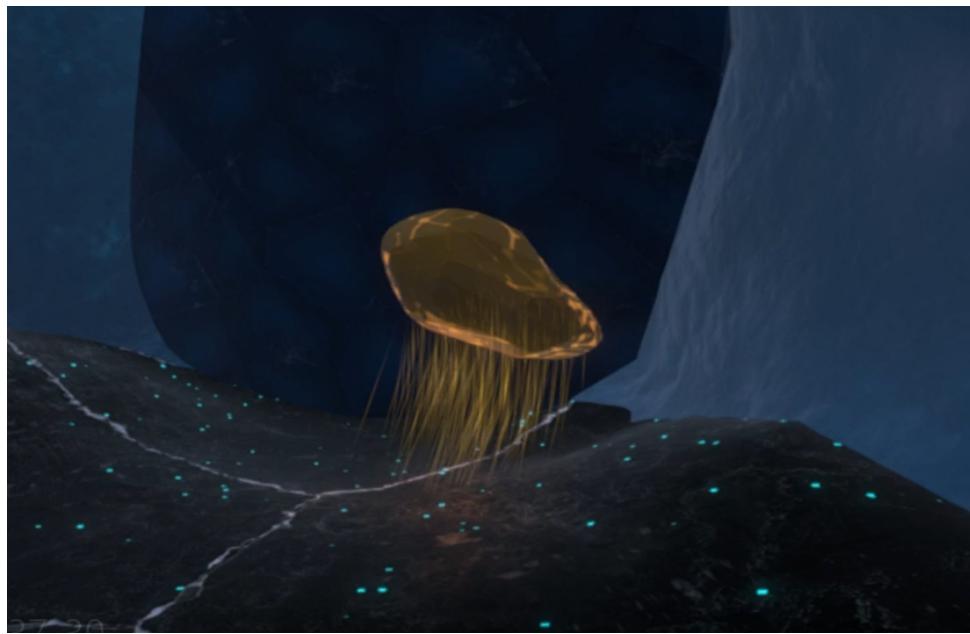


Figure 27: Telekinesis shader while an object is being manipulated

While the object is being manipulated it is translucent. The shader has a Fresnel effect where brighter dots connected with lines appear at the edges of the object. Some inspiration for this Fresnel effect was drawn from constellation cartography in coherence with the science fiction setting. When the object is being manipulated a stream of particles will float in a perpendicular angle towards the surface directly below it. This effect was added to help the user gauge the depth at which the object is being manipulated.

### 5.3.3 Sound Design

At this stage of the prototype, the first implementation of the auditory experience will be made. The primary goal of the sound design for this project is to introduce another level of changeable variables, that can be utilised to further induce the sensation of presence for the user [Section 2.3.1]. What the sound design should do for an application, is an important aspect to take into consideration, as there are many different proposed hypotheses on the topic. The sound design for this project will be based around the multimodal listening hypothesis, which suggests that sound is a "bodily and holistic experience which extends beyond the act of interpreting audible sound signals through our ears" [71]. The focus for the sound design will therefore extend beyond the basic act of interpretation of audible sound signals, and try to create a comprehensive soundscape environment with several layers of sound. For this iteration the stated theory will form the baseline for the creation of the in-game soundscape. A more in-depth analysis and utilisation of the multimodal listening hypothesis will be explored further in the third iteration [Section 6.3.3]. A first stage soundscape will be introduced through two audio files:

- **Wind:** The idea behind the wind audio is to enhance the visual representation of the sky. Together they signify a significant magnitude of power, that should make the user not want to move up and out of the valley - but rather follow the mission into the canyon.
- **Ice crack:** To build suspense, an audio file will be looped to simulate large and intense ice cracking throughout the game experience. A low-pass and reverb filter was added to the audio file to modulate it in accordance to the portrayed environment. This was done in order to mimic the real world attenuation of high frequencies over distance.

### 5.3.3.1 Narrator Voice Lines

The goal for the second iteration will be to create a soundscape that aids the portrayed in-game narrative. A large part of this narrative will be presented through a series of audio cues in the form of a narrator voice. This will be the primary source of information retrieval on how to interact with the prototype for the user. These voice lines from the narrator will explain the user how to proceed forward. The primary goal of these voice lines is to establish the narrative, and most importantly introduce them to the two presented novel interaction methods for dash and telekinesis.

As was stated in the concept idea [Section 5.1], the narrator is to be portrayed as a commander that gives the player orders. To achieve this effect, it was decided that the overall structure for the voice lines were to be short, concise and clear. The recording of the narrator voice lines was made on a entry level high quality microphone called "Blue Microphones - Yeti USB", and the location was in the anechoic chamber at the Multisensory Experience Lab at Aalborg University Copenhagen. This would ensure a clear recording with minimal amount of unwanted noise. Afterwards the recordings were edited in Audacity. Here a band-pass filter was added to create the feeling that the audio signal was emitted through a radio. The idea behind the "radio-sound" of the narrator voice lines was that it would bolster the narrative of being on an far away alien planet and the commands were given from a commander at a control center back home. The voice lines and their use can be seen in the following list:

1. **Introduction to narrative at start of game:** Welcome to Europa, the icy moon of Jupiter, RA-1. Reconnaissance shows abnormal readings from approximately 100 meters from your landing location, buried deep in the ice. Your mission is to recon that area and retrieve any objects of importance.
2. **Introduction to interaction method for dashing:** First of all, let us get you moving RA-1. Point your bionic eyes to the location you wish to dash to. You can see that the location is highlighted. Now, grip your hand .
3. **Confirmation of successful interaction. Triggered by the first dash made:** Well done. Dash around to get familiar with your abilities. Once you feel confident, head over to the opening of the canyon.
4. **Further explanation of interaction the method for dashing. Triggered by entering the canyon entrance:** Your capabilities allow for very precise dashing, such as these ledges on the side of the canyon. Go ahead and advance forward.
5. **Introduction to interaction method for telekinesis. Triggered by reaching the ledge right in front of the rubble:** We knew this wasn't going to be an easy mission, but you are equipped with cutting edge anti-gravity tech embedded in your eyes and hands. Direct your bionic eyes to the rubble and hold your trigger. Now throw the rubble into the canyon by moving your eye unit around.
6. **Further explanation of interaction method for telekinesis. Triggered by clearing the rubble and dashing onto the next ledge:** There is rubble blocking your path once more RA-1 fixate your gaze on the rubble on the next ledge and use both eyes and hands to move the rubble off. Whatever object you are manipulating will move according to your hand movements and eye movements combined.
7. **Final explanation of interaction method for telekinesis. Triggered by reaching the final ledge:** Hold up here RA-1! The energy readings are coming from inside that cave, move that big ice block out of the way. Fixate your eyes once more on the block and move your thumb down on

the trackpad to drag it over the edge.

8. **Hint of how the interaction method can be used on all sorts of objects:** You can also use that same technique to move objects away from you, by looking at an object and moving your thumb up instead of down.

## 5.4 Implementation

The implementation of the second iteration should satisfy the requirements stated in section 5.2. The fulfillment of each will be documented in the proceeding section.

The eye tracking signifier is responsible for the visual feedback to the user on where they will dash if they initiate the action. Currently, as mentioned in the first iteration implementation [Section (4.4)] this is a gameobject with an attached point light. In order to improve the visual fidelity of this signifier a VFX graph was made which could be added to the preexisting gameobject signifier.

As stated in the preceding design, the selectable objects should have states, namely a **default**, **focused** and **selection** state. To achieve this, functions for each state were added to the *Grabbable.cs* script. When the *EyeRaycast.cs* script, mentioned in the first iteration implementation (4.4), returns a selectable object from the raycast, it immediately calls the *Focused()* function (line 15), which activates the outline of the object.

```

1   // set the grabbed object to 'default' selection state. Called either when the user
2   // stops looking at the object, or when it is dropped
3   public void Default()
4   {
5       // in case the outline on the object is highlighted, set it to false
6       outline.enabled = false;
7       // change the materials of the object to the originals
8       matArray[0] = originalMaterial;
9       matArray[1] = originalMaterial;
10      mesh.materials = matArray;
11      isSelected = false;
12  }
13  // set the grabbed object to 'focused' selection state. Called when the user's gaze
14  // fixates on the object
15  public void Focused()
16  {
17      // highlight the outline the grabbed object
18      outline.enabled = true;
19      isSelected = false;
20  }
21  // set the grabbed object to 'selected' selection state. Called when the if the user
22  // is focusing on the object and confirms the selection at the same time
23  public void OnSelect()
24  {
25      // disable the highlighted outline of the object
26      outline.enabled = false;
27      // change the object's materials to the translucent selection material
28      matArray[0] = selectionMaterial;
29      matArray[1] = selectionMaterial;
30      mesh.materials = matArray;
31      isSelected = true;
32  }

```

Listing 10: Default, Focused and OnSelect functions

If the user then proceeds to press the trigger button, the *OnSelect()* function is called, seen on line 23 of the code snippet.

This function disables the outline script and switches the material of the selected object to a semi-transparent material as stated in the design section [Section 6.3]. In both the *OnSelect()* and the *Default()* functions, the material array indices are set to the appropriate materials which are then assigned to the *MeshRenderer* component which has been initialised as "mesh".

When the object is released by the user the *Default()* function is called, setting the materials back to the original.

To cast a signifier onto the ground below the object, as also mentioned in the requirements, it was decided upon to use a particle system which would emit from the base of the object. This was handled within the *Telekinesis.cs* script. The particle system was set active when the object was selected and the *UpdateParticles()* function changed the position of the system to match that of the object.

```

1 // called every frame if the user has selected an object
2     private void UpdateParticles()
3     {
4         // set the position of the particle system to the same as the grabbed object's
5         particles.transform.position = new Vector3(grabbedObject.transform.position.x,
6             grabbedObject.transform.position.y, grabbedObject.transform.position.z);
7     }

```

Listing 11: The *UpdateParticles()* function is called every frame when an object is selected

To implement the voice tutorial, trigger boxes were set up within the level at the appropriate places and a simple script triggered the attached  *AudioSource* component. These triggers handled the majority of the tutorial with the exception of the the introduction to the game (played when the game starts) and the proceeding instructions, which were played after the player makes their first dash. An example of a tutorial trigger box can be seen in figure 28. The snippet below, outlines how the the collision is detected and how the audio is played. It is important that both the player and the triggerbox have  *Collider* components and at least one has a  *Rigidbody* component for Unity to detect the collision. The player's collider is assigned to layer 12 and when the *OnTriggerEnter()* function is called, the layer is compared to that of player to ensure a boulder or other dynamic object does not trigger the audio. If it is indeed the player, the  *AudioSource* component is referenced and the audio played on line 6 and 7. In case any other event needs to be triggered a  *UnityEvent* is defined in the script, which is invoked if not null on line 8. This event can be defined in the inspector.

```

1     private void OnTriggerEnter(Collider other)
2     {
3         if (other.gameObject.layer == 12) // player layer
4         {
5             var src = GetComponent<

```

Listing 12: The code that would play the tutorial audio when the player enters the triggerbox

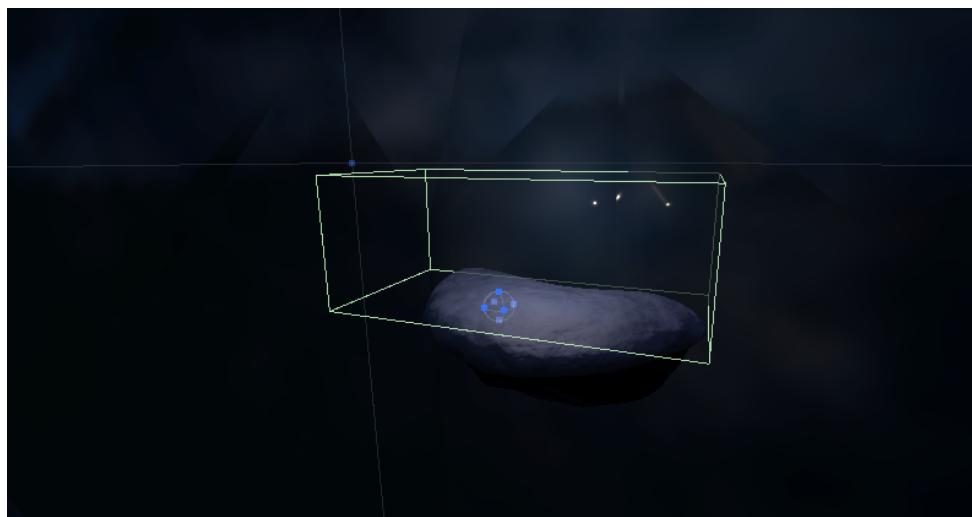


Figure 28: The trigger box that would trigger the tutorial audio when the player enters

The materials of the environment were important to fulfill the convincing and immersive requirement. For the snow and rock materials the standard lit surface shader was sufficient. However, to build a believable and performant shader for the ice, Unity's Shader Graph was utilised. Standard ice textures were used to obtain the roughness and normals of the surface. The albedo however, was duplicated 10 times, each one slightly parallaxed depending on the view direction and its intensity increasingly subdued, this gave the illusion of the fading depth in the ice, seen in figure 29.

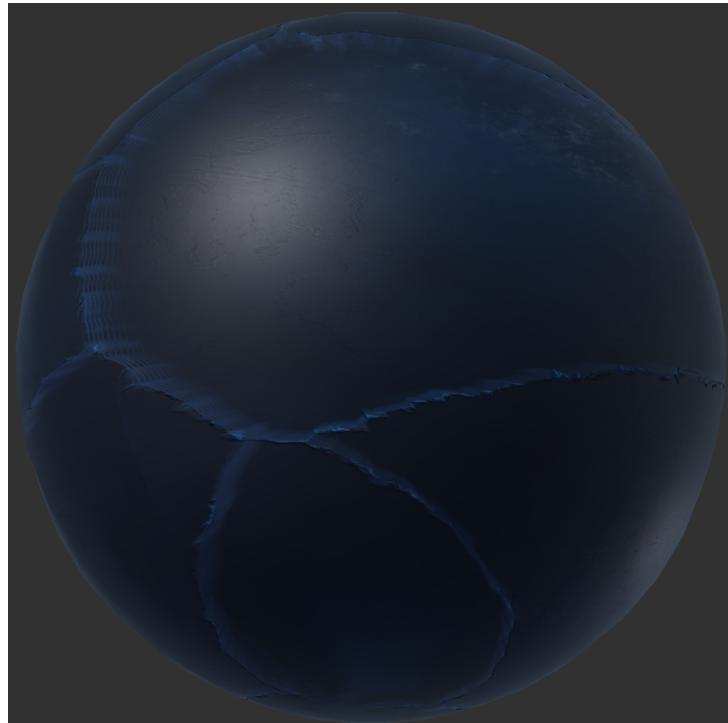


Figure 29: Final result of Ice material

It was necessary, for the designed environment, to have a high resolution skybox of Jupiter and a starry night sky. A scene was set up in Blender to replicate the skies of Europa. This scene was then rendered into 6 different images, which were imported into Unity and used as the skybox and the ambient lighting

of the experience's virtual environment.

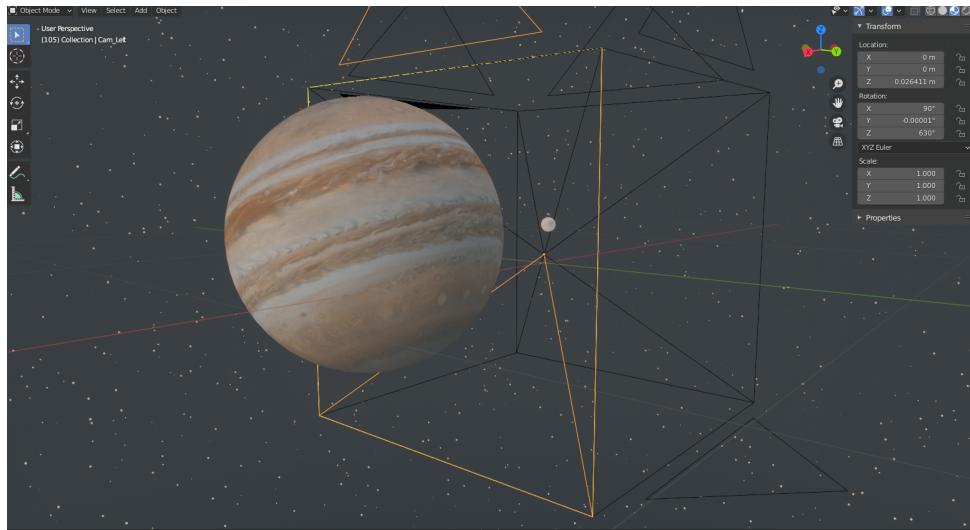


Figure 30: The Blender scene created for the skybox

## 5.5 Evaluation

As it was previously laid out in the methods chapter [Chapter 3] this iteration is aimed to test the prototype's **usability**. All the improvements presented previously in this chapter were aimed to make the prototype more usable and improve upon it. To actually find out if the carried out improvements made the prototype more intuitive to use, a proper usability evaluation has to be carried out. For this, the system usability scale (SUS) has been employed. This method can be particularly helpful for evaluating usability robustly with small sample sizes in a quick manner [Chapter 3].

The main aim of this evaluation stage was to test the usability of the prototype and the tutorial part of the game being developed. The previously detailed narrator voice lines play a significant role in the usability of the prototype, hence those were aimed to gather feedback upon, as well.

The specific improvements on dash and telekinesis were planned to be evaluated by obtaining an individual SUS-score for each interaction technique. Dashing was improved by a revised signifier. As it was presented before, the ledges created in the environment were made to be minor and distant from each other to assess eye tracking's precision for longer ranges.

On the other hand, telekinesis was improved by the various object states for selection & manipulation [Section 5.3.2]. Telekinesis has also encompassed the layer-by-layer introduction of additional input modalities as it was discussed before [Section 5.3.2], and it was intended to find out whether this approach improved this interaction method's learnability for users.

### 5.5.1 Test Procedure

The evaluation phase of the 2nd iteration has also taken place in the Multisensory Experience Lab at Aalborg University Copenhagen. In this section, the sequential procedure of the testing will be detailed.

Firstly, all recruited test participants were briefly explained about the goal and process of this testing scenario then they were asked to provide consent for using their collected data for research purposes. They were also asked about their previous VR experience. Afterwards, they were led to test the actual prototype.

At this stage, participants were introduced to the VR headset and controller. They were explained the different buttons and which input do they stand for. They were told that several voice lines will tell them their tasks in the environment, where they will complete a tutorial level. Participants were also noticed, that if they are unsure about their next action, they could ask the test conductor for help.

After completing the level, participants were asked to fill out two modified version of the SUS, each tailored to dash and telekinesis, separately. These can be found in the appendix C. Instead of the traditional formulation of the SUS questions which uses "*system*", it was replaced by "*telekinesis*" and "*dash*" for the two questionnaires respectively. This way, telekinesis and dash both received separate scores, based on which their usability could be evaluated.

This was followed by a semi-structured qualitative data gathering through an interview based on the scores participants given and observation notes from the test conductors. From their results, questions were directly targeted on the most negative scores they gave. Because of the use of two separate questionnaires for dash and telekinesis, more targeted questions could be asked about the pain points of each. The observation notes can be found in appendix E.

### 5.5.2 Results

A total of 11 participants took part in the usability test of this project on the 19th of November 2020. This section will focus on the presentation of the results and possible interpretations and conclusions will be suggested based on the data. An overview of the gathered SUS scores and their boxplots can be seen in table 1.

| Q. nr.        | Dash |   |   |   |   |   |   |   |   |    | Telekinesis |   |   |   |   |   |   |   |   |   |    |       |
|---------------|------|---|---|---|---|---|---|---|---|----|-------------|---|---|---|---|---|---|---|---|---|----|-------|
|               | 1    | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Score       | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Score |
| Participant A | 5    | 1 | 4 | 2 | 4 | 2 | 4 | 2 | 1 | 3  | 70          | 3 | 2 | 3 | 1 | 4 | 3 | 4 | 2 | 5 | 1  | 75    |
| Participant B | 2    | 4 | 1 | 3 | 2 | 2 | 4 | 3 | 3 | 2  | 45          | 2 | 3 | 4 | 2 | 2 | 3 | 4 | 3 | 4 | 2  | 57.5  |
| Participant C | 4    | 1 | 5 | 1 | 5 | 1 | 4 | 2 | 4 | 2  | 87.5        | 2 | 4 | 3 | 1 | 3 | 2 | 4 | 4 | 3 | 2  | 55    |
| Participant D | 2    | 4 | 5 | 1 | 5 | 1 | 5 | 1 | 5 | 1  | 85          | 5 | 1 | 5 | 1 | 5 | 2 | 5 | 1 | 5 | 1  | 97.5  |
| Participant E | 2    | 4 | 2 | 3 | 3 | 1 | 2 | 4 | 1 | 3  | 37.5        | 2 | 3 | 2 | 3 | 5 | 2 | 2 | 1 | 1 | 2  | 52.5  |
| Participant F | 4    | 2 | 4 | 1 | 3 | 2 | 4 | 2 | 4 | 1  | 77.5        | 3 | 2 | 3 | 2 | 4 | 2 | 3 | 2 | 3 | 2  | 65    |
| Participant G | 5    | 1 | 4 | 1 | 4 | 2 | 5 | 2 | 4 | 2  | 85          | 4 | 2 | 4 | 2 | 5 | 2 | 5 | 2 | 4 | 2  | 80    |
| Participant H | 3    | 2 | 4 | 2 | 3 | 3 | 4 | 2 | 4 | 1  | 70          | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 4 | 3 | 2  | 50    |
| Participant I | 4    | 2 | 2 | 1 | 4 | 1 | 4 | 1 | 4 | 2  | 77.5        | 4 | 2 | 4 | 2 | 5 | 1 | 4 | 1 | 4 | 1  | 85    |
| Participant J | 4    | 2 | 5 | 1 | 3 | 2 | 4 | 2 | 5 | 1  | 82.5        | 3 | 2 | 4 | 1 | 5 | 1 | 3 | 2 | 3 | 2  | 75    |
| Participant K | 4    | 2 | 4 | 4 | 4 | 2 | 4 | 2 | 4 | 2  | 70          | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2  | 75    |

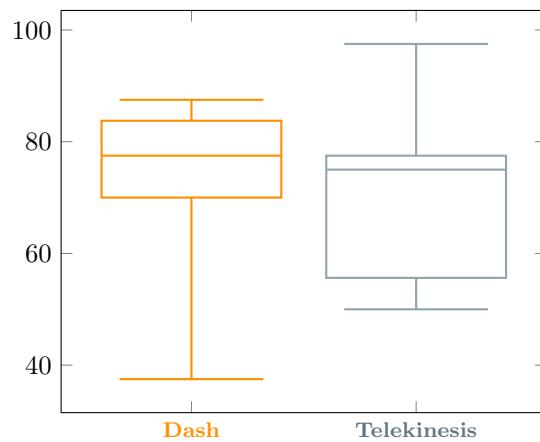


Table 1: Scores and boxplots for SUS scores from usability test as part of 2nd iteration

From the table each participant's SUS score can be seen for dash and telekinesis, respectively. Descriptive statistics of the scores can be seen in appendix D. The overall mean of the two interaction technique's

SUS scores from the 11 participants:

- Mean of SUS score for **dash**: **71.59** with a **standard deviation** of **16.36**.
- Mean of SUS score for **telekinesis**: **69.77** with a **standard deviation** of **15.06**.

However, as it can be observed from the individual scores, the results are scattered. Therefore two boxplots were created to visualise the scores in a more meaningful manner.

To interpret the aforementioned data, SUS scores need to be compared to a certain degree. According to Sauro et al., raw results could be interpreted as percentile ranks [62]. Via this method more than 5000 observations were taken into account, and it was found out that an SUS score higher than 68 is above average, whilst lower than 68 is below average usability. Based on this, it can be stated that both dash and telekinesis has performed above average according to the SUS score. Even though these scores are above the set limit, they cannot be safely interpreted as a major success. Taking into account the more sophisticated data read from the boxplots, dash performed more reliable as even its lower quartile is above 68. Telekinesis, on the other hand is less robust with the lower quartile being 55.625. It is evident based on the aforementioned result that even the prototype's usability is above average, it can be undeniably further improved for the next iteration. To find out the specific pain-points of the prototype and to get a more explanatory overview, the gathered qualitative data has been analysed. The qualitative data consists of

First of all, users have addressed that the experience was overall fun and enjoyable and they did like this novel way of interaction based on eye tracking. They also felt immersed in the environment. When asked about the specific interactions dash was found to be more straightforward, it was intuitive to select the target with the eyes. Yet, the vast majority pointed out that selecting targets for longer distance travel was troublesome and not particularly accurate. When trying to select a target far away, the eye-signifier became "jittery". Participants also commented on the height of the signifier being too tall, resulting in inaccurate target selection.

For telekinesis, the feedback was rather diverse. A few participants still pointed out that moving objects directly with the eye gaze is slightly bizarre, however, users did mention that the highlight of interactable objects did help to improve the usability. Most of the participants pointed out that the physics of the environment were not appropriate and it possibly further complicated the interaction. It was also mentioned that the layer-by-layer introduction of the controls for telekinesis was redundant and confusing.

Additionally, it was also commented on that the tutorial and the voiceovers were understandable and sufficient enough to complete the level. Some also mentioned that the main narrative was less evident but the tasks were clear. It was also observed during the testing phase that participants did not wait until the voice lines finished, they rather tried to move on to based on their own intentions, mostly via their hand movements.

The environment received positive feedback, participants appreciated that it is spacious and it encourages exploring and moving around in it. Nonetheless, it was also pointed out that the canyon was too dark, thus wayfinding and navigation was confusing and complicated. On several occasions users disoriented and went back to the ledge they were previously on. Some users hinted that the wayfinding cues could be more emphasised, even introducing audio cues could be helpful. Finally, it was also pointed out that the canyon was too narrow for moving objects around via telekinesis. The SUS scores and the qualitative feedback gathered in the second iteration suggests further improvements on the design and development of the prototype. These specific changes will be formulated in the third iteration's concept idea.

## 6 Third Iteration

### 6.1 Concept Idea

Following the evaluation of the second iteration, some changes to both the environment and usability and functionality of the design had to be made in order to increase the usability of the prototype. This concept idea section and the design requirements and design sections will detail all design changes that were made for this third iteration. Therefore any section, scene or event not detailed in this sections, and the ones following, have not been altered.

To finally evaluate upon the final problem statement a traditional controller based input has been added to the game. The controller input modality was designed around a combination of inspiration gathered from telekinetic abilities from other VR games as well as travelling methods from Steam-VR. It is also important to note that the controller input for both modalities should be as similar as possible to avoid uncontrolled variables that could influence the evaluation of this iteration.

Based on qualitative feedback from the second iteration evaluation, it was apparent that the environment was remarkably dark. Therefore, the environment should be updated with brighter shaders and textures. Some participants in the second iteration evaluation got turned around and accidentally traveled back to a ledge they just came from. The environment should for this reason be updated to be more unique so the user does not become disoriented. Additionally the target signifier for [Figure 27] proved to be intrusive for the participants. An updated version of the target signifier should therefore be added that give off the same associations

Wayfinding cues for this iteration should also be updated. The changes pertain to adding additional wayfinding cues via audio. The user will be given spatialised auditory wayfinding cues urging them in the right direction. Additional ambient audio has also been added to the game. This new ambient audio have been put in place to increase engagement, presence as well as carrying over the feeling of danger from the second iteration when the dust storm eventually is not present in the cave and the tunnels beneath the surface. To increase realism audio effects to the boulders have also been added when they collide with surfaces.

To facilitate a proper game scenario a secondary section has been added to the game. This second section will begin after entering the cave that was the original ending of the second iteration. In place of the ice sheet from the first iteration cave scene, a deeper and open cave was constructed. The user will need to navigate down into the bottom of the cave in search of the source of the abnormal readings. At the bottom, two new obstructions will be presented where the user will need to use problem solving skills to clear the hindrances. When they have been cleared a puzzle will be introduced. The puzzle revolves around gaining access to an alien artifact that is giving off the abnormal readings. The user will need to use their puzzle solving skills aided by natural lighting and color based wayfinding cues in order to complete the puzzle and finish the game.

### 6.2 Design Requirements

#### Usability and Functionality requirements:

- The target signifier effect should be updated to be less intrusive
- The target signifier should be enlarged based on how far away it is from the user
- A controller based input modality should be added that mimics the eye tracking modality

- The telekinesis should be updated to feel more natural

**Environment and game requirements:**

- When the user starts the game, they should be given access to all layers of telekinesis
- The overall brightness of the environment should be increased
- Ledges should be enlarged and moved closer together
- The texture of the ledges should be changed to resemble the boulders that can be manipulated
- The environment should be altered to be more unique in different sections
- Alien structures should be added that contrasts to the environment
- The tutorial section of the game should seamlessly transition to the puzzle section
- The user will be impeded by several obstacles that they will need to overcome by using telekinesis
- A final puzzle should be implemented that the user will need to solve by using both telekinesis and dashing

**Audio requirements:**

- Spatialised sonic wayfinding cues should be implemented
- More ambient sounds should be added
- An ambient musical track should be added
- Boulders should have realistic sound effects added to them upon collision with the terrain

### 6.3 Design

The design of the third iteration will follow the same structure as the previous design sections and will explain the choice of aforementioned requirements along with the required changes to the prototype to fulfill them. In figure 31 an overview of the level structure is depicted as a top view and side view. The added sections of the environment compared to the 2nd iteration [Figure 18] being the cave, cavern and puzzle.

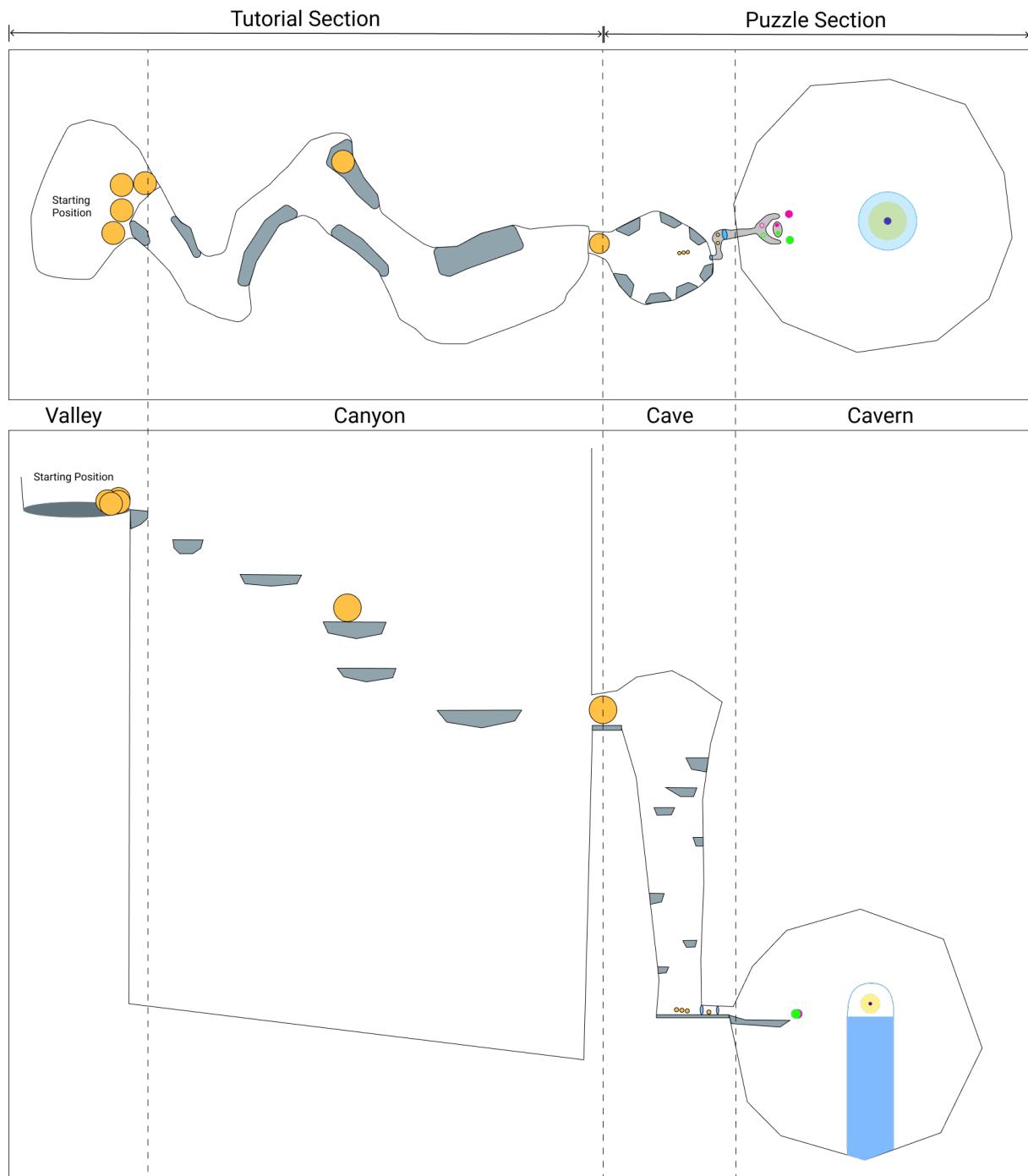


Figure 31: Top and side view of the environment

### 6.3.1 Usability and Functionality Design

The usability and functionality of the game remain much the same as the previous iteration, with some key changes. A problem with the implementation of the signifier in the previous iteration was that users felt it was intrusive and obstructed their view. Since the center of the eye signifier stood above the ground and above where the user was focusing, the user's eyes would tend to shift their focus to this center point. Thus, the user's would find their gaze slowly but continuously drifted further away from where they wished to dash to. Additionally since the center of the eye signifier was not in the center of the eye raycast, users felt that the raycast was inaccurate. This issue was resolved by recentering the

signifier on the ground, reducing the number of particles emitted by it and decreasing its overall height. The reworked VFX signifier can be seen in figure 32.

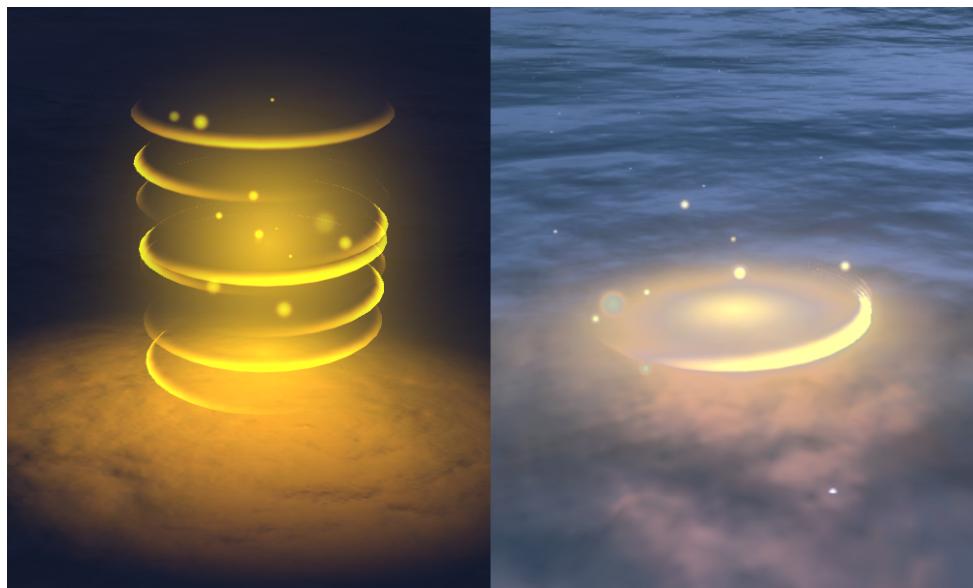


Figure 32: On the left, the signifier from the second iteration. On the right, the reworked signifier

Another critical problem that needed to be addressed in relation to the signifier was its visibility at large distances as seen in figure 33. From observations made in the second iteration evaluation [5.5], some participants had difficulty distinguishing the target signifier at larger distances. To rectify this issue, the signifier now increases in size depending on the distance to the point on which the user is focusing.



Figure 33: The dash signifier seen from a large distance

As this project is investigating the difference in experience between eye tracking input and traditional controller based input, it was necessary to design a controller based interaction for the game. To achieve comparable data sets, the controller interactions should be as similar as possible to the eye gaze based input. Therefore, it was chosen that the controller should emit a raycast in a straight line as seen in figure 34. It should be noted that the eye raycast and the controller raycast differ in that the controller raycast is visible at all times to the user to aid with targeting. Furthermore, when the user is interacting

with an object using the controller the ray protruding from the end of the controller becomes brighter and larger as a form of visual feedback to the user.



Figure 34: The straight raycast from the controller

### 6.3.2 Environment and Game Design

An issue that arose previously, was the overall darkness of the environment. It was intended to create a setting in the second iteration that invoked a feeling of danger or unease for the user which was the reason behind the overall darkness. However, during testing of the second iteration, several observations were made of users having issues with progressing. Due to the dark environment users had issues orienting themselves in the environment and on multiple occasions went back to the ledge they were previously on [Section 5.5]. To rectify this issue, the environment's ambient lighting intensity was increased globally, figure 35 illustrates the change this made.



Figure 35: On the top, the environment lighting from the second iteration. On the bottom, the increased ambient lighting. There is also a difference in the material of the objects.

As shown in figure 35, the ledges were also enlarged and their material were changed in order to make them both contrast better against the ice walls and to make it easier for the player to focus on. The material was changed to the rock material that the boulders within the game also have. This made it clear to the user that objects with this material were interactable in some way. However, it was important to

somewhat distinguish between objects that could be manipulated with telekinesis and objects or surfaces that could be dashed to. To make the difference clear the objects were given two different overlaying emission textures. The objects that could be picked up were colour coded with the orange from the selected colour scheme, as mentioned in section 5.3.2 figure 25. The objects or surfaces that could be dashed to were colour coded in a complimentary blue colour as seen in figure 36. To further reduce the difficulty in dashing for the player, the ledges in the canyon of the game were also moved closer together.



Figure 36: The boulder has an orange emission overlaying the material, the ledge a blue overlay

Having an environment with few distinguishable features can be disorientating. This was a problem in the second iteration as participants lost a degree of spatial awareness after dashing in the mostly featureless environment. It was decided to add more discernible land features in the scene to help combat this issue. Large frozen waterfalls were added throughout the canyon as can be seen in figure 37. This should help to break up the scene into digestible pieces for the user, they also proved useful to hide unwanted UV seams in the canyon.



Figure 37: An example of a frozen waterfall that are scattered throughout the canyon

Throughout the level, evidence of alien presence needed to become increasingly apparent in the environment. This would give the notion to the user that whatever was giving off the abnormal readings was nearby. To achieve this, geometric shapes were used with foreign and alien shaders. As can be seen in figure 38, these structures were scattered throughout the level after the tutorial had finished and became more frequent towards the end. When the user enters the final stretch of the prototype, an alien skull presents the entrance to an ice tunnel they must enter to reach their goal, seen in figure 39.

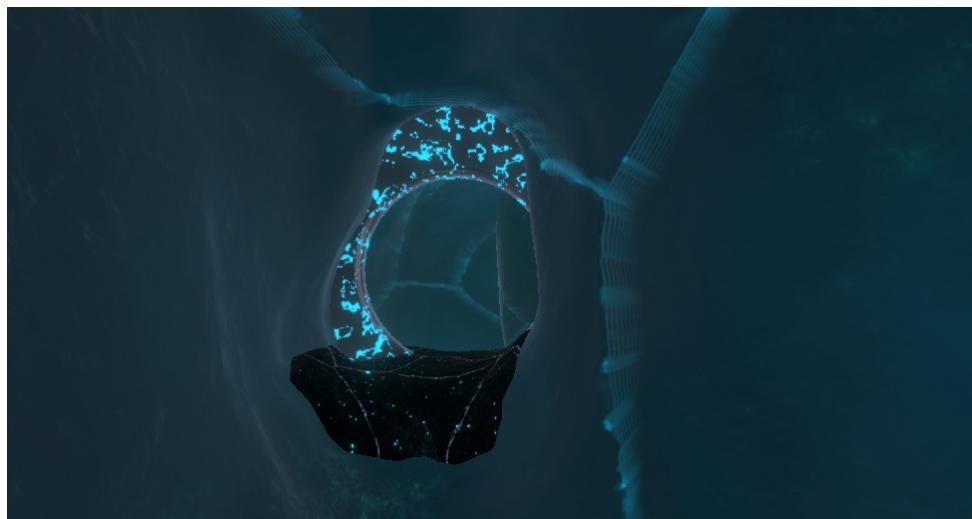


Figure 38: Alien structures such as this became increasingly present



Figure 39: The alien skull that the user must break the ice in to advance

At this point the user received no further guidance and must think independently to proceed. Firstly, they must break the icicles in the mouth of the skull using any one of the boulders scattered around the area, seen in figure 39, and clear the debris to enter the ice tunnel. A blue light was added to the mouth of the skull to make it more intimidating and provide a wayfinding cue to the user. Towards the end of said ice tunnel they are presented with a solid ice sheet blocking their path [Figure 40], again they must break this to gain entrance to the final cavern.



Figure 40: The ice being broken to reveal the final puzzle

Here they are presented with the final puzzle. This puzzle needed to involve aspects of both dashing and telekinesis, it was also required to adhere to the alien narrative. It was decided that the user must have to dash to a certain location and remain there while they remotely manipulate an object into a goal location. This can be seen in figure 41. Where the object labelled 1, is where the user must stand and manipulate object 2 into object 3. When completed on both sides they gain access to the *warpcore* labelled 4.

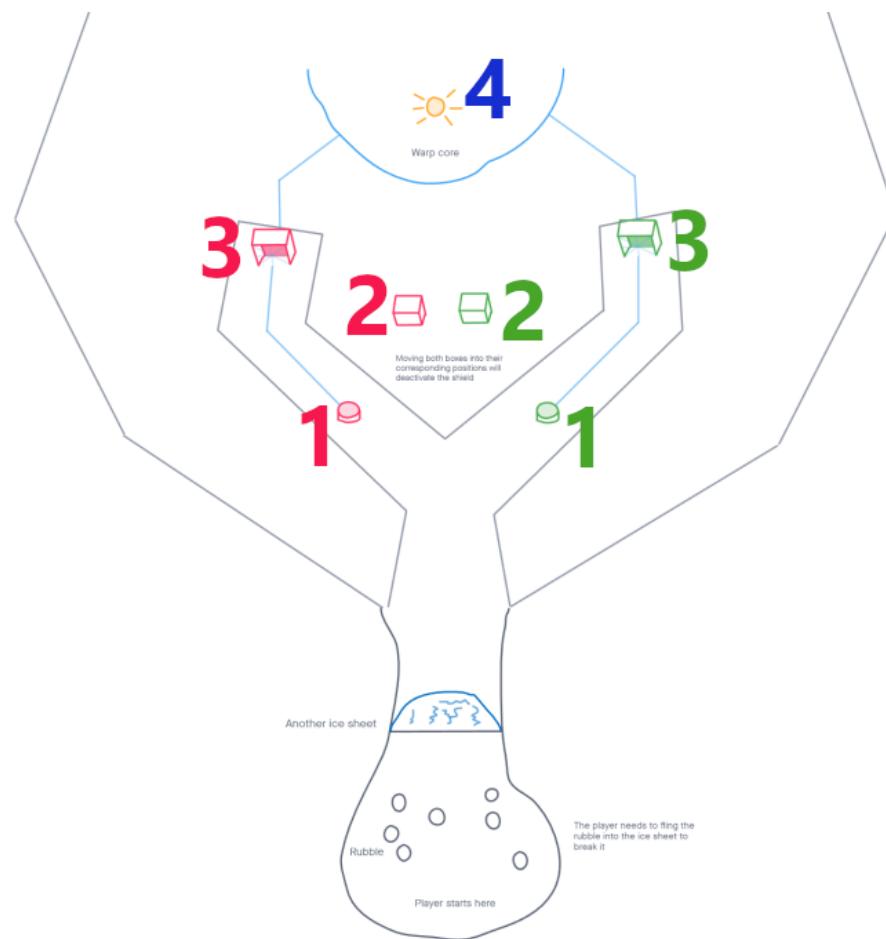


Figure 41: Sketch of initial the puzzle design

The puzzle therefore consists of three elements:

- The *ring* on the ground, in which they must stand,
- the smaller *orb* that they must manipulate and will be from now referred to as the *key*,
- the larger sphere which will be referred to as the *orb*.

The user must stand in the *ring* corresponding to the colour of the side they are solving, they must then proceed to pick up the *key* in the center. If the user picked up the sphere from the correct location, the shader's Fresnel of the *orb* was altered to afford placing the *key* inside, this change can be seen in figure 42.

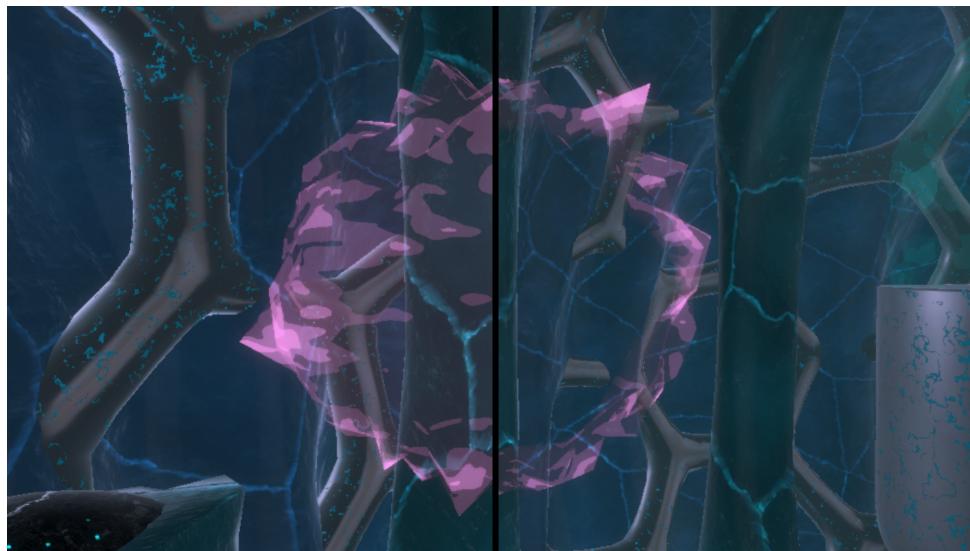


Figure 42: On the left, the *orb* in its normal state. On the right, the *orb*'s Fresnel altered to provide correct feedback to the user

Once the user placed the *key* inside the *orb*, the *key* disappears, the *orb* becomes smooth, as if it is satisfied and the force-field protecting the *warpcore* in the center of the cavern decreases in intensity, seen on the right side of figure 43. If the user successfully solves both the pink and green *orbs*, the forcefield disappears entirely and the *warpcore* begins to pulsate and expand, triggering the end of the game.

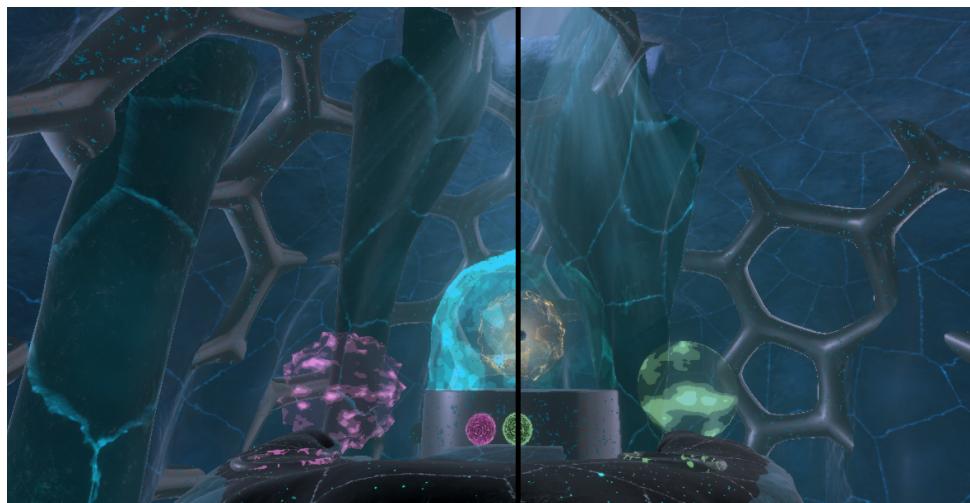


Figure 43: The final puzzle, on the left, how the *orbs* and the protective forcefield look unsolved. On the right, how it looks when half is solved. Notice the *orb* is much smoother and the center forcefield has diminished to an extent

### 6.3.3 Sound Design

As a continuation from the second iteration, the soundscape of the third iteration will be based around the multimodal listening hypothesis. This hypothesis builds upon the fact that sound signals interpreted and emitted through vibrations. In the multimodal listening hypothesis, it is suggested that sound is a "bodily and holistic experience which extends beyond the act of interpreting audible sound signals through our ears" [71]. Thus, the act of multimodal listening is suggested to examine sound signals through not only the ears, but also the sense of sight and touch. This distinction can also be related to

the act of hearing and listening, respectively.

The perception of sound is suggested by Tuuri. et al [71] to be denoted into a range of different types of audible sources. Therefore, a soundscape is not necessarily perceived as a set of abstract qualities. The act of listening is a way for humans to obtain information about the surroundings. Listening is by nature a highly multimodal activity, and it is suggested that different strategies of listening can be interchangeably be utilised to obtain different types of audible information [71]. Thus, one could argue that a soundscape in a game scenario, should try to reflect the portrayed surroundings. If the correlation between what is seen and what is heard does not match - the sense of presence in the virtual environment might be disturbed and impact the experience of the game, as was concretised in the analysis of this project [Section 2.3.1].

There was some noteworthy feedback regarding the sound experience in the second iteration test [Section 5.5.2]. As the soundscape had not been refined in detail for the second iteration, some of this was already apparent for the project group, but a summary of what would be needed for the soundscape for the third iteration was decided to be the following:

- Wayfinding sound cues to help navigate the user.
- Ambient background music to increase the sensation of suspense, but also enhance the narrative with a cinematic like sound.
- Sound effects for interactable objects.
- Implementation of reverb zones to add the same characteristic type of sound to the different parts of the environment.
- Adjustment of amplitude of individual sound cues.
- Spatialisation of certain sounds to heighten the feeling of presence.

#### 6.3.3.1 Design of the Soundscape

The different layers of audio in the presented soundscape were chosen through a system of sequencing and segmentation. This method for making the sound design was introduced in the semester course of Screen Media by prof. Rolf Nordahl, and is a commonly used method for structuring of sound design within game and film production.

To create the system for the sound design. The virtual environment was split into five different sequences that signified a significant change in the environment surroundings. Each of the sequences would also have its own specific *reverb zone*, that would correlate with the environment. An overview of how the different sequences are connected, can be seen pictured in previously shown figure 31. The sequences were the following:

1. **Valley:** The starting area would have a big and open reverb zone, with a small amount of echo.
2. **Canyon:** The sound profile for the canyon would have a long reverb zone, with a decent amount of echo.
3. **Cave:** As the cave is enclosed the reverb zone would be short, but still with some amount of echo.
4. **Tunnel:** The tunnel got the smallest amount of reverb, and no echo due to the small size.
5. **Cavern:** The cavern got some reverb, and some echo due to the significant size of the room.

With the sequences and reverb zones in place, the next part of the process for the sound design was then to create a suggested list of sounds needed for each of the sequences. This list can be summarised the following way:

- **Valley:** Wind blowing and narrator voice lines. Background music starts at the ledge to the canyon.
- **Canyon:** Wind continues, but in a distance. Boulders sound effect. Ice crack looping sound effect. Ledge sound cue for wayfinding and the last of the narrator voice lines.
- **Cave:** New types of ice crack sound effects. Background music is added a suspense build up. The ice breaking in the skull has a sound effect.
- **Tunnel:** Another level of suspense is added through a background ice cave ambience tune. In the middle a massive ice crack to heighten the feeling of danger and suspense.
- **Cavern:** In the cavern a deep and roaring "temple soundscape" is played. Each of the puzzle objects has a selection state sound effect, that indicates when an object has been correctly placed to move on with the puzzle. In the end when the puzzle is completed another more intense roaring deep sound is played to exemplify the release of a massive energy from the alien relic.

After a couple of iterations on the needed list of sounds, the search for open source sound effects and songs began. For this the freesound.org website was used, which is a "collaborative database of Creative Commons Licensed sounds". All the sounds used in the game experience is licensed under the Creative Commons. An overview of all the audio assets used in the prototype can be seen in table 2.

| Sequence | Sound                                       | Play when in sequence         | Amplitude   | Loop | Spatialised |
|----------|---|-------------------------------|-------------|------|-------------|
| Valley   | Background ambience solar wind              | Start                         | Strong      | Yes  | Yes         |
| Valley   | Narrator Voice Line 1 + 2 + 3               | At given points               | Strong      |      |             |
| Canyon   | Background music                            | Start                         | Low         | Yes  |             |
| Canyon   | Background ambience solar wind              | Start                         | Medium      | Yes  |             |
| Canyon   | Boulder movement                            | At each boulder movement      | Low         |      | Yes         |
| Canyon   | Narrator Voice Line 4 + 5 + 6 + 7 + 8       | At given points               | Strong      |      |             |
| Canyon   | Ice crack massive                           | Every now and then            | Strong      |      |             |
| Canyon   | Ledge sound queue for wayfinding            | At each ledge                 | Medium      |      | Yes         |
| Cave     | Ice crack                                   | At each ice stick crack       | Medium      |      | Yes         |
| Cave     | Background music                            | Bottom of cave                | Low         | Yes  |             |
| Cave     | Ice "boulder" movement                      | At each ice boulder movement  | Low         |      | Yes         |
| Cave     | Ice sheet crack                             | At ice sheet crack            | Medium      |      | Yes         |
| Cave     | Background music: Ice cave ambience         | Start                         | Low         |      |             |
| Tunnel   | Ice crack massive                           | Middle                        | Very strong |      |             |
| Tunnel   | Ice sheet crack                             | End                           | Strong      |      | Yes         |
| Cavern   | Background music: Temple ambience           | Start                         | Strong      | Yes  |             |
| Cavern   | Core pulsation                              | Platform                      | Strong      | Yes  | Yes         |
| Cavern   | Relic overload                              | End                           | Very strong | Yes  | Yes         |
| Cavern   | Selection state for sphere in energy sphere | Cube moved into energy sphere | Strong      |      | Yes         |
| Cavern   | Selection state for decrease in force field | Cube moved into energy sphere | Strong      |      | Yes         |
| Cavern   | Selection state sound for platform          | Platform                      | Medium      |      |             |

Table 2: Overview of selected audio files for the prototype

When all the needed sounds were in place, it became apparent that some of them would need to be slightly altered to better fit the presented narrative. E.g. some of the ice cracking audio files had the sound of some running water in them, which would not fit the narrative of an icy planet. This was removed with a low-pass filter. While some audio files needed to be shortened, and some needed a reverb filter to emphasise Audacity and Sonic Visualiser was used to analyse and add changes to the audio files. The final redacted and edited audio list can be seen in appendix F.

Also, the recorded narrator voice lines from the second iteration, needed an update to fit the tutorial for when the game experience would be with the hand held controller interaction method. Here the presented

*"bionic eyes"* were changed to *"bionic hands"*, and half of the voice recordings needed to be updated accordingly. The final result of this can be seen in appendix G.

When all of the audio files were in place, the final implementation of the sounds in the prototype began. Here they would be adjusted according to the suggested amplitude level, set to looped if needed and spatialised if it would make sense to have the localisation of a sound in the environment. A in-house testing of the selected sounds was conducted, and some needed to be removed, changed and altered. Finally, it should also be noted that the wayfinding sound cue for the ledges, was especially aided by the effect of sound spatialisation. This would hopefully mitigate the problem of getting disoriented, like some participants experienced in the test of the second iteration [Section 5.5.2].

## 6.4 Implementation

This section will explain the changes made to the implementation based on the new design requirements of the prototype defined for the third iteration [Sections 6.2].

First of all, from direct observation of test participants along with in-house testing, it became evident that the telekinesis movement had to feel more natural. It had proved to be buggy and slightly intrusive when colliding the selected object with other colliders like the walls or the floor. This was fixed by moving the objects in a more physics based approach, rather than directly changing the position of objects in 3D space. Listing 13 contains the code that enabled this functionality. The reason for the buggy collisions is due to the fact that when the collisions were happening, the user was also trying to move the object. This created a clash between trying to stop the object through collision and the user manipulating it. By moving objects solely through physics based approach, it would allow collisions and object movement to work together cohesively. Additionally, a ray is also to be cast from the selected object and its target position. If there is an object in between, then the target position would then become the hit point of the intruding object. The speed in which objects moved around with telekinesis was also modified to be dependent on the selected object's mass. The bigger the object, the higher the mass, resulting in a lower movement speed.

```

1 // get the direction of the ray (target position - selected object's position)
2 Vector3 direction = telekineticTransform.transform.position - grabbedObject.transform
3 .position;
4
5 // create a ray from the selected object with the calculated direction
6 Ray ray = new Ray(grabbedObject.transform.position, direction);
7
8 RaycastHit hit;
9
10 // if the ray hits any collider (collidable object) on the way, then change the new
11 // target position to the point where the hit of the ray happens
12 if (!Physics.Raycast(ray, out hit, direction.magnitude))
13 {
14     // linearly interpolate the position of the grabbed object between the selected
15     // object and its target position by a step dependent on its mass, using the rigidbody's
16     // MovePosition method
17     rb.MovePosition(Vector3.Lerp(grabbedObject.transform.position,
18         telekineticTransform.position,
19             moveStep / rb.mass));
20 }
21 // else if the ray doesn't hit any colliders in between, move the object towards the
22 // target position
23 else
24 }
```

```

19     {
20         // linearly interpolate the position of the grabbed object between the selected
21         // object and its target position by a step dependent on its mass, using the rigidbody's
22         // MovePosition method
23         rb.MovePosition(Vector3.Lerp(grabbedObject.transform.position, hit.point,
24             moveStep / rb.mass));
25     }

```

Listing 13: Change the movement of objects to a more physics based approach

Real life blinking of the player's eyes was also a problem when moving an object around. The selected object would move towards the eyes' gaze, however, when the player is blinking the data for the eyes is invalid. The object would therefore jump to the origin of the scene and back when the user reopened their eyes. This was solved as shown in Listing 14 by using a method available in Tobii XR's SDK that checks whether or not the gaze ray is valid.

```

1
2     // Check if gaze ray is valid
3     if (eyeTrackingData.GazeRay.IsValid)
4     {
5         eyeOrigin = eyeTrackingData.GazeRay.Origin;
6         eyeDirection = Vector3.Normalize(eyeTrackingData.GazeRay.Direction);
7     }

```

Listing 14: Check if the player's gaze ray is valid

The process in which the user changes focus between objects to move around was also changed from a custom implementation, to use Tobii XR's interface *IGazeFocusable*, which has a method *GazeFocusChanged()* that is called every time a game object containing this script goes in or out of the user's focus. Line 3 in Listing 15 shows that the *GazeFocusChanged()* method has a *hasFocus* boolean parameter, which states whether or not the object currently has focus. This new approach of switching between the object selection states allowed for a more bug-free feedback of the interaction with the prototype's selectable objects.

```

1
2     // The method of the "IGazeFocusable" interface, which will be called when this
3     // object receives or loses focus
4     public void GazeFocusChanged(bool hasFocus)
5     {
6         // if the testing is not using the HTC VIVE Pro Eye stop executing the rest of
7         // the method
8         if(Testing.Instance.eyeTracking != Testing.EyeTracking.HTC) return;
9
10        // if the user already is grabbing an object, stop executing the rest of the
11        // method
12        if(Testing.Instance.Telekinesis.grabbedObject) return;
13
14        // This object either received or lost focused this frame, as indicated by the
15        // hasFocus parameter
16        if (hasFocus)
17        {
18            print(gameObject.name + " is focused by the user");
19            // if this object is already selected, then return
20            if(isSelected) return;
21            // if not, then set the object to focused
22            Focused();
23        }
24        else
25    }

```

```

21     {
22         // else if it's not focused, change this game object's selection state to the
23         // default state
24         Default();
25         Testing.Instance.Telekinesis.focusedObject = null;
26     }

```

Listing 15: Focus mode

Traditional VR input controllers had to be implemented to be able to do the comparison between eye tracking versus VR controllers in dashing and telekinesis. This proved to be a very simple change, as shown in Listing 16. When it came to the user testing the controller input, the raycast is changed to use the hand position as the origin of the ray and the forward vector as the ray's direction. Additionally, the user would have more feedback to the place they're pointing at, displayed as a laser pointer. The latter is provided by the Steam VR package as a *SteamVR\_LaserPointer* script, as shown in line 6 of Listing 16.

```

1 // if the player is using the controllers instead of the eyes in the current test
2 case Testing.EyeTracking.Controllers:
3 {
4     // enable the laser pointer
5     hand.GetComponent<SteamVR_LaserPointer>().enabled = true;
6     // use the hand's position in world space as the eyes's origin instead
7     eyeOrigin = hand.transform.position;
8     // use the hand's normalized vector representing the blue axis of the transform
9     // in world space as the eye's gaze direction instead
10    eyeDirection = hand.transform.forward;
11    // use the updated hands 3D vector positions for creating the cast gaze ray
12    // instead of the eyes'
13    GazeCast(eyeOrigin, eyeDirection);
14    break;
}

```

Listing 16: Eye gaze origin direction replaced with the VR handheld controller

Furthermore, the wayfinding cues previously were static point lights on each ledge of the canyon. It was decided to have these lights animated and a spatialised audio cue to play, as mentioned in [Section 6.3.3]. This would further help the player to find their way through the level. When the user reaches a ledge, the point light illuminating that ledge would fade out and the following ledge's light would fade in and the audio would play.

To achieve this a script was created named *TheMasterManager.cs* in which the integer *positionIndex* was checked each frame. When the player would enter the trigger box of the ledge, it would increment this value. This would in turn, fade the next ledge's light in, seen on line 12 of listing 17 and fade the current ledge's light out, seen on line 22. The audio would then play at the location in a similar way as described in the second iteration, [Section 5.4].

```

1 // called every frame
2 private void Update()
3 {
4     // if the position index is still within the bounds of the lights array
5     if (positionIndex < lights.Length)
6     {
7         // increase the intensity of the next ledge's light if it exists
8
}

```

```

9         if (lights[positionIndex + 1].intensity <
10            helpers[positionIndex + 1].transform.GetComponent<AudioTrigger>().
11            lightIntensity)
12            {
13                lights[positionIndex + 1].intensity += fadeSpeed;
14            }
15        // check that the player's position is a ledge that comes after the first one
16        if (positionIndex > 0)
17        {
18            // if the intensity is higher than 0, decrease it
19            if (lights[positionIndex].intensity > 0)
20            {
21                lights[positionIndex].intensity -= fadeSpeed;
22            }
23            // if it's not, deactivate the light
24            else
25            {
26                lights[positionIndex].gameObject.SetActive(false);
27            }
28        }
29    }

```

Listing 17: The Master Manager was responsible for advancing the wayfinding cues

Last but not least, the puzzle had to be implemented. A trigger box was first placed on the *ring* of the puzzle where the user must stand to solve the puzzle, as mentioned in [Section 6.3.2]. If the player is detected within this trigger [Listing 18, line 3], then the materials of the *ring* can be changed to provide positive feedback, seen on line 6. If the user then proceeds to pick up the *key*, the *orb* material's Fresnel can be changed and an audio cue played to provide further feedback, seen on lines 12 to 14.

```

1 // if the player is standing inside the ring
2 if (ring.onTrigger)
3 {
4     // change the emission property of the ring material to 1.5, where "Em" is the
5     // emission property of the shader.
6     ring.materials[1].SetFloat("Em", 1.5f);
7     // if the right key is not null, then set the emission on the material of the
8     // right orb to 0.6
9     if(key) key.material.SetFloat("Em", 6.0f);
10    // if the right key is selected, then play its audio source and the orb's fresnel
11    // power is increased
12    if (key.isSelected)
13    {
14        keyRightAudioSrc.Play();
15        orb.material.SetFloat("FresnelPower", 1.5f);
16        orb.material.SetFloat("Em", 10.0f);
17    }
18    // else if it's not selected, if there is an audio source available then stop it,
19    // and also change the fresnel power and emission of the material on the right wormhole
20    else
21    {
22        if(key AudioSource) key AudioSource.Stop();
23        orb.material.SetFloat("FresnelPower", 0f);
24        orb.material.SetFloat("Em", 5.0f);
25    }
26}

```

Listing 18: An example of how the materials are changed depending on where the user is in the puzzle

Below in listing 19, the final logic of the puzzle and the prototype is shown. If both *orbs* are solved the forcefield's material is given an alpha of zero (line 6), and the VFX of the *warpcore* will begin to increment in size. On lines 17 to 20, the  *AudioSource* of the *warpcore* will then begin to loop the sound effect detailed in [Section 6.3.3]. The  *WaitForEnd()* coroutine begins, which waits for a set number of seconds before displaying a simple canvas to the user, thanking them for testing and suggesting that they may remove the headset whenever they want.

```
1 // if the player placed both of the objects correctly
2 if (leftWormhole.correct && rightWormhole.correct)
3 {
4     // Forcefield gone and expand the core
5     forcefieldR.material.SetFloat("Forcefield_Speed", 0.00f);
6     forcefieldR.material.SetFloat("Forcefield_Alpha", 0.0f);
7     coreSizeMultipliyer += sizeChangeInterval;
8
9     // if it's not finished yet, wait until it finishes
10    if (!finito)
11    {
12        StartCoroutine(WaitForEnd());
13    }
14
15    if (!full)
16    {
17        full = true;
18        shieldSrc.clip = complete;
19        shieldSrc.loop = true;
20        shieldSrc.Play();
21    }
22}
```

Listing 19: Final puzzle logic

## 7 Evaluation

### 7.1 Evaluation of Game Experience

Following the implementation of the eye tracking interaction method along with the controller based method into a VR game, an evaluation of the game experience was to take place. The main goal of this evaluation was to determine whether participants had significantly different experiences with different interaction methods. Furthermore, if a significant difference exists, which method is preferred by the users, and in which subscale of the game experience does the difference emerge. This should provide insight into how does interaction methods affect the gaming experience. Specifically, while this testing would most likely not provide a conclusive answer to the FPS [Section 2.4.1] of this project, it could help determine if eye tracking as a novel interaction technique has a positive or negative effect on the game experience of VR games.

#### 7.1.1 Testing Method

As discussed earlier in the methods [Chapter 3], the finished prototype of the project will be evaluated through a repeated-measure experimental design. The decision to select this experimental design was made due to its economical nature and sensitivity to detect effects that are the result of the manipulation of the independent variable. It is more economical than other designs because participants can be used several times. Using the same participants in all conditions of the study is also what makes it more sensitive, because it decreases random variations that could potentially obscure the effect of the manipulated variable.

While the within-group design minimizes random noise and is robust, there are disadvantages that should be considered. The main drawback of such a design is the so called *carry-over effect*. This effect refers to the issue, where the manipulation of the independent variable may not have had any effect on the participants behaviour or experience yet they still give marginally different responses in the different experimental conditions. I.e. participants gaining practice when undergoing the experiment the first time, which will carry over to the next experimental condition. Other examples include getting bored, or getting tired. A way to tackle the effects of these systematic confounding variables, can be to counterbalance the order of experimental conditions. Entailing, that half the participants would start the experiment with condition A, or the controller interaction method and then proceed to condition B, the eye tracking assisted interaction method. For the other half of the participants the order would be reversed to start with B and then move on to condition A. Through this method, the order of conditions also becomes an independent variable, that is manipulated by the experimenter. Hence, it can be incorporated into the statistical analysis of the data [23].

To construct and more accurately describe the experiment that is to be conducted, the following section will define the variables of the testing. The FPS [Section 2.4.1] of the report inquires about "*How does eye gaze assisted telekinesis and dash effect the game experience of virtual reality games compared to handheld controllers?*". From this statement, it can be determined that the variable which is to be manipulated is the interaction method. In other words, **interaction method** is the **independent variable** of the experiment. Thus, the **dependent variable** on which the independent variable or **cause** has an **effect** on would then be the **game experience** [23].

To put into context, participants of the experiment will partake in a VR game experience that was developed and implemented throughout this project. The game can be played with two different types of interaction methods. One is the eye gaze assisted method, while the other is the more traditional hand-

held controller-based method. The interaction method that the participants will be subjected to first is counterbalanced. Participants of the test should be randomly and independently drawn. Counterbalancing is applied to reduce the effects of confounding variables, such as familiarity with VR games or eye tracking technology in VR, age and gender. For sampling the non-probabilistic method of convenience sampling will be utilised.

The **null hypothesis (H0)** of the experiment is defined as follows:

*There is no difference in game experience between using eye tracking assisted and controller based interaction methods.*

While the **alternative hypothesis (H1)** states:

*There is a difference in game experience between using eye tracking assisted and controller based interaction methods.*

## 7.2 Outline of Test Requirements

The requirements of the testing procedure are specified to be the following:

### Testing Environment

- Multisensory Experience lab at Aalborg University Copenhagen
- An area separated where participants can fill out the questionnaire without being observed

### Equipment for Testing

- HTC Vive Pro Eye HMD
- The headset's built-in headphones
- HTC Vive base stations
- One HTC Vive Controller
- A computer to run the VR HMD
- A computer to where participants can fill out the consent form and questionnaire

### Documents for Testing

- Consent Form [Appendix H]
- GEQ questionnaire
- Scoring sheet to record the choices of participants

### Miscellaneous

- Hand sanitizer
- Cleanbox (VR HMD smart tech hygiene solution for decontamination)
- Alcohol Wipes

This sums up the requirements for the testing procedure. Miscellaneous items were used to keep equipment clean in accordance with the regulations set by Aalborg University to prevent the spread of COVID-19. The next section of the report will precisely elaborate on how the process of the testing should look.

### 7.3 Process of Testing

As discussed above, the experiment is a repeated measure design. Each recruited test participant will partake in the the implemented VR game experience of this project twice. Once with the eye tracking assisted interaction method, and once with controller based interaction method. The earlier segments of the report discussed how the construction of the game was done according to player experience and core game elements theory. This was done so that the **ecological validity** of the experiment can be maximised, and the experience of an actual game can be measured rather than just recording scores of a person put in a regular VR environment with monotonous activities.

Participants are first given a brief introduction to the scope of the experiment. Followed by filling out a consent form [Appendix H] to ensure willing participation, and communicate that all information is treated confidentially. Afterwards, the test conductor explains what each button on the HTC Vive controller [Figure 8] is referred to as, so that participants are able to understand what the narrator voice lines in the tutorial are referring to. After the demo of the controller, participants will be informed by the conductor which interaction type they will be starting with. If it is the eye tracking assisted method, the headset will be calibrated using the integrated Tobii software in Steam VR to calibrate according to the participants eyes, and ensure the right accuracy and efficiency of the eye tracker.

Participants are told that if they feel like they need a hint, assistance, or guidance with the game, they can ask the test conductor. Once the controller demo, calibration and introduction is complete, the participants are asked to freely explore and experience the game scenario. After finishing with the first interaction method, participants will be asked to fill out the extended GEQ in-game questionnaire that can be seen in appendix J. Giving test scores is a private activity, that could potentially be influenced by the test conductor observing the participants, therefore an isolated location will be offered to complete the questionnaire. Following the completion of the GEQ after the first interaction technique, participants will be asked to go through the game experience once more, with the other interaction method. Upon completion, the extended in-game GEQ will be filled out once again by the participants. This concludes the testing procedure of the third and final iteration.

## 8 Results

A total of 30 participants ( $n=30$ ) took part in the final testing of this project between the 3rd and 4th of December 2020. Age of the participants ranged between 20 to 30. 10 participants were female, while the other 20 were male. 15 participants had previous experiences with eye tracking used for interaction in VR, while the other half had never used this technology. 63% of participants have played VR games a few (1-5) times before, while 17% used it some (6-15) times before and the remaining 20% had played VR games a lot (15+) of times prior to the testing.

Appendix K shows the scores of every participant after testing each interaction method.  $IM$  stands for the interaction method with which the participants scored the results that follow.  $C$  stands for controller, and  $E$  stands for eye tracking, denoting the interaction methods. The following headings adhere to the subscales presented in the GEQ:

- Competence (Comp.)
- Sensory and Imaginative Immersion (Sens I. I.)
- Flow
- Tension
- Challenge (Chal.)
- Negative affect (Negative)
- Positive affect (Positive)

The last two column headers are travel and selection & manipulation (Selection M.), and each of them refer to the control subscale that has been added from another categorisation of game experiences. As discussed in the analysis, this categorisation is largely based on the GEQ. It was further broken down into two subscales to measure if the two separate 3D interaction techniques with the different input modalities result in different effects, rather than just taking control as a whole. Therefore it can be detected if dash or telekinesis is preferred with the controller or the eye tracking.

Each subscale has two corresponding questions that can be answered on a 5-point intensity-based unipolar scale. The scores that can be seen in appendix K are calculated by taking the average of these two ratings. On five of the scales the higher the score the participants give the better their experience was, while the other two subscales are related to negative experiences. These are negative affect and tension, and higher scores here mean a worse experience.

The final scores of each factor per interaction method were calculated by taking the average of all participants scores in that specific subscale. An overview of these results, and a visual data representation consisting of bar charts with interquartile range for display of error rate can be seen in table 3.

|                                | Comp.  | Sens. I.I. | Flow  | Tension | Chal.  | Negative | Positive | Travel  | Selection M. |
|--------------------------------|--------|------------|-------|---------|--------|----------|----------|---------|--------------|
| <b>Eye tracking Controller</b> | 2.70   | 3.17       | 2.95  | 0.78    | 2.22   | 0.47     | 3.32     | 2.13    | 2.95         |
|                                | 2.76   | 2.96       | 2.93  | 0.67    | 1.75   | 0.59     | 3.07     | 2.98    | 3.37         |
| Diff.                          | -0.06  | 0.21       | 0.02  | 0.12    | 0.47   | -0.13    | 0.25     | -0.85   | -0.42        |
| Change %                       | -2.15% | 6.93%      | 0.63% | 17.70%  | 26.88% | -21.39%  | 8.11%    | -28.40% | -12.41%      |

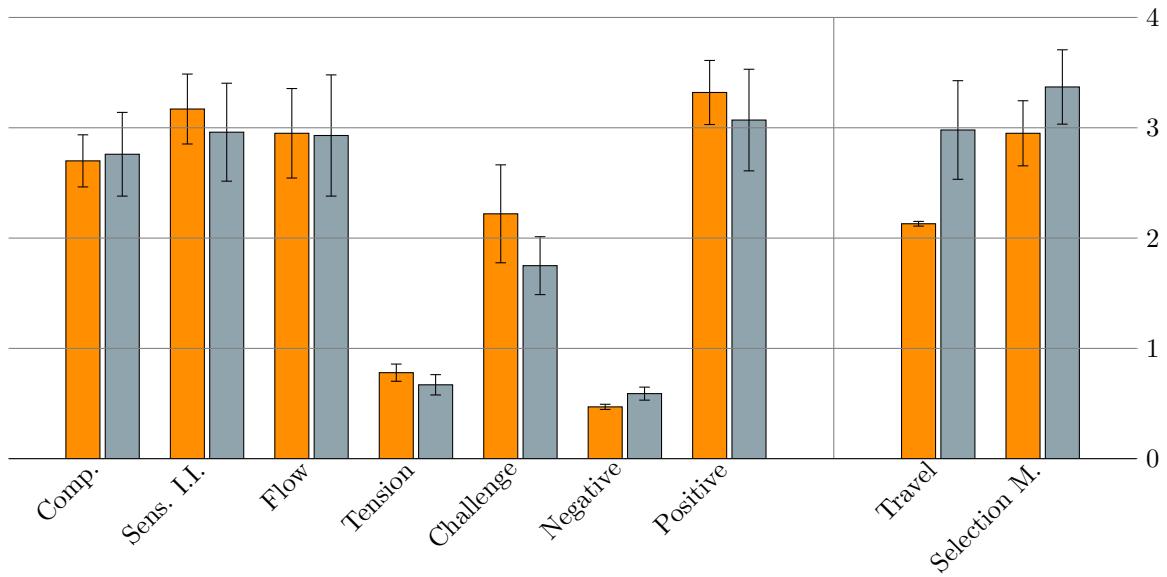


Table 3: GEQ scores with the two added subscales of *travel* and *selection & manipulation*. Interquartile range indicates the error rate

## 8.1 Evaluating Assumptions

Parametric testing methods are preferred most of the time due to the fact that these methods have more power to detect experimental effects. There also exists a larger selection of parametric tests to choose from. However, to be able to employ parametric tests, certain assumptions must be met. Because parametric tests work on the arithmetic mean, the data on which these tests are performed must be measured on a ratio or interval level [23]. The GEQ measures on an interval level, therefore this assumption is met [54].

Another assumption for parametric tests is that the data comes from a population with a normal distribution. Since the GEQ scores will be compared on a subscale level, the distribution of each data set should be investigated with a Shapiro-Wilks test of distribution. Furthermore, the assumption of homogeneity of variance should be tested using Levene's test. This assumption refers to comparison groups having the same variance [23].

The results of the Shapiro-Wilks and Levene's tests can be seen in appendix I. While the results of the Levene's test met the assumption of homogeneity, the Shapiro-Wilks test showed that most of the data in the subscales does not come from a normal distribution. In conclusion, because not all of the assumptions are met a non-parametric tests must be used to evaluate the results. Specifically, the Wilcoxon Signed-Rank Test is going to be utilised. This method of non-parametric statistical evaluation is used to test differences between groups when an experiment has two conditions and the same participants experience both conditions. Because non-parametric methods test differences between ranks rather than means, outliers are not affecting the data. Therefore, there is no need to remove or plot outliers [23]. Furthermore because the alternative hypothesis does not assume the direction of the effect, a two-tailed test is going to be used. The following section will discuss the results of the Wilcoxon Signed-Rank test.

## 8.2 Results of the Wilcoxon Signed-Rank Test

The Wilcoxon Signed-Rank test was performed to analyse the results from each subscale of the GEQ with the controller interaction method and with the eye tracking assisted method. The aim of test was to see if the eye tracking assisted method had a significant affect on any of the dimensions of the game experience. Results of the test for each subscale can be seen in table 4.

|           | Comp. | Sens. I.I. | Flow  | Tension | Chal. | Negative | Positive | Travel | S. & M. |
|-----------|-------|------------|-------|---------|-------|----------|----------|--------|---------|
| Statistic | 113   | 136        | 186   | 40      | 71.5  | 155      | 161      | 105    | 106     |
| P-value   | 0.443 | 0.951      | 0.942 | 0.146   | 0.004 | 0.838    | 0.497    | 0.042  | 0.122   |

Table 4: Results of the Wilcoxon Signed-Rank test for each subscale

For the statistical evaluation of this project an alpha level of 5% was set ( $/alpha = 0.05$ ). If the P-value is under the alpha value a significant difference is detected. In other words  $H_0$  can be rejected in favor of  $H_1$ . On the other hand, if P-value is larger than the set alpha, no significant difference can be declared, and  $H_0$  cannot be rejected.

**Competence** with the controller ( $\bar{X} = 2.66 \pm 0.91$ ) scored slightly lower than competence with the eye tracking assisted method ( $\bar{X} = 2.81 \pm 0.82$ ), however the test detected no statistically significant difference ( $T = 113, p = 0.443$ ). As earlier discussed in the analysis, competence and control are related concepts. Competence is associated with feelings of accomplishment, euphoria and pride while control has components of autonomy and power [54].

**Sensory and imaginative immersion** for the controller ( $\bar{X} = 2.85 \pm 0.96$ ) was once again lower by a very small amount than the eye tracking ( $\bar{X} = 2.90 \pm 0.85$ ), but there was no statistically significant difference ( $T = 136, p = 0.951$ ). This subscale is the combination of two immersion types. Sensory immersion refers to the aesthetics of a game, while imaginative immersion relates to the narrative element of a game [54].

**Flow** was yet again only marginally smaller for the controller ( $\bar{X} = 2.90 \pm 0.90$ ) compared to the eye tracking ( $\bar{X} = 2.93 \pm 1.01$ ), and therefore no statistically significant difference was found ( $T = 186, p = 0.942$ ). Flow, or the state of total absorption is related with experiences of loosing track of time and space as due to high concentration [54].

**Tension** had a somewhat greater score for the eye tracking ( $\bar{X} = 0.86 \pm 0.88$ ) than the controller ( $\bar{X} = 0.55 \pm 0.91$ ), but still not a statistically significant difference ( $T = 40, p = 0.146$ ). The experience of tension is associated with negative emotions, such as restlessness, frustration and being annoyed [54].

**Challenge** for the eye tracking ( $\bar{X} = 2.18 \pm 0.92$ ) seemed to score much higher than the controller ( $\bar{X} = 1.46 \pm 1.07$ ), and the Wilcoxon test detected a statistically significant difference in this subscale ( $T = 71.5, p = 0.004$ ). Challenge is a component of the gaming experience that keeps players engaged, and therefore it is tightly related to the subscale of flow. Challenging a player causes arousal, and a strong will to win can arise [54].

**Negative affect** for the controller ( $\bar{X} = 0.56 \pm 0.81$ ) was virtually the same as for the eye tracking ( $\bar{X} = 0.55 \pm 0.74$ ), and **positive affect** was also fairly close between the controller ( $\bar{X} = 3.06 \pm 0.81$ ) and the eye tracking ( $\bar{X} = 2.88 \pm 0.84$ ). Neither for negative affect ( $T = 155, p = 0.838$ ) nor for positive ( $T = 161, p = 0.497$ ) was there a statistically significant difference. This subscale encompasses emotions of anger, irritation and shame [54].

The last two subscales together constitute the **control** dimension, that was involved to specifically compare the experiences of travel and selection & manipulation with eye tracking to the controller.

**Travel** with the controller ( $\bar{X} = 3.11 \pm 0.83$ ) scored quite a bit higher than with the eye tracking ( $\bar{X} = 2.58 \pm 0.95$ ). The results show that there is a statistically significant difference in this factor ( $T = 105, p = 0.042$ ) [54].

**Selection & manipulation** for the controller ( $\bar{X} = 3.41 \pm 0.60$ ) resulted in a somewhat higher score than that of the eye tracking ( $\bar{X} = 3.16 \pm 0.79$ ), and there was no statistical difference identified ( $T = 106, p = 0.122$ ). These two last subscales were added to probe to what extent dashing and telekinesis allowed for player to make the game their own. Performing one's will in the game is key in reaching ownership, and feeling competent [54].

In summary, for seven out of the nine game experience factors, namely for competence, sensory and imaginative immersion, flow, negative affect, positive affect, tension and selection manipulation the null hypothesis could not be rejected, concluding that there is no significant difference in experiences between eye tracking and controller interaction methods. On the subscales of travel and challenge the null hypothesis could be rejected in favor of the alternative hypothesis. Eye tracking seems to be more challenging for users, and controller is the preferred method for travel based on the experiences of users.

The Jupyter notebook with the evaluation of assumptions, descriptive statistics and calculations of the Wilcoxon Sign-Ranked test for each subscale can be seen in appendix I.

## 9 Discussion

A discussion on this research project's approach, process and achieved results will now be presented drawing inspiration from the method of a SWOT/SOAR analysis. It will be based on the following questions:

- What do the achieved **results** show and how can they be interpreted? [Section 9.1]
- Which **weaknesses** exist for the project? [Section 9.3]
- What are the project's main **strengths**? [Section 9.2]
- What **opportunities** does the project indicate for future work? [Section 9.4]

### 9.1 Results

The aim of this research project was to investigate what effect does a novel form of interaction, specifically eye tracking, have on the game experience of players in VR. To be able to discern effects of the interaction, the more traditional and widely adopted VR controller was used as a benchmark to measure how eye tracking does in comparison. The results of the experiment showed minimal differences between most subscales of the game experience when using a controller versus the eye tracking assisted interaction. In fact these differences were so slight, that no statistically significant difference could be established.

These results can be addressed from different perspectives. Eye tracking is not a widely adopted interaction method in VR headsets. The first commercially available VR HMD with integrated eye tracking, the HTC Vive Pro Eye came out in the first half of 2019 [21]. Since then, there has only been a few more headsets following the lead of HTC [69]. Because of its limited availability, for half of the participants in the study this experiment was one of their first encounters with eye tracking technology in VR [Appendix K]. This could have introduced certain biases, when performing the test. For example, because people are more familiar with the use of a controller they would be more inclined to prefer that as an interaction method. The novelty of eye tracking could have skewed the responses in a similar fashion. However, just by simply looking at the results it could be concluded that eye tracking performed just as good as the controller in most subscales.

There were two subscales where a significant difference was detected. In the challenge subscale the eye tracking performed better. According to the GEQ, challenge is related to the difficulty of a game, and is associated with how much concentration is required. On one hand, the more difficult a game, the more concentration is required - which can be a positive aspect of game experience. Matching difficulty and challenge to player skill level is a crucial pillar of achieving the sensation of flow for the user. On the other hand, the GEQ reports that when games get too difficult people tend to give up. This sense of defeat could result in a negative experience. In the development of the GEQ it was also discovered, that a lack of challenge is also associated with negative emotions and experiences such as *disappointment* and *frustration* [54]. Also to be noted, is the score for eye tracking in the challenge subscale had a mean value quite close to the middle of the scale. Thus, it could be argued that the eye tracking is a more challenging form of interaction and therefore could perhaps offer a better game experience.

The other part of the GEQ results where there was a significant difference was the subscale of travel. This added subscale relates to the dimension of control, that was explored in the analysis in relation to game experiences. A low score in control, could arguably mean that the player is incapable of manipulating the game. And, therefore they cannot perform actions through which they would take ownership of the game. Not being able to execute their own will in the game experience, could mean that they cannot

make the experience their own. Thus, a high rating in the control dimension - could indicate that more players took ownership of the game experience. Dashing with the eye tracking scored notably lower than controller. Hence, it would seem that the controller was able to offer a better experience to players.

Examining the selection & manipulation subscale, one of the reasons why there was not a noteworthy difference, might have been because the eye tracking assisted telekinesis was not a purely 2-step interaction, like with dashing. The implementation of the eye tracking assisted telekinesis involved the movements of the controller, which in some cases seemed to dominated the interaction. Had a more eye tracking focused implementation been created, the results might have offered a more significant difference. Alternatively, different results could have been also achieved if eye tracking was only used for selection, but not for manipulation. This could have potentially made the selection of objects users want to interact with much faster while retaining a more gesture-based approach for the manipulation.

Also one could argue, that with a larger sample size, there would be more significant differences detected. Additionally, as the project aimed to achieve a high ecological validity, test participants might have been focusing less on the interaction methods themselves, and more on the aesthetics and tasks at hand.

## 9.2 Strengths

Based upon the previously detailed results, and overall process of this project, the strengths will be presented in this section. First of all, even though the H0 could not be rejected in favour of H1, as it was presented in [Section 9.1], the obtained results do seem auspicious. As it has been detailed previously, eye tracking based interaction did achieve remarkably similar results compared to traditional controller based input. In fact, eye tracking did achieve better scores compared to the controller based input method in five out of the nine subscales. Although, these were not statistically significant enough to reject the H0, except from the challenge subscale. Thus, there was no statistical difference in most of the compared subscales. Nonetheless, introducing a novel interaction method which conceivably enhances the aspect of challenge in a VR game experience, is a noteworthy finding of this study. As introduced in the analysis [Section 2.3.2], the aspect of challenge in a game is an important element of game experience. And, seeking challenges plays a notable part for many when gaming.

The aforementioned results indicate that the designed and developed eye gaze based novel interaction methods performed relatively similarly to handheld controllers in a VR gaming experience. This could be considered a positive outcome, since traditional controller based input has been under development for years and it is well-known control mechanic of VR games. Thus, creating a novel interaction method within several months achieving similar results could be judged promising. Furthermore, this could indicate that the learnability of the eye gaze based interaction technique is fairly high. However, without any quantitative or qualitative proof this is still a assumptive theory. As the prototype was developed through an iterative process, formative evaluations were carried out at the end of each iteration [Section 4.5.1] [Section 4.6.2] [Section 5.5] [Section 7.1]. From these four tests, it seems that the prototype and the interaction method of using the eye tracker, continuously improved. Thus, one could argue that with further iterations, more significant differences between the two interactions method could appear.

To properly evaluate whether eye tracking based interactions in VR games could elevate the game experience, a high fidelity game experience prototype was created. Throughout the process of design and development the level of fidelity kept rising. Even though it is difficult to precisely pinpoint where the limit is set, in regards of categorising the prototype as a game, the finished experience seems to have met the suggested requirements from the analysis [Section 2.3.1]. Henceforth, this relatively high production value prototype, helped to provide a medium for evaluating game experience. This approach also seems to have helped enhance the ecological validity of the project. Arguably, conducting a comparative in-

teraction method research experiment on game experience with a low-fidelity prototype could yield less correlation to real-world scenarios.

Also to be noted, was the many positive comments and feedback given from test participants on the project. The prototype seems to have offered a high rate of enjoyment among test participants. From the qualitative data gathering at second iteration, it became apparent that most participants found the eye tracking based input enjoyable and a fun way of novel interaction [Section 5.5]. This is an affirmative answer on the research topic of integrating eye gaze based interaction in VR games, as enjoyment does play a momentous role in said topic. Despite the encouraging feedback collected in post-test interviews, a proper comparative evaluation of enjoyment could further investigate this theory.

To round up this section, the project group finds the most noteworthy achievement of the prototype to be the interaction of **selection** with eye gaze. Selection played a significant role in telekinesis as a selection & manipulation technique [Section 2.2.1.1] and in teleportation as a target based travel technique [Section 2.2.2]. In both cases, users pointed out that selecting objects or targets with their eyes felt intuitive, fast, easy and natural [Section 4.5.1] [Section 4.6.2] [Section 5.5]. This could probably have been an important factor in the inducement of the overall enjoyment of the experience. However, it needs to be addressed that eye gaze based selection found to be less precise and inadequate for longer distances. Weakness like these, will be further discussed in the following section.

### 9.3 Weaknesses

To begin with, it could be argued that studying the individual interaction methods separately, would allow for a more in depth and extensive research. Meaning that one would make a separate research experiment for both the *selection & manipulation* (telekinesis) and the *travel* (dashing). With this in mind, focusing on one of these topics could have led to test results yielding more significant differences, than the aforementioned experiment results.

Furthermore, due to the nature of the GEQ test, the obtained results might not represent the appropriate value of this novel interaction, as it was mentioned earlier [Section 9.1]. Even given the fact, that it was set out to investigate whether a novel interaction method could impact on the game experience, an evaluation method with a focus on the actual interaction could have detected a more distinguishable difference. Additionally, as the prototype's relative high production value was intended to provide a medium for evaluating game experience, it could have simultaneously introduced more disturbances in the experiment. Therefore, detecting a statistically significant difference could have been presumably more evident via a more simple and less detailed prototype for testing environment.

It is also important to mention the accuracy of the Tobii XR's eye tracker. For long range distances and small objects, it is both stated on their official documentation website and from the results of the tests conducted throughout the project, that raycasting from the eyes is not pixel sized accurate, nor the best representation of how the eyes work in real life [68]. This might be one of the reasons that the players, while going through the game experience, may have found the eye tracking interaction more inaccurate. Thus, less comfortable to use in comparison with pointing with the VR controllers. Changes to the design of the level to improve accuracy of the tracked eyes' raycast, could possibly have helped mitigate this problem. There are a variety of options to accomplish this, e.g. the colliders on the selectable objects could have been increased in size. Thereby increasing the chance of the user's eyes raycast hitting said colliders. However, this approach would come with other drawbacks, such as the fact that colliders that are bigger than their actual rendered meshes may overlap with other meshes.

Another possible variance for the design of this project's game experience is reducing the scale of the

environment to an overall smaller size. As the ledges and objects are smaller, the accuracy of the eyes could have varied for the better. However, there is an alternative solution suggested and provided by Tobii XR, called the *Tobii G2OM* (Gaze-2-Object-Mapping) [68]. This object mapping solution improves the reliability of raycasting by using, as stated in their documentation: "*a machine-learned selection algorithm, accurately predicting what the user is looking at*" [68]. Taking advantage of this algorithm could have had an effect in the results of this project's research experiments.

Furthermore, as mentioned in the analysis, the eyes are not organs evolved for manipulation of objects. They are merely perceptual. Therefore, even though eye tracking can have a favourable contributing factor to selection of objects, this prototype also attempted to research its ability to manipulate objects. Telekinesis of objects requires not only the selection of objects, but also moving them around, whereas the hands evolved specifically for the manipulation of the environment. It is therefore trivial that the use of VR controllers for moving objects around may feel more natural and intuitive for users. The hand controllers may also allow more precision in long range pointing at small objects, whereas the eye tracking provides with more speed of movement, in regards of this project's dashing and telekinesis.

Another factor worth mentioning, is that this prototype did not include system control in the experience. Not only could researching the effect that eye tracking has on the selection of UI elements have interesting results, but it could have also altered the game experience of the users. As an example, system control could enable the functionality for changing the sound effects of different elements in the game. Moreover, players could have had the ability to take a look at the button controls and interaction options, or the ability to restart the game whenever they desired. However, even though adding system control could have had an effect on the experience, it is true that it could have added more confounding variables for the correct evaluation of the experiment. More about the system control will be specified in the opportunities discussion of this project [Section 9.4].

Last but not least, bugs in the prototype's implementation were discovered during the execution of the final experiment. Had it been a completely bug-free code, the player's experience may have been different, favouring the project in terms of the user's game experience.

## 9.4 Opportunities

Areas of this project could be improved and built upon in the future. Notably, the GEQ used was limited in the sense the user only had 4 intervals in which they could rate their response to each question. A test with different methods, or a more elaborate scale, e.g. ranging from 0 to 100, could reveal more slight nuances that remain unseen in the current results.

The prototype was designed and built with eye tracking in consideration. It could prove interesting to design more diverse challenges within the game scenario, and measure how well eye tracking works as an input method for each, compared to traditional input. E.g. the project group suggests that X-ray vision in a game scenario, could be an interesting route to explore for future research.

It is worth noting, although this project explored multiple ways of combining the eyes with other modalities for telekinesis, there are certainly several more ways of implementing an eye gaze based telekinesis interaction. A gesture elicitation study on this topic, could provide many new ideas going forward, and present a revised version of telekinesis. Another potential approach to explore more methods of implementing eye gaze based superhuman interactions would be to analyse novel interactions occurring in science fiction movies.

System control was absent in the developed prototype, due to the scope of this project. In a future higher fidelity version, this could prove to be a consistent third layer of interaction for the eye tracker. Although

in a testing environment, options such as restarting the game could have an effect on the result due to the added variables. However, in a finished game built for eye tracking it is a necessary feature to be designed and implemented.

It is possible that, due to the learning curve involved with eye tracking interaction, a longitudinal study could allow users to grasp and become adept with the eye tracking technology. Users completing such a study could prefer using eye tracking after familiarisation with said interaction technique.

This prototype, although designed for eye tracking, still had to accommodate the use of controllers for input. Without this constraint, a truly unique and novel experience could be designed. Especially, considering the current fast paced technological advancements of HMDs, it is inevitable that more accurate eye tracking hardware and software solutions will be available in the future.

As mentioned in the preceding weaknesses, TobiiXR's G2OM, could improve the accuracy involved in dashing to larger distances. Including this in a future iteration of the project or in an alternate prototype, could possibly have an interesting effect on the interaction method of eye tracking, as accuracy was a recurring issue with participants.

## 10 Conclusion

Current technological advancements within virtual reality has made it possible for a large consumer base to acquire HMDs in the last decade. The currently leading area of VR utilisation is largely in entertainment and games. VR has opened many new doors in the terms of creating novel interactions. One novel interaction technique that has been somewhat overlooked for VR gaming is eye tracking. The aim of this project was to investigate the uses of eye tracking in VR games and the following initial problem statement was formulated:

*How can eye tracking technology within head mounted displays be used in virtual reality games as a novel form of human-computer interaction to enhance user experience?*

A comprehensive analysis was formed revolving around interaction in 3D environments, eye tracking as a form of input and examples of how eye tracking is already present in VR games. An in depth analysis of 3D interaction techniques was constructed. Analysing theory on 3D interaction was paramount to create a foundation of what categories eye tracking could have an influence on. The interaction method categories of *travel* and *selection & manipulation* were chosen to be the interaction techniques of interest for this project. These were then evaluated and compared to traditional controller based input. Furthermore, gaming in VR was analysed. Specifically, the formalities of how to design an enjoyable game and how to measure game experience of said game. From analysing 3D interaction techniques and game design theory, two core game mechanics were chosen for evaluation: telekinesis for *selection & manipulation* and dashing for *travel*. These were considered to be viable solutions to create eye-gaze assisted superhuman interaction techniques [Section 2.4]. Based on the following analysis a final problem statement was formulated:

*How does eye gaze assisted telekinesis and dash affect the game experience of virtual reality games compared to handheld controllers?*

To ensure that eye tracking would perform at a high standard compared to controllers, as well as creating a fluid and arguably enjoyable game experience - an iterative procedure of design, implementation and evaluation was established. It was deemed that a three iteration cycle would be suitable to meet the goals of utility, usability and desirability as presented through the user experience circle [Figure 6] in the methods [Chapter 3].

Firstly, the category of utility had to be established within the first iteration [Chapter 4]. The goal of this iteration was to establish a baseline of eye tracking assisted 3D interactions and learn how it works from an implementation standpoint. The early iteration of dashing seemed promising but lacked polish. However the evaluation of the early implementation of telekinesis had mixed results and therefore needed to be further evaluated with different modalities to establish utility. Once the evaluation of the telekinesis additional modality inputs was finalised it was possible to advance into the next stage of production.

The goal of the second iteration was to enhance usability with the interactions and the environment of the game experience [Chapter 5]. To facilitate a proper game it was necessary to utilise the categories of puppetry described in section 2.3.1. These categories became the foundation of the design requirements of the second iteration and from these requirements a game scenario was created. To enhance the usability of the game scenario, the second iteration aimed for creating a tutorial for the game, where the game's mechanics and systems are explained to the user within the game experience. An evaluation took place of this second iteration where the usability of both the interaction techniques and the environment was investigated. It was found that both telekinesis and dashing performed above average, achieving SUS scores of respectively 69.77 and 71.59. Qualitative results were also collected on the interaction techniques

and environment which would create the basis for the design requirements of the third iteration.

The purpose of the third iteration [Chapter 6] was to establish desirability by designing and implementing the necessary changes to the environment based on user feedback from the second iteration. As well as a final puzzle section, where the user would have to use their abilities they learned from the tutorial to overcome certain challenges. Additionally, within the third iteration controller based telekinesis and dashing was implemented to create the necessary control parameters for formulating a viable answer to the final problem statement.

Null (H0) and alternative (H1) hypotheses were formulated [Section 7.1.1] to facilitate correct experimental conditions. H0 states that there is no difference in game experience when comparing eye tracking interaction methods and controller based interaction methods. Whilst H1 states that there is a difference when comparing the two interaction methods.

Participants played through the third iteration twice using both interaction types in randomised order and were asked to answer an adapted version of the Game Experience Questionnaire (GEQ). The results of this final evaluation yielded rather intriguing results. For six out of the nine subscales the null hypothesis could not be rejected whereas for two subscales it could.

Based on these results, it can be concluded that eye tracking as an input method for travel and selection & manipulation, in this study, did not yield results that suggested an enhancement or a diminution of the game experience in an exploration and puzzle solving game scenario when used as the primary control and input method.

What is important to note, is the broad scope of this project seems to be able to recommend further research into eye tracking as an input for VR games. Games in general vary significantly. Therefore, it is not possible to conclude anything definite based on the results of the test on one type of game. And, whether a novel interaction method such as eye tracking would have a different effect on other types of games is yet to be discovered. Hence, in essence it can be deduced that the created eye tracking input method does not yield any significant changes to the game experience when compared to the input method of the HTC hand controller.

Thus, it could be interpreted that the eye tracking interaction method presented in this project, being on par with the controller. Challenge was a subscale where a difference was detected to the benefit of the eye tracking. Heightened challenge can be a positive experience, as it can make players more concentrated and engaged with the game. The other subscale where a difference was notable was the travel subscale of the control dimension. Here users preferred the controller, but this might have been due to the long distance inaccuracy of the eye tracking. For a game that requires short range rapid travel, results might be different.

A key takeaway of this project was how well selection worked with eye tracking in games. It allowed for high speed selection and close range accuracy, that has the potential to replace selection with a VR controller. To properly answer the final problem statement of this report many different game scenarios would need to be created and various eye tracking based interactions should be tested in these scenarios. Nevertheless, eye tracking as an input for VR games was found to be enjoyable based on qualitative feedback throughout the iterative process of this project. Thus, it shows potential as a novel form of interaction in VR games.

# Appendices

## A Utility Testing Manuscript and Notes

### **Manuscript for pilot utility testing:**

Welcome to the pilot utility testing of our semester project. In the following experiment you will be testing eye tracking assisted interaction methods.

*Make sure the equipment is sanitized, and the participants wear a mask under the headset.*

#### **Dash Task:**

The following experiment is a think aloud test, so we would ask you to speak your mind during the tasks. You can tell us if something does not feel right, is complicated or easy, and in general however you feel about the prototype.

The first task will be a locomotion method, where you will need to transport yourself across a U-shaped room to get to the end. You will be using eye tracking assisted dashing. You will need to dash to blue circles. The next blue circle of destination will only appear if you successfully dashed to the previous destination. To dash, you will need to look at the desired destination, and pull the trigger to initiate it. The location of your gaze will be shown with a highlight.

When you complete the task, we will load another experiment, which we will explain in depth once we get there.

#### **Telekinesis Task:**

In the following test you will be given telekinetic powers. You will need to move boxes from point A to point B. The next box will only appear once you have successfully moved the previous one to its target destination. To pick up an object rest your gaze on it, and then pull the trigger. Keep the trigger held down as long as you want to control it. You will be able to move it around with your eye gaze in a 2-Dimensional space. If you want to move it closer to you place your thumb down on the trackpad and to move it further away place it up on the trackpad.

After placing each cube to its target location, you will be asked to turn around, where you will need to place a ball in each of the three buckets that are ascending in size.

Once again, this is a think aloud test, so please feel free to share any information regarding the telekinesis with us.

#### **Results:**

Participants are asked to rank their familiarity with VR on a 4-point likert scale, that is as follows:

1. Not at all familiar
2. Somewhat familiar
3. Quite familiar
4. Very Familiar

#### **1st Participant**

**Sex: Male****Somewhat familiar with VR**

The aiming at the dashing could be less flickering, he would prefer a smoother highlight.

At the box section of the telekinesis, the box does not seem like it is moving any closer or further away from him, or maybe he just could not tell.

At the ball and bucket section of the telekinesis it seemed like he was controlling the ball on the Z axis, not on the X and Y.

**2nd Participant****Sex: Female****Somewhat familiar with VR**

Did not find the moving of objects intuitive at the telekinesis section.

Seemed to be using head gaze instead of eye gaze at the telekinesis section.

Focused on where she wanted to place the object, which made the telekinesis feel weird.

**3rd Participant****Sex: Female****Somewhat familiar with VR**

Placed the cube behind her at the telekinesis section, which is noted as a difficulty in the completion of the task.

She found the experience overall fun.

**4th Participant****Sex: Male****Somewhat familiar with VR**

He found the eye tracking dashing intuitive and easy to use.

In the telekinesis section, he “scrolled” on the trackpad of the controller, rather than just touching down or up.

He found the distance hard to gauge at the telekinesis section.

**5th Participant****Sex: Female****Somewhat familiar with VR**

She found it nice that she could see where she was aiming at the dash section.

She felt that it was more intuitive to move her head, instead of her eyes.

She felt that selection of dashing was mostly done with head gaze, rather than eye gaze, since she did not even think about her eye positions.

She found the telekinesis section confusing, since she wanted to look around in the scene to find the target location of objects.

She found the experience very different, but very cool.

### **6th Participant**

**Sex: Female**

**Quite familiar with VR**

She found it difficult to manipulate distance of object at the telekinesis section.

She found it hard to coordinate her eye movement with her hand movements.

It was hard for her to focus her gaze on the object, and at the same time find its target location.

### **7th Participant**

**Sex: Male**

**Very familiar with VR**

He completed the dash test extremely quickly.

He completed the telekinesis task extremely quickly.

Meticulous

So far, the only participant that lifted the cube from the ground, rather than just dragging it on the floor.

He asked if we are measuring how good is depth perception is.

He found it a very interesting way of interacting with the world in VR.

Instinctively he wanted to use his head to flick the objects, which he found difficult to be done with his eyes.

### **8th Participant**

**Sex: Male**

**Very familiar with VR**

He found the experience very cool.

### **9th Participant**

**Sex: Male****Very familiar with VR**

He found the dashing very easy to use and nice.

The highlight for the destination of the dash is jumpy, and he would prefer if it would be smoother.

He remarked that he felt like he wanted to blink to move.

The green box disappeared outside of geometry in the telekinesis section.

He found the balls, in the balls and bucket section hard to select. He remarks that it was a bit tricky since manipulated objects did not cast a shadow below themselves.

"the spot you are looking at kind of jumps around"- which he thinks in a realistic game environment might be a bit annoying.

**10th Participant****Sex: Female****Somewhat familiar with VR**

She found it nice that the first object at the telekinesis section are big.

Telekinesis felt "jumpy" and small objects were harder to select and manipulate.

She would prefer if everything, including the depth was also controlled with the eyes.

She found the first two tasks very straightforward and simple to complete.

**11th Participant****Sex: Male****Somewhat familiar with VR**

He found the experience fun.

The trackpad seemed weird for him, and he would have preferred if instead of using his finger he could have used his eyes, or perhaps some gesture.

He suggested that it could be used to train the eye.

All in all, he found the test very nice, and is eager to see where it is heading.

## B Telekinesis Additional Input Modality Evaluation

### **Manuscript for utility testing 1.5**

Welcome to the usability testing of our semester project. In the following experiment you will be testing different interaction methods for telekinesis assisted by eye tracking.

*Make sure the equipment is sanitized.*

Before we begin, we would like to ask you to rank how familiar you are with VR on a 1-4 scale, where one stands for not familiar at all, and four stands for very familiar.

1. Not at all familiar
2. Somewhat familiar
3. Quite familiar
4. Very Familiar

*Demonstrating controller*-Let us take a quick look at the controller before-Grip buttons, Trigger, Touchpad which you can touch and also click

*Help the participant put the headset on so it fits well.*

First of all, we will need to calibrate the headset to your eyes, so the eye tracking is as precise as possible

Find the arrow on the floor and face that way.

Now that that is done, we will launch the scene where you will be asked to complete some simple tasks. The testing we are conducting follows the think aloud protocol, so while you are completing the task, we will ask you to tell us what you are thinking whether its positive or negative remarks. After you complete the task, we will switch the interaction type, and you will have to complete the same tasks again. In total you will complete these tasks 3 times, with three different interaction types. In between the tasks, we will explain how the different interaction types work.

To move around the map, you can look on the floor anywhere. The location of your gaze will be shown to you with a pink highlight. If you want to move where you are currently looking, press the grip button.

As for the tasks you will be asked to do, first, you will have to move some cubes on top of the same color cylinders. Then you will have to move one ball through two hoops. Last, we will give you a Jenga tower, with what you can do whatever you want. You can remove as many blocks without destroying it as you can, or you can just fool around, it is up to you.

*The order of the interaction methods is randomizes, to reduce possible bias.*

*Gesture method-*

1. Pick up the cube by looking at it and pulling the trigger.
2. Try moving your eyes.

3. Now try moving/swinging the controller up, left right, away from you and towards you
4. If you want to reset the object to the location of your eyes, CLICK down on the touchpad.

*Touchpad method*

1. Pick up the cube by looking at it and pulling the trigger.
2. Try moving your eyes around.
3. If you want to move the cube closer to you, you have to touch down on the touchpad. Only touch not click. If you want to move it away from you, just touch up on the touchpad. Once again, only touch not click.

*Combined method*

1. Pick up the cube by looking at it and pulling the trigger.
2. Try moving your eyes
3. Now try moving/swinging the controller up, left right, away from you and towards you.
4. If you want to move the cube closer to you, you have to touch down on the touchpad. Only touch not click. If you want to move it away from you, just touch up on the touchpad. Once again, only touch not click.
5. If you want to reset the object to the location of your eyes, CLICK down on the touchpad.

*Questions while users are still wearing the headset, and playing around with Jenga:*

Which interaction type did you prefer the most out of the three?

What did you like about this interaction type?

Which one was the worst in your opinion?

What didn't you like about this?

**Transcript of Testing**

3. november 2020  
12:57

**1st Participant**

**VR Rating:**

3-Quite familiar with VR

**Order of interaction types:** 1. Combined, 2. Gesture, 3. Touchpad

**Notes:****Combined:**

Dashing and Telekinesis performed at the same time results in propelling the cubes outside of the scene

*"It feels more natural when I either click the dpad or scroll it, rather than just touching."*

**Gesture: X****Touchpad:**

Had some difficulty from far away on putting the cube on the yellow pillar.

Had some difficulty with the other cube as well.

**Jenga: X**

**Preferred: Combined** – felt most natural and intuitive, the fact that there are different ways to perform the same action is good.

**Worst: Gesture only** – Moving objects on the Z axis is not very efficient with the gesture

**2nd Participant****VR Rating:**

2-Somewhat familiar with VR

**Order of interaction types:** 1. Touchpad, 2. Gesture, 3. Combined

**Notes:****Touchpad:**

Confused by the pink indicator for the dashing.

He thought it was indicating the position of the cube when performing telekinesis.

Completed the second task with the yellow cube with some difficulty.

Was very close to the hoops and completed it quickly.

**Gesture:**

He felt like the gestures made more sense, but it was also more difficult to make things move closer or further away from him.

*"Difficult to perceive distance."*

Accidentally moving the controller results in unwanted actions.

**Combined:**

*"Combining both the trackpad and eyes I can make more accurate movements. Moving with my eyes feels too fast. I feel like I have more control and I am not limited to only using my eyes or my hands."*

**Jenga:**

Jumped onto the ledge with no difficulty

The participant felt it got easier when he had interacted with it for a while.

**Preferred:** Combined – more options result in more freedom of interaction

**Worst:** Gesture – unwanted movements

**3rd Participant**

VR Rating:

3-Quite familiar with VR

**Order of interaction types:** 1. Gesture, 2. Combined, 3. Touchpad

**Notes:****Gesture:**

Has some difficulty with the yellow cube, better with the blue cube, hoops completed without a lot of difficulty

Remarks that maybe it is difficult to interact because he has not quite got the hang of it, and with time it might be different.

**Combined:**

Put the blue cube on top very easily, the hoops were also completed with ease.

*"It is a lot more intuitive to control, the other one didn't feel like it reacted properly. Felt better overall, but maybe because I am getting used to it."*

**Trackpad:**

The participant was a lot more fluid and completed the tasks a lot quicker.

**Jenga: X**

**Preferred:** Trackpad-easiest to complete tasks with

**Worst:** Gesture-difficult to move on Z axis

**4th Participant****VR Rating:**

3-Quite familiar VR.

**Order of interaction types:** 1. Combined, 2. Gesture, 3. Touchpad

**Notes:**

**Combined:**

*"Yellow cube was difficult, but the blue was very easy"*

Yellow cube requires more precision.

Felt overwhelmed by the amount of interactions possible. Would prefer something simpler.

**Gesture:**

Takes a long time to complete the blue cube, that should require the least precision.

Remarks that she would expect the objects to move much more on the Z axis with the gestures.

**Touchpad:**

*"I miss the gestures"*

Completes all tasks very quickly.

**Jenga:**

Asked for the gesture interaction type and asked if the values for how much the objects move with gestures could be adjusted. After increasing the values, she liked this type the most.

**Preferred:** Gesture – after the values are adjusted so gestures are more sensitive, this would be the most preferred out of the 3.

**Worst:** Combined- overwhelming, too much to handle.

**5th Participant**

**VR Rating:**

1-Not at all familiar

**Order of interaction types:** 1. Touchpad, 2. Gesture, 3. Combined

**Notes:**

**Touchpad:**

Very quickly completes all task.

**Gesture:**

Difficulties fine tuning distance.

**Combined:**

Uses trackpad rather than gestures, especially for Z axis.

**Jenga:**

Forgot that it was eye tracking, kept using head gaze instead.

**Preferred:** Combined – affords the most freedom and precision.

**Worst:** Gesture -issues with moving things on the Z axis.

**6th Participant****VR Rating:**

1-Not at all familiar

**Order of interaction types:** 1. Gesture, 2. Trackpad, 3. Combined

**Notes:****Gesture:**

Dashes while performing telekinesis, which results in an unwanted force push that throws the cube out of bounds of the scene.

Difficulties with the Z axis.

Depth precision is found to be hard.

**Trackpad:**

Keeps clicking the trackpad instead of just touching.

Remarks that it is easier than the gesture method and affords for more fine tuning on the Z axis.

**Combined:**

Mostly uses trackpad for depth control.

Uses practically no gestures.

**Jenga: X**

**Preferred:** Trackpad- best for precision.

**Worst:** Gesture

**7th Participant****VR Rating:**

2-Somewhat familiar

**Order of interaction types:** 1. Combined, 2. Gesture, 3. Touchpad

**Notes:****Combined: X**

**Gesture:**

Asked if she could use the trackpad.  
Problems fine tuning the distance.  
Finds it difficult to grasp distance with arms.  
Finds the hoops easier than the cubes.  
Mentions that there is a learning curve and with time it's becoming easier

**Touchpad:**

*"Much easier than the previous ones"*

Completes tasks very fast.

**Jenga:**

*"Gesture more for Jenga, trackpad more for the other tasks"*

**Preferred:** Touchpad – easy to understand and use.

**Worst:** Combined – Might be because it was the first one, she used, and she felt overloaded.  
She found it too confusing, and to be too much input.

**8th Participant****VR Rating:**

2-Somewhat familiar

**Order of interaction types:** 1. Touchpad, 2. Combined, 3. Gesture

**Notes:****Touchpad:**

*"A little strange for the eyes, but also fun"*

little strange for the eyes, but also fun

Likes the control of depth with the trackpad, and the eye tracking in this method.

**Combined:**

Keeps using the touchpad for depth.

Uses very little gestures, practically not enough to influence the movement of objects.

*"It is too much to handle, it is confusing and I feel overloaded"*

Finds this method too complex to use.

**Gesture: X**

**Jenga: X**

**Preferred:** Touchpad – simple, easy, precise

**Worst:** Gesture – Issues controlling depth

## C Modified SUS Questionnaires with Consent Forms

12/17/2020

Consent Form for Test Participation

### Consent Form for Test Participation

Hello!

We are six students from Medialogy at Aalborg University Copenhagen. For our semester project you are asked to participate in our testing procedure of our semester project within the subject called "Audio Visual Experiments" at the Multisensory Experience Lab (ME-Lab).

In this testing procedure, you will go through a virtual reality (VR) experience involving a novel interaction method, and you will be asked to fill out a questionnaire about your experience.

Thank you for your time and participation in the test of our semester project.

Now, please fill out the details below.

\*Required

1. I confirm that I have heard and understood the aforementioned information about the testing. I have had the opportunity to consider the information, ask questions, and have had these answered satisfactorily.\*

*Mark only one oval.*

Yes

No

2. I understand that my participation is voluntary and that I am free to withdraw without giving any reason.\*

*Mark only one oval.*

Yes

No

12/17/2020

Consent Form for Test Participation

3. I understand that all personal information will be anonymized and treated confidentially.\*

*Mark only one oval.*

Yes

No

4. How many times have you tried a virtual reality experience?

*Mark only one oval.*

Never

A few (1-5)

Some (6-15)

A lot (15+)

Please prepare to move to the ME-lab

What  
is  
Dash?

In the VR experience you were told to use your eyes to look at a certain location and press the controller to move to that location. This way of moving in VR is called a dash.

5. Do you understand what the term "dash" refers to?\*

*Mark only one oval.*

Yes

If no, please let the test conductor elaborate the term before moving on.

Usability Evaluation  
for Dashing

There are a total of 10 questions. Please answer the questions with a VR gaming experience in mind.

12/17/2020

## Consent Form for Test Participation

6. I think that I would like to use this method for dashing frequently \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

7. I found the method for dashing unnecessarily complex \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

8. I thought the method for dashing was easy to use \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

9. I think that I would need the support of a technical person to be able to use this method of dashing \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

12/17/2020

Consent Form for Test Participation

10. I found the various functions in this method of dashing were well integrated \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

11. I thought there was too much inconsistency in this method of dashing \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

12. I would imagine that most people would learn to use this method of dashing very quickly \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

13. I found the method of dashing very cumbersome to use \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

12/17/2020

Consent Form for Test Participation

14. I felt very confident using the method of dashing \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

15. I needed to learn a lot of things before I could get going with this method of dashing \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

What is  
Telekinesis?

In the VR experience you were told to use your eyes to look at a object and press the controller to move it around with your eyes and controller. This way of moving objects in VR is called telekinesis.

16. Do you understand what the term "telekinesis" refers to? \*

*Mark only one oval.*

Yes

If no, please let the test conductor elaborate the term before moving on.

Usability Evaluation for  
Telekinesis

There are a total of 10 questions. Please answer the questions with a VR gaming experience in mind.

12/17/2020

Consent Form for Test Participation

17. I think that I would like to use this method of telekinesis frequently \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

18. I found the method of telekinesis unnecessarily complex \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

19. I thought the method of telekinesis was easy to use \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

20. I think that I would need the support of a technical person to be able to use this method of telekinesis \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

12/17/2020

Consent Form for Test Participation

21. I found the various functions in this method of telekinesis were well integrated \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

22. I thought there was too much inconsistency in this method of telekinesis \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

23. I would imagine that most people would learn to use this method of telekinesis very quickly \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

24. I found the method of telekinesis very cumbersome to use \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

12/17/2020

## Consent Form for Test Participation

25. I felt very confident using the method of telekinesis \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

26. I needed to learn a lot of things before I could get going with this method of telekinesis \*

*Mark only one oval.*

1      2      3      4      5

Strongly Disagree      Strongly Agree

Questionnaire Complete

Please see test conductor for final instructions

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Google Forms

## D Descriptive Statistics of SUS Scores

```
In [22]: import pandas as pd
from scipy import stats
d={"Scores for Dash":[70,45,87.5,85,37.5,77.5,85,70,77.5,82.5,70]}
df=pd.DataFrame(data=d)

d2={"Scores for Telekinesis":[75,57.5,55,97.5,52.5,65,80,50,85,75,75]}
df2=pd.DataFrame(data=d2)
```

```
In [23]: df.describe()
```

```
Out[23]:
```

| Scores for Dash |           |
|-----------------|-----------|
| count           | 11.000000 |
| mean            | 71.590909 |
| std             | 16.365846 |
| min             | 37.500000 |
| 25%             | 70.000000 |
| 50%             | 77.500000 |
| 75%             | 83.750000 |
| max             | 87.500000 |

```
In [24]: df2.describe()
```

```
Out[24]:
```

| Scores for Telekinesis |           |
|------------------------|-----------|
| count                  | 11.000000 |
| mean                   | 69.772727 |
| std                    | 15.060484 |
| min                    | 50.000000 |
| 25%                    | 56.250000 |
| 50%                    | 75.000000 |
| 75%                    | 77.500000 |
| max                    | 97.500000 |

```
In [ ]:
```

## E Observation Notes from 2nd Iteration Test

| Test number | General notes   | Dash   | Telekinesis   |
|-------------|---|--|---|
| 1           | The introduction needs to be streamlined. Less talk from conductor  | The eye tracking dash is a bit laggy. Test participant went outside the environment once.  | Used head gaze for telekinesis.   |
| 2           | Introduction is well and precise. Eye calibration was forgotten, but reminded before it started.  | The grip button is somewhat difficult for the test participant to use in the beginning. Spent quite some time to get to the first ledge. Has a bit difficulty understanding the eye part, seems maybe to be using the head gaze instead. | The test participant is confused as to what is the trigger button and what is the grip button.  |
| 3           | Very precise introduction, and the test participant seems onboard with the concept. Did not wait fully for the audio to play, before moving on. Last comment, CRAZY!  | Went back to a previous ledge. Dashed through the environment for the last part, with the iceicle  | Uses the telekinesis quite vividly, not sure if he understands that it is the eyes that move it. Last boulder stuck in the cave entrance a bit  |
| 4           | Participant tries the eye tracking with glasses, and it seems to work. Asks about where he is, and seems surprised that he is still in the canyon. Last comment, super nice with the eye tracking and that it works with glasses!   | Takes a long time before trying the dash. Really plays around a lot and tests all the angels on the ledges. Dashed through the wall on one of the ledges.  | Removed all the boulders before the sound played, so the trackpad assignment was completed without the trackpad.  |
| 5           | Eye calibration seems a bit jumpy. Big bug, the grip got stuck and she kept dashing forward from wherever she looked. Hard restart needed. Probably has a lot of VR experience, but not a lot of VR gaming experience - which should be considered instead in the questionnaire | After second ledge she dashed all the way back to the start area. Got stuck on one ledge, did not understand to move to the ledges. Woaw maybe environment is too dark in the canyon and hard to see the next ledge                      | She gets the gesture part and uses intuitively, no trackpad succes here either :(   |
| 6           | Second time that a participant . Super cool, never tried that   | Had a bit of issues selecting and dashing to the 3rd ledge   | Seems comfortable with the task, was instructed clearly to wait and listen to the audio - this seems to have helped.  |
| 7           | Had some issues with the controller for dashing, had to be guided. Is calm and slow paced, listens to the tutorial fully.   | No issues  | No issues   |
| 8           | Listens carefully to the voice commands.  | Understood the dashing easy.   | He seems to have a bit of difficulties understanding the telekinesis in the start; seems to have a bit of issues with how it behaves when he blinks and that you can drop it after lifting it. The trackpad was not completely on point, but he removed the boulder. Ice blocks do not react to his press |
| 9           | Takes good time to survey the landscape. Seems to listen to the voice carefully   | Dashes without any issue, and takes his time to move to the rift. First ledge no issue, and s  | Telekinesis works smoothly, and without any big trouble. The big boulder of the cave was moved without any issue  |
| 10          | Textbook example  | Textbook example   | Textbook example  |
| 11          | Has a lot of fun. Enjoys the environment, needs to be brighter to see more.   | Had some troubles finding the entrance   | Was to begin with not aware that he was using his eyes, even though he was - which could suggests a very fluid interaction.   |

## F Final Audio Asset List

| Sequence | Complete | Sound Needed                                      | File name                            | Description of sound   | Play when in sequence                                  | Amplitude   | Loop | Spatialisation |
|----------|----------|---|--------------------------------------|--|--|-------------|------|----------------|
| Canyon   | x        | Background music                                  | kai_snowfall_intro.mp3               | Low intensity ambience music for suspension and build up     | Start  | Low         | Yes  |                |
| Canyon   | x        | Background ambience solar wind                    | solar_wind.ogg                       | Weak solar wind  | Start  | Medium      | Yes  |                |
| Canyon   | x        | Boulder movement                                  | boulder_movement.wav                 | Boulder movement   | At each boulder movement                               | Low         |      | Yes            |
| Canyon   | x        | Narrator Voice Line 4 + 5 + 6 + 7 + 8             | x                                    |  | At given points  | Comfortable |      |                |
| Canyon   | x        | Ice crack massive                                 | ice_massive_break_lowpass.ogg        | Medium massive ice crack sound                               | Put every now and then at certain points in the canyon | Strong      |      |                |
| Canyon   | x        | Ledge sound queue for wayfinding                  | ledge_wayfinding_queue_lowpass.mp3   | Pulsation tune to direct attention to next ledge             | At each ledge  | Medium      |      | Yes            |
| Cave     | x        | Ice crack   | ice_medium_break.ogg                 | Ice crack for stick ice in mouth of skullhead                | At each ice stick crack                                | Medium      |      | Yes            |
| Cave     | x        | <b>Background music</b>                           | skullhead_suspense_build.wav         | Add level of distant roaring low freq tune to build suspense | Bottom of cave   | Low         | Yes  |                |
| Cave     | x        | Ice "boulder" movement                            | ice_boulder_movement.wav             | "Ice" boulder movement                                       | At each ice boulder movement                           | Low         |      | Yes            |
| Cave     | x        | Ice sheet crack                                   | skullhead_ice_sheet_crush_reverb.wav |  | At ice sheet crack                                     | Medium      |      | Yes            |
| Cave     | x        | <b>Background music: Ice cave ambience</b>        | suspense_build_low_cut.wav           | Low intensity ambience music for suspension and build up     | Start  | Low         |      |                |
| Cavern   | x        | <b>Background music: Temple ambience</b>          | temple_soundscape.wav                | Temple like music to signify goal reached                    | Start  | Strong      | Yes  |                |
| Cavern   | x        | Core pulsation                                    | core_pulsation.aiff                  | For the force fields   | Platform   | Strong      | Yes  | Yes            |
| Cavern   | x        | Relic overload                                    | relic_pulsation_overload.wav         | Roaring happy tune   | End  | Very strong | Yes  | Yes            |
| Cavern   | x        | Selection state sound for sphere in energy sphere | selection_forcefield.wav             | Sound indicating that task is successfully completed         | Cube moved into force field                            | Strong      |      | Maybe          |
| Cavern   | x        | Selection state sound for decrease in force field | decrease_force_field.wav             | Sound indicating that task is successfully completed         | Cube moved into force field                            | Strong      |      | Maybe          |
| Cavern   | x        | Selection state sound for platform                | force_field_platform_pulse.wav       | Sound indicating that platform activates the cubes           | Platform   | Medium      |      |                |
| Tunnel   | x        | Ice crack massive                                 | ice_massive_break.ogg                | Put once in the middle of tunnel, louder than in the canyon  | Middle   | Very strong |      |                |
| Tunnel   | x        | Ice sheet crack                                   | tunnel_ice_sheet_crack_reverb.wav    |  | End  | Strong      |      | Yes            |
| Valley   | x        | Background ambience solar wind                    | solar_wind.ogg                       | Stormy wind to indicate strong winds above slopes            | Start  | Strong      | Yes  | Yes            |
| Valley   | x        | Narrator Voice Line 1 + 2 + 3                     | x                                    |  | At given points  | Comfortable |      |                |

## G Narrator Voice Lines for Eye Tracking and Controller

| Voice Line for Eye Interaction   | Voice Line for Controller Interaction   | Description  |
|--|---|--|
| Welcome to Europa, the icy moon of Jupiter, RA-1. Reconnaissance shows abnormal readings from approximately 100 meters from your landing location, buried deep in the ice. Your mission is to recon the area and retrieve any objects of importance.                                     | Welcome to Europa, the icy moon of Jupiter, RA-1. Reconnaissance shows abnormal readings from approximately 100 meters from your landing location, buried deep in the ice. Your mission is to recon the area and retrieve any objects of importance.      | Introduction to narrative at start of game.  |
| First of all, let us get you moving RA-1. Point your <b>bionic eyes</b> to the location you wish to dash to. You can see that the location is highlighted. Now, grip your hand.  | First of all, let us get you moving RA-1. Point your <b>bionic hand</b> to the location you wish to dash to. You can see that the location is highlighted. Now, grip your hand.   | Introduction to interaction method for dashing.  |
| Well done. Dash around to get familiar with your abilities. Once you feel confident, head over to the opening of the canyon.   | Well done. Dash around to get familiar with your abilities. Once you feel confident, head over to the opening of the canyon.  | Confirmation of successful interaction. Triggered by the first dash made.  |
| Your capabilities allow for very precise dashing, such as these ledges on the side of the canyon. Go ahead and advance forward.  | Your capabilities allow for very precise dashing, such as these ledges on the side of the canyon. Go ahead and advance forward.   | Further explanation of interaction method for dashing. Triggered by entering the canyon entrance.                            |
| You are equipped with cutting edge anti-gravity tech embedded in your <b>eyes and hands</b> . Direct your <b>bionic eyes</b> to the rubble and hold your trigger. Now throw the rubble into the canyon by moving your <b>eye</b> unit around.  | You are equipped with cutting edge anti-gravity tech embedded in your <b>hands</b> . Direct your <b>bionic hands</b> to the rubble and hold your trigger. Now throw the rubble into the canyon by moving your hand unit around.                           | Introduction to interaction method for telekinesis. Triggered by reaching the ledge right in front of the rubble.            |
| There is rubble blocking your path once more RA-1 <b>fixate your gaze</b> on the rubble on the next ledge and use both <b>eyes and hands</b> to move the rubble off. Whatever object you are manipulating will move according to your <b>hand movements and eye movements combined</b> . | There is rubble blocking your path once more RA-1, <b>point your hand towards</b> the rubble on the next ledge and use <b>your hands</b> to move the rubble off. Whatever object you are manipulating will move according to your <b>hand movements</b> . | Further explanation of interaction method for telekinesis. Triggered by clearing the rubble and dashing onto the next ledge. |
| The energy readings are coming from inside that cave, move that ice block out of the way. <b>Fixate your eyes</b> once more on the block and move your thumb down on the trackpad to drag it over the edge.  | The energy readings are coming from inside that cave, move that ice block out of the way. <b>Point your hand towards</b> the block once more and move your thumb down on the trackpad to drag it over the edge.   | Final explanation of interaction method for telekinesis. Triggered by reaching the final ledge.                              |
| You can also use the same technique to move objects away from you, by looking at an object and moving your thumb up.   | You can also use the same technique to move objects away from you, by looking at an object and moving your thumb up.  | Hint of how the interaction method can be used on all sorts of objects.  |

## H Consent Form for Desirability Test

### Consent Form for Test Participation

Hello!

We are six students from Medialogy at Aalborg University Copenhagen. You are asked to participate in our testing procedure of our semester project within the subject called "Audio Visual Experiments" at the Multisensory Experience Lab (ME-Lab).

In this testing procedure, you will go through a VR experience involving a novel interaction method, and you will be asked to fill out a questionnaire about your experience.

Thank you for your time and participation in the test of our semester project. If you want to be part of a draw to win two cinema tickets, please enter your email address, as well.

Now, please fill out the details below.

\* Required

Have you used eye tracking for interaction in Virtual Reality before?

Yes

No

Email address

Your answer

I understand that all personal information will be anonymized and treated confidentially.\*

Yes

No

Age \*

Your answer



I confirm that I have heard and understood the aforementioned information about the testing. I have had the opportunity to consider the information, ask questions, and have had these answered satisfactorily.\*

Yes

No

How many times have you tried virtual reality games before?

Never

A few (1-5)

Some (6-15)

A lot (15+)

Gender \*

Male

Female

Non-Binary

Other

Prefer not to say

I understand that my participation is voluntary and that I am free to withdraw without giving any reason. \*

Yes

No

Next

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Google Forms



# I Results of the Assumption Checks and the Wilcoxon Signed-Rank Test

## StatisticalEval

December 13, 2020

```
[80]: import pandas as pd
from scipy import stats
df=pd.read_csv('results.csv')
```

### 1 Descriptive Statistics

```
[84]: df[['EyeComp','EyeSens','EyeFlow','EyeTens','EyeChal','EyeNeg','EyePos','EyeAround','EyeObj']]
      ↵describe()
```

|       | EyeComp   | EyeSens   | EyeFlow   | EyeTens   | EyeChal   | EyeNeg    | \ |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|---|
| count | 30.000000 | 30.000000 | 30.000000 | 30.000000 | 30.000000 | 30.000000 |   |
| mean  | 2.816667  | 2.900000  | 2.933333  | 0.866667  | 2.183333  | 0.550000  |   |
| std   | 0.825074  | 0.855006  | 1.014833  | 0.889918  | 0.923667  | 0.746832  |   |
| min   | 1.000000  | 1.000000  | 0.000000  | 0.000000  | 0.000000  | 0.000000  |   |
| 25%   | 2.125000  | 2.500000  | 2.125000  | 0.000000  | 1.500000  | 0.000000  |   |
| 50%   | 3.000000  | 3.000000  | 3.000000  | 0.500000  | 2.000000  | 0.250000  |   |
| 75%   | 3.500000  | 3.500000  | 3.875000  | 1.500000  | 3.000000  | 1.000000  |   |
| max   | 4.000000  | 4.000000  | 4.000000  | 3.000000  | 3.500000  | 3.000000  |   |
|       |           |           |           |           |           |           |   |
|       | EyePos    | EyeAround | EyeObj    |           |           |           |   |
| count | 30.000000 | 30.000000 | 30.000000 |           |           |           |   |
| mean  | 2.883333  | 2.583333  | 3.166667  |           |           |           |   |
| std   | 0.847749  | 0.956676  | 0.791478  |           |           |           |   |
| min   | 1.000000  | 0.500000  | 1.500000  |           |           |           |   |
| 25%   | 2.125000  | 2.000000  | 3.000000  |           |           |           |   |
| 50%   | 3.000000  | 2.500000  | 3.500000  |           |           |           |   |
| 75%   | 3.500000  | 3.375000  | 4.000000  |           |           |           |   |
| max   | 4.000000  | 4.000000  | 4.000000  |           |           |           |   |

```
[83]: df[['CtrlComp','CtrlSens','CtrlFlow','CtrlTens','CtrlChal','CtrlNeg','CtrlPos','CtrlAround','C
      ↵describe()']]
```

|       | CtrlComp  | CtrlSens  | CtrlFlow  | CtrlTens  | CtrlChal  | CtrlNeg   | \ |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|---|
| count | 30.000000 | 30.000000 | 30.000000 | 30.000000 | 30.000000 | 30.000000 |   |
| mean  | 2.666667  | 2.850000  | 2.900000  | 0.550000  | 1.466667  | 0.566667  |   |
| std   | 0.912871  | 0.96624   | 0.904014  | 0.913028  | 1.074255  | 0.817200  |   |
| min   | 1.000000  | 0.50000   | 1.000000  | 0.000000  | 0.000000  | 0.000000  |   |

|       |           |            |           |          |          |          |
|-------|-----------|------------|-----------|----------|----------|----------|
| 25%   | 2.125000  | 2.50000    | 2.125000  | 0.000000 | 0.500000 | 0.000000 |
| 50%   | 3.000000  | 3.00000    | 3.000000  | 0.000000 | 1.500000 | 0.500000 |
| 75%   | 3.375000  | 3.50000    | 3.500000  | 0.500000 | 2.000000 | 0.500000 |
| max   | 4.000000  | 4.00000    | 4.000000  | 3.000000 | 4.000000 | 3.000000 |
|       | CtrlPos   | CtrlAround | CtrlObj   |          |          |          |
| count | 30.000000 | 30.000000  | 30.000000 |          |          |          |
| mean  | 3.066667  | 3.116667   | 3.416667  |          |          |          |
| std   | 0.817200  | 0.837518   | 0.602914  |          |          |          |
| min   | 1.000000  | 1.000000   | 1.500000  |          |          |          |
| 25%   | 2.500000  | 2.625000   | 3.000000  |          |          |          |
| 50%   | 3.000000  | 3.500000   | 3.500000  |          |          |          |
| 75%   | 4.000000  | 3.875000   | 4.000000  |          |          |          |
| max   | 4.000000  | 4.000000   | 4.000000  |          |          |          |

## 2 Shapiro-Wilks Test

```
[76]: stat, p = stats.shapiro(df['CtrlComp'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')
```

Statistics=0.910, p=0.015  
Not Normal Distribution

```
[4]: stat, p = stats.shapiro(df['CtrlSens'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')
```

Statistics=0.908, p=0.013  
Not Normal Distribution

```
[6]: stat, p = stats.shapiro(df['CtrlFlow'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')
```

Statistics=0.912, p=0.017

```
Not Normal Distribution
[7]: stat, p = stats.shapiro(df['CtrlTens'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')

Statistics=0.658, p=0.000
Not Normal Distribution

[8]: stat, p = stats.shapiro(df['CtrlChal'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')

Statistics=0.941, p=0.095
Normal Distribution

[9]: stat, p = stats.shapiro(df['CtrlNeg'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')

Statistics=0.706, p=0.000
Not Normal Distribution

[10]: stat, p = stats.shapiro(df['CtrlPos'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')

Statistics=0.897, p=0.007
Not Normal Distribution

[11]: stat, p = stats.shapiro(df['CtrlAround'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
```

```
        print('Normal Distribution')
else:
    print('Not Normal Distribution')

Statistics=0.879, p=0.003
Not Normal Distribution

[12]: stat, p = stats.shapiro(df['CtrlObj'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')

Statistics=0.831, p=0.000
Not Normal Distribution

[13]: stat, p = stats.shapiro(df['EyeComp'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')

Statistics=0.942, p=0.102
Normal Distribution

[14]: stat, p = stats.shapiro(df['EyeSens'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')

Statistics=0.925, p=0.037
Not Normal Distribution

[15]: stat, p = stats.shapiro(df['EyeFlow'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')

Statistics=0.884, p=0.003
Not Normal Distribution
```

```
[16]: stat, p = stats.shapiro(df['EyeTens'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')
```

Statistics=0.860, p=0.001  
Not Normal Distribution

```
[17]: stat, p = stats.shapiro(df['EyeChal'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')
```

Statistics=0.931, p=0.052  
Normal Distribution

```
[18]: stat, p = stats.shapiro(df['EyeNeg'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')
```

Statistics=0.761, p=0.000  
Not Normal Distribution

```
[19]: stat, p = stats.shapiro(df['EyePos'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')
```

Statistics=0.922, p=0.030  
Not Normal Distribution

```
[20]: stat, p = stats.shapiro(df['EyeAround'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
```

```

else:
    print('Not Normal Distribution')

Statistics=0.942, p=0.105
Normal Distribution

[25]: stat, p = stats.shapiro(df['EyeObj'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Normal Distribution')
else:
    print('Not Normal Distribution')

Statistics=0.851, p=0.001
Not Normal Distribution

```

### 3 Levene's Test

```

[23]: stat, p = stats.levene(df['CtrlComp'].dropna(),df['EyeComp'].dropna())
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Difference between the variances is roughly zero')
else:
    print('the assumption of homogeneity of variances has been violated')

Statistics=0.104, p=0.748
Difference between the variances is roughly zero

[26]: stat, p = stats.levene(df['CtrlSens'].dropna(),df['EyeSens'].dropna())
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Difference between the variances is roughly zero')
else:
    print('the assumption of homogeneity of variances has been violated')

Statistics=0.106, p=0.746
Difference between the variances is roughly zero

[27]: stat, p = stats.levene(df['CtrlFlow'].dropna(),df['EyeFlow'].dropna())
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Difference between the variances is roughly zero')
else:
    print('the assumption of homogeneity of variances has been violated')

```

```

Statistics=0.048, p=0.828
Difference between the variances is roughly zero

[28]: stat, p = stats.levene(df['CtrlTens'].dropna(),df['EyeTens'].dropna())
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Difference between the variances is roughly zero')
else:
    print('the assumption of homogeneity of variances has been violated')

Statistics=0.537, p=0.467
Difference between the variances is roughly zero

[29]: stat, p = stats.levene(df['CtrlChal'].dropna(),df['EyeChal'].dropna())
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Difference between the variances is roughly zero')
else:
    print('the assumption of homogeneity of variances has been violated')

Statistics=0.919, p=0.342
Difference between the variances is roughly zero

[30]: stat, p = stats.levene(df['CtrlNeg'].dropna(),df['EyeNeg'].dropna())
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Difference between the variances is roughly zero')
else:
    print('the assumption of homogeneity of variances has been violated')

Statistics=0.012, p=0.914
Difference between the variances is roughly zero

[31]: stat, p = stats.levene(df['CtrlPos'].dropna(),df['EyePos'].dropna())
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Difference between the variances is roughly zero')
else:
    print('the assumption of homogeneity of variances has been violated')

Statistics=0.148, p=0.702
Difference between the variances is roughly zero

[32]: stat, p = stats.levene(df['CtrlAround'].dropna(),df['EyeAround'].dropna())
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05

```

```

if p > alpha:
    print('Difference between the variances is roughly zero')
else:
    print('the assumption of homogeneity of variances has been violated')

Statistics=0.396, p=0.531
Difference between the variances is roughly zero

[33]: stat, p = stats.levene(df['CtrlObj'].dropna(),df['EyeObj'].dropna())
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('Difference between the variances is roughly zero')
else:
    print('the assumption of homogeneity of variances has been violated')

Statistics=2.721, p=0.104
Difference between the variances is roughly zero

```

#### 4 Wilcoxon Signed-Rank Test

```

[70]: df['CompDifference']=df['CtrlComp']-df['EyeComp']
stat, p = stats.wilcoxon(df['CompDifference'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('fail to reject H0')
else:
    print('reject h0')

Statistics=113.000, p=0.443
fail to reject H0

[56]: df['SensDifference']=df['CtrlSens']-df['EyeSens']
stat, p = stats.wilcoxon(df['SensDifference'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('fail to reject H0')
else:
    print('reject h0')

Statistics=136.000, p=0.951
fail to reject H0

[57]: df['FlowDifference']=df['CtrlFlow']-df['EyeFlow']
stat, p = stats.wilcoxon(df['FlowDifference'])
print('Statistics=% .3f, p=% .3f' % (stat, p))

```

```
alpha = 0.05
if p > alpha:
    print('fail to reject H0')
else:
    print('reject h0')
```

Statistics=186.000, p=0.942  
fail to reject H0

```
[58]: df['TensDifference']=df['CtrlTens']-df['EyeTens']
stat, p = stats.wilcoxon(df['TensDifference'])
print('Statistics=%3f, p=%3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('fail to reject H0')
else:
    print('reject h0')
```

Statistics=40.000, p=0.146  
fail to reject H0

```
[59]: df['ChalDifference']=df['CtrlChal']-df['EyeChal']
stat, p = stats.wilcoxon(df['ChalDifference'])
print('Statistics=%3f, p=%3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('fail to reject H0')
else:
    print('reject h0')
```

Statistics=71.500, p=0.004  
reject h0

```
[60]: df['NegDifference']=df['CtrlNeg']-df['EyeNeg']
stat, p = stats.wilcoxon(df['NegDifference'])
print('Statistics=%3f, p=%3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('fail to reject H0')
else:
    print('reject h0')
```

Statistics=155.000, p=0.838  
fail to reject H0

```
[61]: df['PosDifference']=df['CtrlPos']-df['EyePos']
stat, p = stats.wilcoxon(df['PosDifference'])
print('Statistics=%3f, p=%3f' % (stat, p))
alpha = 0.05
```

```
if p > alpha:
    print('fail to reject H0')
else:
    print('reject h0')

Statistics=161.000, p=0.497
fail to reject H0

[63]: df['AroundDifference']=df['CtrlAround']-df['EyeAround']
stat, p = stats.wilcoxon(df['AroundDifference'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('fail to reject H0')
else:
    print('reject h0')

Statistics=105.000, p=0.042
reject h0

[77]: df['ObjDifference']=df['CtrlObj']-df['EyeObj']
stat, p = stats.wilcoxon(df['ObjDifference'])
print('Statistics=% .3f, p=% .3f' % (stat, p))
alpha = 0.05
if p > alpha:
    print('fail to reject H0')
else:
    print('reject h0')

Statistics=106.000, p=0.122
fail to reject H0
```

## J Game Experience Questionnaire with Added Subscales for Control Dimension

### In-game Questionnaire (iGEQ)

Please indicate how you felt while playing the game for each of the items, on the following scale:

| not at all | slightly | moderately | fairly | Extremely |
|------------|----------|------------|--------|-----------|
| 0          | 1        | 2          | 3      | 4         |
| < >        | < >      | < >        | < >    | < >       |

1. I was interested in the game's story
2. I felt successful
3. I felt bored
4. I found it impressive
5. I forgot everything around me
6. I felt frustrated
7. I found it tiresome
8. I felt irritable
9. I felt skilful
10. I felt completely absorbed
11. I felt content
12. I felt challenged
13. I felt stimulated
14. I felt good

### Additional questions concerning the Control subscale

#### Travel:

15. I felt like I was in control while I was moving around in the environment
16. I felt I was competent in moving around in the environment

#### Selection & Manipulation:

17. I felt like I was in control while I was moving objects around in the environment
18. I felt I was competent in moving objects around in the environment

#### Scoring guidelines iGEQ

The In-game questionnaire consists of seven components, identical to the core Module. However, only two items are used for every component. The items for each are listed below.

Component scores are computed as the average value of its items.

**Competence:** Items 2 and 9.

**Sensory and Imaginative Immersion:** Items 1 and 4.

**Flow:** Items 5 and 10.

**Tension:** Items 6 and 8.

**Challenge:** Items 12 and 13.

**Negative affect:** Items 3 and 7.

**Positive affect:** Items 11 and 14.

## K Overview of Data Collected in Final Testing

| Participant Id | Interaction Method | Comp. | Sens. I.I. | Flow | Tension | Chal. | Negative | Positive | Travel | S & M | Used Eye Tracking Before |
|----------------|--------------------|-------|------------|------|---------|-------|----------|----------|--------|-------|--------------------------|
| 1 C            |                    | 1.5   | 1.5        | 0    | 1.5     | 3     | 0.5      | 2.5      | 3      | 3     | 3 Yes                    |
| 1 E            |                    | 1     | 2.5        | 1.5  | 1       | 3     | 0.5      | 3.5      | 3      | 3     | 3 Yes                    |
| 2 C            |                    | 3.5   | 3          | 3    | 0       | 1     | 0        | 4        | 4      | 4     | 3.5 No                   |
| 2 E            |                    | 3     | 3.5        | 3    | 0.5     | 2     | 0.5      | 4        | 2      | 3     | 3 No                     |
| 3 C            |                    | 4     | 4          | 3.5  | 0       | 0.5   | 0        | 4        | 4      | 4     | 4 No                     |
| 3 E            |                    | 3     | 4          | 3.5  | 0.5     | 2.5   | 0        | 3.5      | 3.5    | 4     | 4 No                     |
| 4 C            |                    | 3.5   | 3          | 3    | 0.5     | 1.5   | 1        | 2.5      | 4      | 3.5   | 3.5 Yes                  |
| 4 E            |                    | 3     | 2          | 3    | 0       | 1.5   | 1        | 2.5      | 4      | 3.5   | 3.5 Yes                  |
| 5 C            |                    | 3.5   | 2.5        | 3    | 0       | 1     | 0.5      | 2        | 3.5    | 4     | 4 No                     |
| 5 E            |                    | 3.5   | 3          | 3.5  | 0       | 1.5   | 0.5      | 2        | 3      | 3.5   | 3.5 No                   |
| 6 C            |                    | 4     | 4          | 4    | 0       | 1     | 0.5      | 4        | 3.5    | 3.5   | 3.5 No                   |
| 6 E            |                    | 4     | 2.5        | 4    | 0       | 1.5   | 0        | 4        | 4      | 4     | 4 No                     |
| 7 C            |                    | 1.5   | 2.5        | 3.5  | 0       | 0     | 0.5      | 4        | 4      | 4     | 4 No                     |
| 7 E            |                    | 3.5   | 4          | 4    | 0       | 1.5   | 0        | 3        | 3.5    | 4     | 4 No                     |
| 8 C            |                    | 1     | 2.5        | 2    | 3       | 3     | 2.5      | 1.5      | 1      | 3.5   | 3.5 No                   |
| 8 E            |                    | 3     | 3          | 1.5  | 3       | 3     | 3        | 1.5      | 1.5    | 2     | No                       |
| 9 C            |                    | 4     | 4          | 4    | 0       | 3.5   | 0        | 4        | 4      | 4     | 4 No                     |
| 9 E            |                    | 3     | 4          | 4    | 0       | 2     | 0        | 4        | 3.5    | 3.5   | No                       |
| 10 C           |                    | 2.5   | 3          | 3.5  | 1       | 3     | 0        | 3        | 1.5    | 1.5   | Yes                      |
| 10 E           |                    | 2.5   | 3          | 3.5  | 0       | 1.5   | 0        | 2.5      | 3      | 3     | Yes                      |
| 11 C           |                    | 4     | 3.5        | 4    | 0.5     | 2     | 2        | 3        | 3.5    | 4     | Yes                      |
| 11 E           |                    | 3     | 3.5        | 2.5  | 0       | 3     | 1        | 3        | 2.5    | 2.5   | Yes                      |
| 12 C           |                    | 1     | 3.5        | 3.5  | 1       | 3.5   | 0        | 2        | 2      | 2     | Yes                      |
| 12 E           |                    | 2.5   | 3.5        | 2.5  | 0.5     | 2.5   | 0.5      | 2.5      | 3      | 3     | Yes                      |
| 13 C           |                    | 3     | 4          | 4    | 0.5     | 2     | 0        | 4        | 2.5    | 3.5   | No                       |
| 13 E           |                    | 2.5   | 4          | 4    | 1       | 2.5   | 0        | 4        | 3.5    | 3.5   | No                       |
| 14 C           |                    | 3.5   | 2.5        | 3    | 0.5     | 1     | 1.5      | 3.5      | 2.5    | 3     | Yes                      |
| 14 E           |                    | 3.5   | 1.5        | 4    | 0       | 0     | 0.5      | 3        | 3      | 4     | Yes                      |
| 15 C           |                    | 3.5   | 4          | 2    | 0       | 0     | 0        | 4        | 3      | 4     | No                       |
| 15 E           |                    | 2     | 4          | 2.5  | 0.5     | 1.5   | 0        | 4        | 2      | 2.5   | No                       |
| 16 C           |                    | 2     | 3.5        | 3    | 2       | 3.5   | 0        | 2        | 2.5    | 3     | Yes                      |
| 16 E           |                    | 2.5   | 3.5        | 3    | 2       | 2     | 3        | 2.5      | 4      | 3     | Yes                      |
| 17 C           |                    | 2     | 3.5        | 4    | 2       | 3     | 0        | 3        | 2      | 4     | Yes                      |
| 17 E           |                    | 1     | 3.5        | 4    | 3       | 4     | 0        | 3        | 2      | 1.5   | Yes                      |
| 18 C           |                    | 2     | 3          | 3    | 3       | 3.5   | 0.5      | 2        | 2.5    | 2     | Yes                      |
| 18 E           |                    | 4     | 2          | 3.5  | 0       | 0     | 0        | 4        | 4      | 4     | Yes                      |
| 19 C           |                    | 3     | 3          | 2.5  | 0       | 1     | 1        | 2.5      | 3      | 3     | No                       |
| 19 E           |                    | 1.5   | 3.5        | 2    | 0.5     | 2     | 0        | 2.5      | 2      | 2.5   | No                       |
| 20 C           |                    | 2.5   | 1.5        | 2.5  | 1       | 2     | 1        | 3        | 0.5    | 3.5   | No                       |
| 20 E           |                    | 1.5   | 2          | 2    | 0       | 0.5   | 0        | 3        | 2.5    | 4     | No                       |
| 21 C           |                    | 3     | 0.5        | 1    | 0       | 1     | 0        | 2        | 4      | 4     | No                       |
| 21 E           |                    | 1.5   | 1.5        | 2    | 1.5     | 3.5   | 1.5      | 1        | 0.5    | 3.5   | No                       |
| 22 C           |                    | 2.5   | 3          | 3    | 1       | 2     | 0.5      | 3        | 2.5    | 3     | Yes                      |
| 22 E           |                    | 3.5   | 3          | 3    | 0       | 0     | 0        | 3.5      | 4      | 4     | Yes                      |
| 23 C           |                    | 2.5   | 2.5        | 2.5  | 0       | 1     | 1.5      | 3.5      | 3.5    | 4     | Yes                      |
| 23 E           |                    | 2     | 2.5        | 2    | 1.5     | 3     | 0        | 2        | 2      | 2     | Yes                      |
| 24 C           |                    | 3     | 3          | 2    | 1       | 2     | 1        | 3        | 3      | 3     | Yes                      |
| 24 E           |                    | 3     | 3          | 2    | 0.5     | 0.5   | 1        | 3        | 3.5    | 3.5   | Yes                      |
| 25 C           |                    | 4     | 2.5        | 3.5  | 0.5     | 2     | 0        | 4        | 3      | 4     | No                       |
| 25 E           |                    | 3     | 3          | 3    | 2       | 3     | 0        | 3        | 2      | 4     | No                       |
| 26 C           |                    | 3     | 4          | 3.5  | 0       | 1.5   | 0        | 4        | 3      | 4     | No                       |
| 26 E           |                    | 4     | 4          | 4    | 0       | 1.5   | 0        | 4        | 3.5    | 3.5   | No                       |
| 27 C           |                    | 3     | 1          | 1    | 0       | 0.5   | 0.5      | 2.5      | 3.5    | 3.5   | No                       |
| 27 E           |                    | 2.5   | 2.5        | 1    | 0       | 2.5   | 0        | 2.5      | 2      | 2     | No                       |
| 28 C           |                    | 2     | 2          | 3.5  | 2       | 2     | 0.5      | 2.5      | 2.5    | 3.5   | Yes                      |
| 28 E           |                    | 3     | 2          | 3.5  | 0       | 0.5   | 0.5      | 3        | 3.5    | 3.5   | Yes                      |
| 29 C           |                    | 3     | 3          | 4    | 0       | 1     | 0.5      | 3        | 3.5    | 3.5   | Yes                      |
| 29 E           |                    | 2.5   | 3          | 4    | 0       | 1     | 0        | 3.5      | 3      | 3.5   | Yes                      |
| 30 C           |                    | 1.5   | 1          | 2    | 2       | 2     | 2.5      | 1        | 1.5    | 3     | No                       |
| 30 E           |                    | 3     | 1          | 2    | 1.5     | 2     | 1.5      | 2        | 1      | 2     | No                       |

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