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Eliciting the supernatural: Designing and comparing gesture elicitation-based supernatural interactions with an established technique

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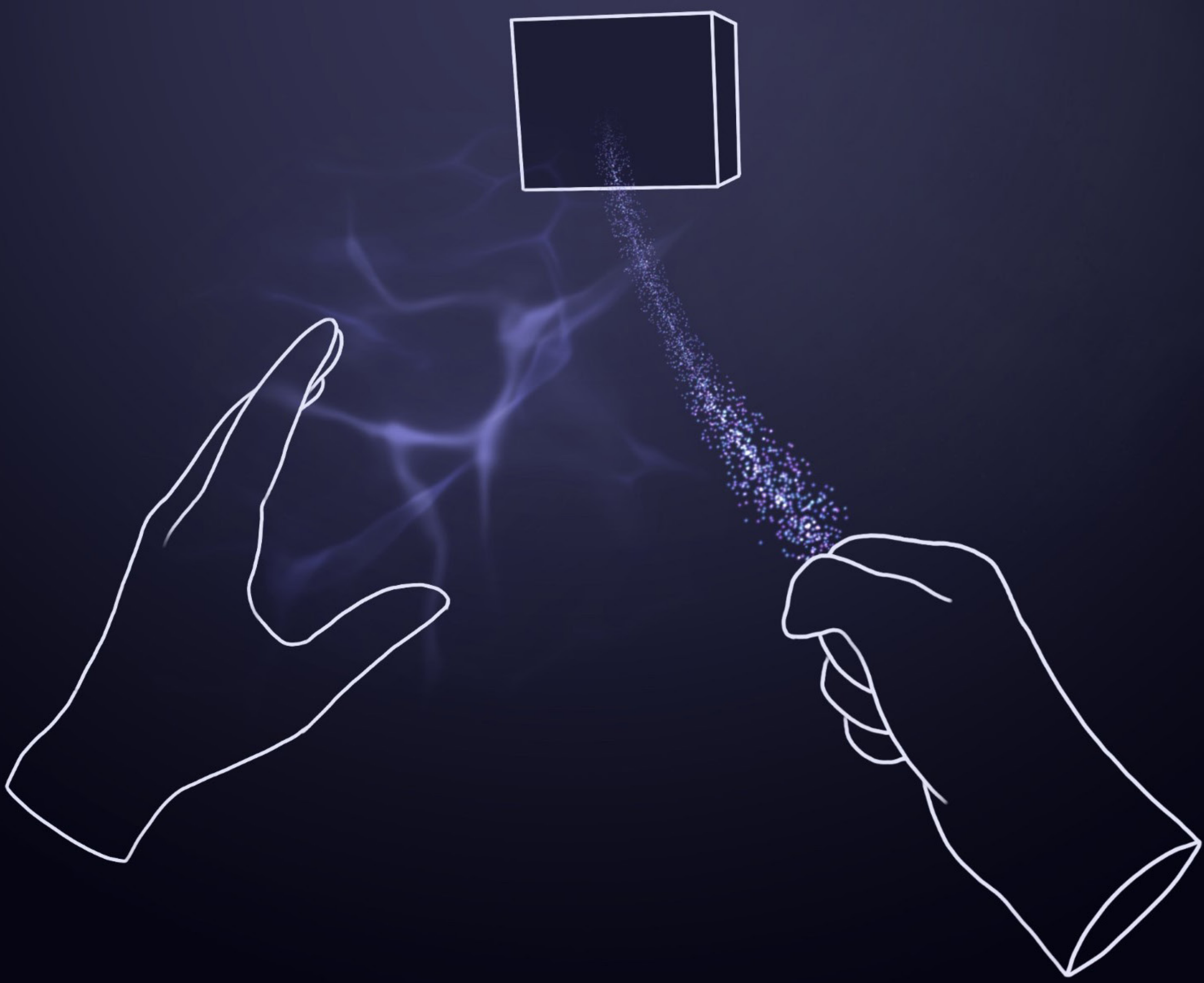
Abstract:

In this thesis, I seek to answer the research question "How can gesture elicitation help create supernatural/nonisomorphic interaction techniques and how do these compare to already established techniques?". To begin with, supernatural/nonisomorphic travel and selection and manipulation are investigated. These types of interaction techniques can prove to be more useful and engaging than isomorphic interaction. However, these interaction techniques can be a challenge to design. This thesis uses the participatory design technique of gesture elicitation study ($n = 20$) to provide a consensus set for the nonisomorphic travel and selection and manipulation techniques; flight and telekinesis. while the agreement rates for telekinesis were medium (> 0.1) to high (> 0.3), the agreement rates for flight were mostly low (< 0.1) to medium and it was therefore deemed more appropriate to focus the implementation on telekinesis. To evaluate telekinesis, an established interaction technique, the GoGo hand was adapted and would serve as a comparison. In the final evaluation ($n = 20$) telekinesis scored significantly lower mean ($t(19) = 3.789$, $p = 0.0012$) on the system usability scale than GoGo. Telekinesis scored a mean of 65.5 (median = 65, SE = 4.29). GoGo scored a mean of 81.1 (median = 81.2, SE = 2.90). However, user ratings of the fun the participants had while interacting were similar between the two interaction techniques ($W = 63.0$, $p = 0.793$). The telekinesis mean rating of fun was 7.75 (Median = 7.5, SE = 0.39) and GoGo mean rating was 7.85 (Median = 8, SE = 0.32). Suggesting that even though telekinesis was less usable than GoGo, users still enjoyed it enough to not let the frustrations of the low usability get in the way of the experience of interacting with it.

Medialogy Master Thesis

ELICITING THE SUPERNATURAL

Designing and comparing gesture elicitation-based supernatural interactions with an established technique



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Contents

1 Introduction

Virtual Reality (VR) is a technological leap forward within immersive technology. Using natural analogues for locomotion and manipulation can provide a more immersive experience for digital media such as games when compared to traditional input methods such as mouse and keyboard. Experiences in VR are often rooted in what one can do physically in the real world. Picking up objects in VR feels natural because it has a real-world counterpart, the same can be said about locomotion. These methods of manipulating the digital environment or our position in it, require little or no teaching for the player to master it. However, VR is still able to give users superhuman abilities such as telekinesis and flight. But how should we design for these superhuman abilities?

Several interaction techniques exist for travel and selection and manipulation, that have been created by researchers and developers [18]. Some of these interactions deal with what is referred to as nonisomorphic interaction, i.e., interactions that do not have a 1:1 relation to real-world movements. Laviola et al [18]. state that these nonisomorphic interactions can prove more useful by enhancing users' abilities in virtual environments (VE). But the interactions that are presented have one thing in common; they are designed by researchers and developers. Gesture elicitation studies (GES) is a method within participatory design for enhancing the usability of applications. Here users are presented with referents i.e., the desired outcome of an input. Users then provide a gesture that they deem appropriate for that outcome. These gestures are then recorded and a consensus set is created that will be used to design the interaction [30]. There exists a gap in the literature of researchers using gesture elicitation studies to design novel interaction techniques but they do not compare them to existing and established interaction techniques [2, 27, 11, 31].

This thesis presents a GES [30] (n = 20) with referents gathered from travel and selection and manipulation task decompositions [18]. The elicited gestures for selection and manipulation interaction technique, dubbed telekinesis, had relatively high agreements. While the travel technique, dubbed flight, had lower agreement rates. These results indicate that implementation of the consensus set would not draw any of the benefits of gesture elicitation [30]. It was therefore decided to focus the implementation on telekinesis. Once telekinesis had been implemented, an established nonisomorphic interaction technique was also adapted from an existing source [16], namely the GoGo hand [22, 18].

Comparing designs from elicited gestures is an overlooked component of using GES. Providing a comparison, or control, interaction technique is a vital part of gauging the viability of the consensus sets [17]. The final evaluation of this thesis provides this type of comparison and it was found that telekinesis had lower usability than GoGo. Additionally, this thesis discuss legacy bias and its effects on the design of interaction techniques through elicited gestures. There is a divide in the gesture elicitation research community on whether legacy bias is a positive or negative effect on gesture elicitation. Some researchers state that legacy bias causes the elicited gestures to fall into a local minima of usability [19], while other researchers state that legacy bias helps in the adoption and learning of novel interaction techniques [17]. In this thesis, legacy bias is present in telekinesis, which might have hurt usability. However, it did not affect how fun participants thought telekinesis was when compared to GoGo.

The main contributions of this thesis are a consensus set for both telekinesis and flight, that can be refined in future iterations. This thesis also provides further investigations into the legacy bias discussion concerning the question if legacy bias is a detriment or benefit to GES. Mainly this thesis provides an answer to the broader research question: "How can gesture elicitation help create supernatural/nonisomorphic interaction techniques and how do these compare to already established techniques?"

2 Analysis

The following analysis section will explore the realms of travel and selection and manipulation in virtual space. The analysis of these will be used to form the base of knowledge needed for further implementation. Following this, the state of the art within these realms and related research will be investigated. Gesture elicitation studies will then be analysed so they can be put to use towards designing interaction techniques for the final evaluation.

2.1 3D Manipulation in Virtual Space

A virtual environment (VE) gives designers the opportunity to create novel selection and manipulation techniques. These selection and manipulation techniques can empower the user with the necessary tools to complete particular tasks. It is necessary to note before going into specifics of the 3D interaction needed for this thesis that the majority of selection and manipulation tasks in a 3D environment wholly depend on their individual use cases. For instance, LaViola et al. claim that the selection and manipulation skills needed to carry out surgical procedures in a medical simulator greatly differ from those needed to quickly rearrange items in an immersive 3D modelling application [18].

So-called *"spatial rigid object manipulation"* or manipulations that keep the form of the objects, may be used in 3D interactions. The four standard manipulation tasks — **selection**, **positioning**, **rotation**, and **scaling**—can help to further simplify the concept of manipulation. In most VEs, when a selection and manipulation interaction type is used, independent of particular use cases, these four main manipulation tasks may be seen [18]. The last standard manipulation task, scaling, may not serve a particular use case within the scope of this thesis. Some use cases can be imagined, but to keep the thesis more focused this task has been discarded. Additionally, scaling objects is not widely represented in the state of the art [section 2.3]. This also keeps the interactions within the confines of 6 degrees of freedom (6-DOF).

Laviola et al. also provide classifications by task decompositions as seen in figure 1. The figure shows how each classification consists of smaller sub-operations. In selection, the flow of the interaction will be that the user indicates an object, confirms that selection and receives feedback from the system that the selection has been made. Within this flow, Laviola et al. gives examples of how each step can be accomplished. The advantage of decomposing these classifications is that most 3D selection techniques can be built around these building blocks [18]. This allows a designer to focus on each step of the interaction, as well as ensure there is a flow that makes sense for the user.

Creating the same decomposition for manipulation does however involve imagining some constraints on the user, also in terms of what metaphor would be most appropriate in the given scenario. For instance, moving an object from one place to another can be done in a multitude of different metaphors. If one user is more accustomed to AutoCad software they might expect that moving an object involves moving it along a global axis, a metaphor used by Ortega et al. [21]. However, if a user is not aware of this metaphor they might move an object around as if their hand is extended beyond their reach such as with the GoGo hand metaphor [18, 22].

Laviola et al. state that 3D interaction can fall into two categories, namely isomorphic and nonisomorphic. Isomorphic interaction is a form of interaction in which the user's inputs directly and predictably affect the results of the system. In other words, there is a strict one-to-one mapping between the user's input and the system's output. Because the user's physical motions are directly translated to the movements of the virtual item. Using a joystick to control the movement of a virtual object in a game is an example of isomorphic interaction. Although it can be simple to use and can offer a high level of user control, isomorphic interaction may not be suitable for complicated tasks [18].

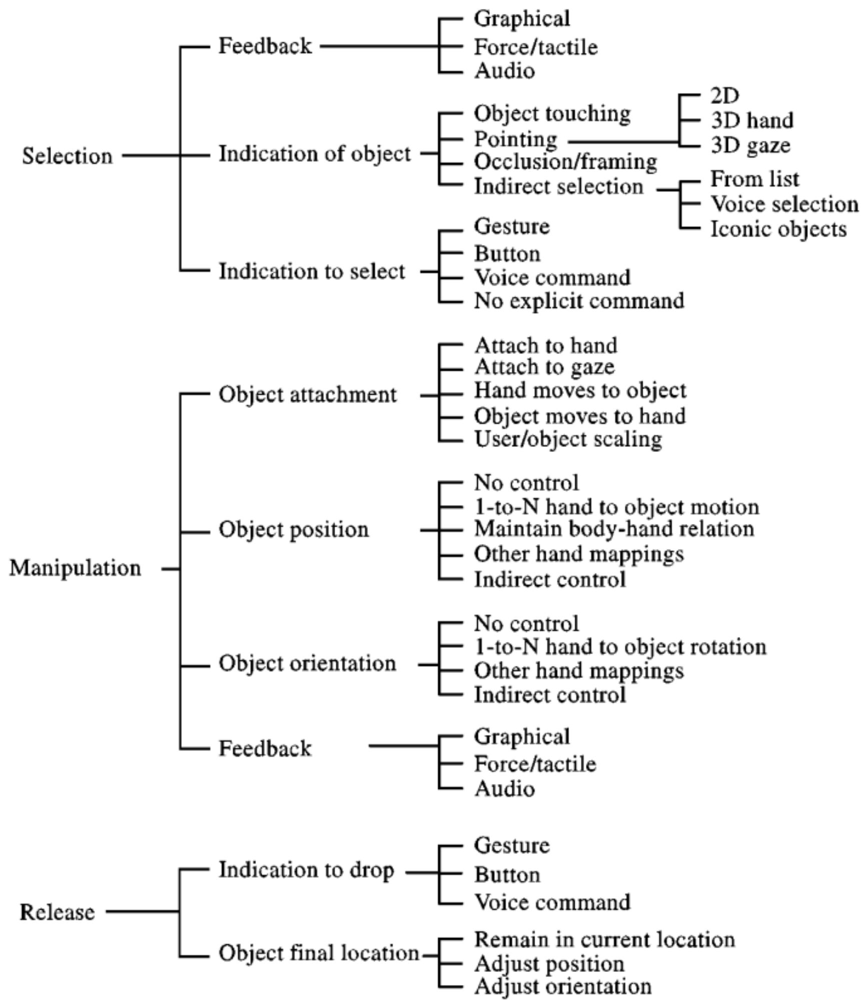


Figure 1: Classifying and decomposing selection techniques [3]

Contrarily, nonisomorphic interaction describes a style of interaction which deviates significantly from strictly realistic interaction. Often this type of interaction is called magical or supernatural interaction. In nonisomorphic interaction, the mapping between input and output may be complicated or even arbitrary, and the user's actions might not have a clear and immediate influence on the system's output. Nonisomorphic interaction can be beneficial for difficult jobs requiring a high level of adaptability or originality, but it can also be difficult for users to learn and may require a higher cognitive load to utilize properly. Using a mouse to traverse a hierarchical menu or a touch screen to handle a 3D model are two examples of nonisomorphic interactions [18]. Additionally, nonisomorphic 3D interactions do not always mean that the interaction is hard to learn. LaViola et al. also state that when strict realism is not a major requirement of the application, nonisomorphic interaction can prove to be more engaging, intuitive and useful [18]. One can imagine that building a house would be less time-consuming if you had the power of telekinesis to move around heavy objects at a distance instead of moving them through strict isomorphic techniques. Superhuman abilities, since they do not have a strict one-to-one physical translation, therefore fall within the nonisomorphic category. Since nonisomorphic interaction can be more powerful than isomorphic interaction, it would be pertinent to investigate these interaction techniques further and provide possible solutions to the difficulty of designing good nonisomorphic interaction.

2.2 Travel

A high-level definition for travel can be 'the act of moving from point A to point B' and is the motor component of navigation. Navigation consists of a much more complex series of events and decisions, these are mostly cognitive tasks that happen within the user's head space. Travel is where the bulk of interaction takes place. Travel in itself consists of a multitude of different actions that the user has to perform to complete his or her task of reaching point B. Travel is comprised of three components: **Exploration, Search** and **Maneuvering** [18].

Exploration can be defined as exploring the environment without any clear goal or destination. The user builds up knowledge about the space, making mental notes of landmarks or having the system mark them automatically. Exploration can only be supported if the user has some direct control over the movement, at the very least being able to stop any ongoing movement and reorient the viewport [18].

Search involves a defined goal location. The user might not have any clear idea of the location of the goal or how to find it. Take the example of a player needing to travel to an exit to progress further in the game, the player will then need to *search* for that exit. Search comes in two parts, which are: naïve search and primed search. In naïve search. Using our previous example, the user will be given the goal of finding the exit but has no knowledge of where exactly the exit is, or the path to it. In primed search, the user might have seen the exit before they are given the task of finding it again, or they are given some other knowledge of its position. To help guide the user in both scenarios the designer can provide wayfinding cues [18]. These cues can be discreet, such as the path to the exit being lit by light sources along the way or can be indiscreet by way of having a path set on the player UI, in a minimap or being shown by arrows directly in the environment.

Manoeuvring is the more refined task of travel which involves positioning the viewport precisely in the environment. The use cases for this task can be that the user needs to check the position of an object they have been manipulating, that it lines up with another object for instance. Another example of manoeuvring is in 3D CAD software one can usually position the viewport in useful positions via single button presses. This saves only a few seconds, but these small manoeuvres play a big factor in minimising user frustration and the total time spent as a whole [18, 3].

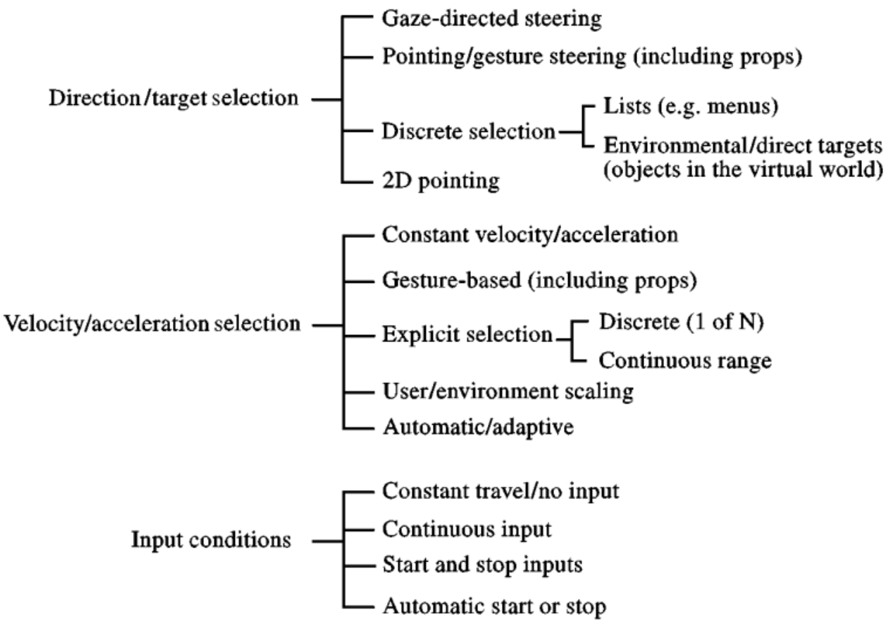


Figure 2: Decomposition of travel [3]

Travel can also be decomposed into specific tasks similarly to selection and manipulation as seen in figure 2. The first task is **direction/target selection**, specifying the direction of the motion or the endpoint of the motion. Specifying direction can be as simple as rotating the viewport, where the forward vector of that viewport designates the direction [3]. Direction can also be designated through gestures. *Mind OVR Matter* uses a nonisomorphic flying technique, where the user thrusts their hands in the direction they desire to move in [15]. Target selection could be, as some multiplayer online battle arena (MOBA) games use it, where the user selects a point on the terrain with their mouse pointer and the player avatar moves to the designated location. The user could also be required to create a specific path for their avatar, defining a path through a series of points and the amount of curvature between those points [18].

velocity/acceleration selection pertains to the act of specifying at which speed one should move towards the given target or in the given direction [18, 3]. A real-world example of this is travelling by car, where the driver specifies the direction with the steering wheel and the acceleration by the gas pedal.

Conditions of input is the means of how travel is initiated, continued and terminated [3, 18]. As an example, *Resist* travel is initiated by performing a jump through a button press, continued by extending tethers above the indicated threshold, performing a swing from that tether then subsequently releasing it at an appropriate time. Finally, the movement is terminated by landing on a flat surface [24].

2.3 State of the art

Virtual reality and especially virtual reality games have seen a surge in popularity, because of VR's unique ability to create more immersive and interactive gaming experiences. Additionally, VR offers the user greater interactivity and control. However, the development of VR games faces its own set of challenges such as technical limitations and the need for specialised expertise. The following are a few examples of novel supernatural interaction techniques, that give an overview of how the public is currently engaging with these. These examples also indicate how possible legacy bias looks. Legacy bias can arise when using the gesture elicitation method, further detailed in section 2.5.1.

"The Gallery - Episode 2: Heart of the Emberstone" Is The second game in the "The Gallery" VR game series, developed by Cloudhead Games. The game features novel gameplay elements like the ability to interact with magical artefacts and manipulate objects via telekinesis. Players can pick up objects to study them, uncover mysteries, and solve puzzles with their VR controllers. The player's telekinetic abilities allow them to bi-manually interact with objects. When moving objects a flexible ray protrudes from the user's palm to the object being manipulated. The ray bends and stretches in some fashion like a fishing rod pulling along a weight. This gives the user added feedback on the weight of objects and makes the interaction seem more rooted in the physics of the world [6]. Figure 3 shows a player using the telekinesis power

Telekinesis is not only used for manipulating objects but also as a tool in the game mechanics. For example, players may encounter puzzles where they need to move and arrange objects in a specific way to reveal a hidden pathway or activate a mechanism. By utilizing their telekinetic powers, they can grab and manipulate these objects, rotate them, or position them correctly, to progress through the game [6].

Figure 3: Telekinetic power in "The Gallery - Episode 2"

"Vader Immortal" is a VR game set in the Star Wars™ universe, developed by ILMxLAB [12]. Besides featuring combat gameplay using light sabres, the game also allows players to use the force. The telekinetic powers of the force are utilised in several ways. Players will use it to solve puzzles and manipulate objects in the environment to their advantage as well as progress through the game.

To activate and control the Force, players typically use hand gestures and movements with their VR controllers. Different hand gestures can be employed for various Force powers, such as raising your hand to call something to you or making a grabbing motion to telekinetically control an object. Players can typically reach out their hand toward an object they want to interact with and make a specific motion to grab and manipulate it. Player hand motions allow them to move, throw, or manipulate it in accordance with the game's physics. Different Force abilities, such as Force push or Force choke, may be triggered through specific gestures or button combinations on the VR controllers. These actions allow players to utilise the Force in combat or puzzle-solving scenarios.

"Resist" is a science fiction action VR game, set in the not-too-distant future. The goal of the player is to establish a resistance against mega corporations oppressing the citizens of the city they inhabit.

The game incorporates shooter combat elements as well as a novel travel technique. In the game, the player initiates travel by holding a button that, when released, launches them into the air. Following this, players can shoot tethers towards the high-rise buildings surrounding them. Players then swing from these tethers, release and fire another rope. Players can also fire a single rope towards their target location and pull themselves directly towards it instead of relying on timing their swings perfectly. This also allows the player to have some mid-air control of their heading. This novel travel technique provides a supernatural traversal feature to the expansive world of Resist. This travel technique seems to have been inspired by the Spiderman™ comic book character, who employs a similar technique to travel around New York City.

2.4 Related Research

To find a suitable method for designing good supernatural/nonisomorphic travel and selection and manipulation, some investigations into previous work should be done. Some of the related research that was found employed a participatory design technique called gesture elicitation study. This technique puts the user in the role of the designer by way of the designer eliciting gestures that the user deems appropriate for a given interaction. This technique will be further explored in section 2.5.

Vatuva et al. created a gesture elicitation study for TV controls. Their paper presents the results of a study investigating users' preferences for free-hand gestures when controlling TV displays. To date, there are no regulations or recommendations that could help those who design and use these interfaces. In addition to offering guidelines and suggestions for practitioners interested in prototyping free-hand gestural designs for interactive TV, the paper proposes a set of gesture commands for fundamental TV control tasks [27].

Twenty participants in the study were asked to use free-hand gestures to complete simple TV control tasks. After conducting an agreement analysis on the user-elicited gestures, a set of 12 gesture instructions were recommended for common TV control activities. The suggested set includes motions for channel-switching, volume-controlling, and accessing menus. Covering issues like the size and shape of the gesture space, the number of fingers used in the gesture, and the gesture's directionality. This study is one of the earlier gesture elicitation studies performed, and inspired a great deal of further research using this design technique [27].

Many challenges still lie in the way of creating intuitive and efficient user interfaces for VR environments. One approach is to use whole-body gestures for selection and manipulation interactions instead of traditional input devices such as keyboards or controllers. Ortega et al. [21] aimed to investigate the type of gesture agreement rates for these interactions in VR environments.

A whole-body gesture elicitation study was conducted using Head Mounted Displays (HMDs) with 23 participants from different backgrounds. Participants were asked to perform gestures for 20 distinct referents with multiple gestures per referent for selection and manipulation. The study also explored legacy bias reduction methods and suggested that further research is needed to determine if the currently accepted methodology is optimal. Overall, this study provides insights into the type of gestures that are appropriate for selection and manipulation interactions in VR environments, which can help improve the user experience for whole-body interactions in VR applications. Further research is needed to explore legacy bias reduction methods and optimise the use of whole-body gestures in VR environments [21].

Bhomwick, Kalita and Sorathia [2] wrote a paper describing a two-stage elicitation investigation for nail size items and object selection in dense and obstructed virtual environments (VEs). Target items in virtual environments can be as small as nails, obscured, and placed at various distances from users, which makes object selection more difficult. The first stage found the movements that were the most intuitive and natural for this type of interaction. For four separate VEs, 40 participants contributed a total of 737 gestures [2].

In the second stage, the selected gestures were evaluated in terms of accuracy and task completion times. The results showed that users preferred one-handed interaction and interactions that allow them to alternate between their hands. The final results of this study, offer suggestions for enhancing task completion rates and accuracy for nail-sized object selection tasks in dense and occluded VEs with a wide range of object distances. The findings imply that employing intuitive and natural gestures can enhance user performance in these tasks. The preference for one-handed interaction also emphasises how crucial it is to develop interfaces that are pleasant to use for lengthy periods. Future studies could examine how these results can be utilised to enhance current interfaces for object selection tasks or how they can be applied to different virtual experiences [2].

Ganapathia and Sorathia [11] wrote a paper that presents a study on the most natural and intuitive body gestures for virtual travel tasks in various virtual environments. The use of proxy gestures for virtual travel in VEs presents specific limitations concerning the gestures' naturalness, intuitiveness, and fatigue involved while performing the gesture in real space. The requirements of the proxy gestures were that they had to be natural, demand less effort, and have the ability to move long virtual distances without colliding with real-world boundaries. To address this issue, a gesture elicitation study was conducted to identify the most natural and intuitive body gestures for virtual travel tasks in three different VEs in a sitting position.

The study consisted of two experiments. In Experiment 1 ($n = 40$), participants were required to perform gestures of their choice for travel without any body part limitations for each of the multitasking environments. In Experiment 2 ($n = 40$), a new group of participants evaluated the gesture set obtained in Experiment 1 based on appropriateness, ease of use, effort, and user preference. The results showed that certain body gestures were more natural and intuitive than others for virtual travel tasks in VEs. These findings can inform the design of HMD-VR interfaces that require locomotion through proxy gestures.

2.5 Gesture Elicitation

Participatory design (PD) is the method of having the end user engaged with the design of a system from the very beginning. PD flips the established design pipeline on its head and instead views the end user as the expert of what interactions they need and what tools they require to complete their tasks. Here the designer assumes the role of a technical consultant instead of being the expert. A gesture elicitation study (GES) stems from this design philosophy, where under controlled circumstances the designer can elicit the interactions that are most appropriate from their end users. The gist of a GES is to prompt users with a certain interaction they have to perform and ask them to provide a gesture they deem appropriate for it. Therefore, in theory, allowing for greater usability of the application by way of increasing the guessability of each specific interaction [23, 30]. GES has been used in a wide array of participatory design studies [Section 2.4]. Gesture elicitation can be a good way to create both novel and intuitive controls for gesture-based interaction. A "good" gesture for any interaction is one that satisfies certain design criteria. Such as discoverability, ease of use, performance, memorability, or reliability. GES represents an approach to naturally extract these "good" gestures [19] where user-defined gestures are both more memorable as well as guessable [30]. The prompt that participants are told to perform, is called a referent. The referent can be given to a participant in several ways [30]. Some studies have used animations on user interfaces where the interaction is shown to the user and they then have to do a gesture that they think would cause that interaction [31, 2]. Referents can also be given via spoken word or shown as text [28, 21, 30]. When users have performed that referent, their gestures will be recorded.

Different data-gathering methods exist for GES. One of the more technical approaches could involve depth sensors and point clouds [26, 27]. Other more primitive data gathering methods involve setting up cameras and then manually reviewing and classifying gestures [2, 11]. These gestures will then be sorted into equivalence classes based on the features that the gesture possesses and the similarities between them. This of course introduces some human bias to the final design of the gestures but can nevertheless provide significant results if there is limited time or equipment [2, 21].

Once the gestures have been categorised, the agreement rate $AR(r)$ or agreement index $A(r)$ has to be determined between each gesture. The agreement index can be seen as the number of pairs in agreement divided by the total number of pairs. The agreement of a gesture set gives the researcher an idea of how intuitive the elicited gesture is [30, 31].

$$A(r) = \sum_{P_i \subseteq P} \left(\frac{|P_i|}{|P|} \right)^2 \tag{1}$$

P is the set of all proposals for the referent r, and P_i is the subset of equivalent proposals taken from all proposals. However using this formula, gestures would have a non-zero agreement rate since a gesture could agree with itself. This means that a total disagreement between participants would never be shown by $A(r)$ A revised formula would give overall lower agreement rates but would eliminate the issue. The revised formula can be seen below [29].

$$AR(r) = \frac{|P|}{|P|-1} \sum_{P_i \subseteq P} \left(\frac{|P_i|}{|P|} \right)^2 - \frac{1}{|P|-1} \tag{2}$$

The higher the agreement rate, then theoretically the more intuitive the gesture will be for uninitiated users. Williams and Ortega state that for a study of 20 participants an agreement rate of higher than 0.3 denotes a high agreement and lower than 0.1 denotes a generally low agreement [30].

This design technique has proven to be advantageous in designing nonisomorphic interaction techniques [Section 2.4]. This thesis will use this technique to design and implement both nonisomorphic travel and selection and manipulation, in the hopes of creating ”good” interaction design.

2.5.1 Legacy Bias

Legacy bias is what arises when participants have a shared reference point for a given referent. As an example, flying interactions has some legacy bias in that we see that birds flap their wings to fly and Superman extends both arms above his head to fly. This legacy can come up in GES when users are prompted with a referent [31]. The legacy bias can be useful in some cases, where the intention is the ease of use and quick adaption by the user [19]. However, they can provide a limitation in the sense that the study can fail to uncover the most useful gesture for the desired interaction, as Wobbrock et al. describe as a local minima [19].

Three techniques can be used to improve the responses to a GES as well as reduce legacy bias. In a **production** study users will be told to perform multiple gestures for each referent. This may force them to move beyond legacy-inspired gestures and allow the user to employ a higher reflection in their responses. This can increase the variety and creativity of the gesture responses again reducing the chance of falling into a local minima [19]. Furthermore, users can also be told to perform a new gesture until one is performed that has not been performed by any other participants in the study.

Priming involves getting users to think about the possibilities of interaction involving new technology. For example, users who were primed with performing tasks using physical objects before using a multi-touch table were less likely to use pointing-based gestures compared to users who were primed with a traditional display [19]. This priming can come in several different forms, for instance, the desired task result, such as an object moving from one place to another on a display can be shown in the physical space by the experimenter, or through a video of an example gesture and interaction taking place. This can correct any misconceptions that the user might have about the given technology [19]. For instance, some users might not know that certain VR controllers can offer precise finger position tracking.

Using **Partners** means performing an elicitation study in groups rather than as individuals. Here a group of users collaborate on providing the appropriate gestures for the given interaction, engaging in a form of participatory sense-making [10, 19]. Using groups to commonly reach an understanding as well as build on each other's ideas can provide better understandings and more novel interactions. This can also increase the ecological validity of multi-user systems [19].

In this study, however, it can be argued that legacy bias can be both a hindrance and an opportunity. Users having some previous commonality with how they think a supernatural interaction should operate can be hard to eliminate. Most people are familiar with some form of supernatural interaction from digital media, be it Star Wars, Harry Potter, Minority Report or the plethora of Marvel superhero movies. Mubin et al. [20] performed a workshop revolving around science-fiction-inspired design in HCI and its advantages. Researchers were shown a collection of interfaces from science fiction media. The participants in the workshop all agreed that inspiration from science fiction can be integral to each phase of the design cycle. Especially for the conceptualisation stage, it can be useful to extract design requirements and that the influence of science fiction is to inform the implementation of prototyping for novel interfaces [20]. An example of this sci-fi-inspired design is Resist, detailed in section 2.3

Ortega et al. [21] also discuss legacy bias on multiple fronts. They still saw legacy bias present in their final results even though they used the production method for reducing legacy bias. They also question if legacy bias can be definitively eliminated and if it is even as big of a problem for systems designed with elicited gestures than what is stipulated in the literature [21, 19, 30]. Köpsel and Nikola [17] also discuss how legacy bias can be beneficial, especially for novel interfaces and interactions. They argue that users can feel more at ease and take less time and effort to learn new modes of interaction by taking the good aspects of prior systems and incorporating them into new ideas. Additionally, they state that designers should compare designs created from gesture elicitation with established designs in the same areas [17].

2.5.2 Defining Referents for Selection and Manipulation

Based upon the investigation of 3D selection and manipulation [Section 2.1] some referents can be defined. But before that, in the interest of creating a more focused thesis, some restrictions on user interaction will be established. As previously mentioned the scaling of objects is not widely represented in any of the games mentioned from the state of the art [Section 2.3]. Therefore this thesis will focus on the first three aspects of 3D manipulation **Selection, Positioning and Rotation**. To define the referents used in this thesis I will base them on the 3D manipulation task decomposition in figure 1. What will not be present in the referent list is how feedback is given. The feedback is given to the user from the system and is not in itself an input. Additionally, the indication to select and object attachment tasks carry over into each other. When the user gestures to select the object, the object will subsequently be attached. The process of object attachment is also a process determined by the system, meaning that the attachment to whatever the final interaction technique is, will be done to the user, instead of by the user. Going through the selection and manipulation task decomposition 11 referents can be defined.

Selection	Positioning	Rotation
Find object	Translate X	Rotate X
Designate object	Translate Y	Rotate Y
Confirm designation	Translate Z	Rotate Z
Release	Hold	

Table 1: Referents for 3D manipulation.

2.5.3 Defining Referents for Travel

Based on the task decompositions of travel [Section 2.2, Figure 2] some referents can be defined. The referents will be focused on nonisomorphic travel techniques, specifically flight. This means that the user will have the ability to travel 3-dimensionally instead of being grounded on a 2d plane.

Direction/target selection	Velocity/accelaration selection	Input conditions
Fly up	Increase speed	Start flight
Fly down	Hold Speed	End flight
Fly forward	Decrease speed	
Strafe left	Hover	
Strafe right		
Turn (left/right)		

Table 2: Referents for flight

Direction/target selection contains all the interactions that a given user needs for controlling his or her flight, and the means of going from A to B. It was deemed necessary to give users the ability to strafe i.e. the ability to look in one direction while moving in another. This can be critical to letting users keep their spatial orientation of the area they are navigating. Turning however involves changing the travelling vector. **Velocity/acceleration selection** will allow the user to have more control over the flight system. If more fine-grained control of user position is needed they would need to decrease their speed and if the user wishes to arrive at their destination faster they would need to increase speed. Additionally, users will also have to perform a certain gesture to hold the speed they are at, for some gestures, this might be a slight change or the continuation of a gesture to hold the current speed. Hover is distinguished from reducing the speed to 0 because it is a separate action where participants will perform a certain gesture to keep their current position in the air. **Input Conditions** is simply starting and ending the flight, this can be done through discrete actions such as ending flight on ground collision or a specific gesture to start flight.

2.6 Summary of Analysis

In this analysis, the realm of supernatural interaction was explored. Starting with selection and manipulation, several interaction techniques and metaphors were examined [Section 2.1]. Selection and manipulation consists of the four standard manipulation tasks - selection, positioning, rotation and scaling. However, the last of those standard tasks, scaling, will not be included in this thesis. The two main reasons are, scaling is not widely represented in the state of the art and it lies outside the scope of this thesis. Selection and manipulation can come in two forms, isomorphic interaction and nonisomorphic interaction. Isomorphic interaction is the interaction that conforms to the physical constraints of a given user, meaning there is a 1:1 mapping of input to output. Nonisomorphic interaction breaks free from the bonds of realism and allows users to engage in interaction that lies outside their physical limitations. Some of these interactions can be represented as magical within the context of the system. Nonisomorphic interactions can be intuitive as well as highly productive, but they are also a challenge to design.

Travel was similarly investigated, both high-level definitions and fine-grained components were explored [Section 2.2]. The three components of travel: Exploration, search and manoeuvring were also defined. Similarly to selection and manipulation, travel can also be defined as isomorphic and nonisomorphic. The same benefits apply to nonisomorphic travel. They can be intuitive and powerful.

Investigating related research [Section 2.4] uncovers that many researchers have designed both nonisomorphic travel and selection and manipulation using the gesture elicitation method. These research projects each investigate possible solutions to respective problems within nonisomorphic interaction, either improving upon existing designs or imagining new ones from the results of their gesture elicitation studies. These also provide a view of how GES is performed in the current literature.

Given the difficulties in designing good nonisomorphic interaction, is where gesture elicitation can prove beneficial in this design process and for creating natural and usable supernatural selection and manipulation. To employ and perform a GES some referents need to be defined in this regard the task decompositions from travel and selection and manipulation are used. Figure 1 shows the task decomposition for selection and manipulation, and figure 2 shows the task decompositions for travel. The resulting referents are defined in table 1 and 2.

These referents will become the basis of the gesture elicitation study detailed in the coming section [Section 4]. GES has the opportunity to spawn truly novel ideas for how to design a nonisomorphic interaction space. If agreements are high in both travel and selection and manipulation, the product of this thesis could create new ideas for designing such interaction techniques. Moreover, the resulting interactions should be compared to an already established nonisomorphic interaction technique as mentioned in section 2.5.1. This will allow us to investigate the usefulness of the implemented interactions.

From this analysis, the research question of this thesis can be formulated as: "How can gesture elicitation help create supernatural/nonisomorphic interaction techniques and how do these compare to already established techniques?"

3 Methods

The remainder of this thesis will consist of the following sections. The gesture elicitation study, Design and implementation of the results from the GES, an evaluation comparing the implemented interaction technique and lastly a discussion and conclusion of that evaluation.

The gesture elicitation study was designed based on the guidelines presented by Williams and Ortega [30]. The study is a within-subjects design and the procedure will see participants perform gestures for both referent sets, travel and selection and manipulation. Participants starting referent sets will be alternated between participants. Participants are video and audio recorded for subsequent analysis of their gestures. Participant gestures are qualitatively analysed from the video footage and entered into a data set. This data set will then be analysed for agreement using the agreement rate formula [Equation 2]. Following this, the consensus set for each interaction will be formed which will then be implemented for the subsequent comparison and evaluation. A more in-depth explanation of the procedure and the results can be found in section 4.

However,it was concluded that the flight gestures that were elicited had too poor agreement rates to be considered viable. These gestures were therefore not implemented. This is further discussed in section 4.2.2 and 7. The point of designing from elicited gestures is that they are easily guessable once implemented. If a consensus set consistently lies below the 0.3 threshold, which denotes a high agreement [30], it could not benefit from what gesture elicitation has to offer. These points are further discussed in section 7

Once the telekinesis or nonisomorphic interaction had been implemented, the interaction technique could then be evaluated and compared to an established interaction technique, GoGo hand [18, 22]. Following a within-subjects design, participants interacted with both interaction techniques and completed two tasks for each [Section 5.4]. The tasks are the same and the order of what interaction technique the participant tried first, was alternated each time. After interacting with the first technique participants answered a questionnaire and then interacted with the next. Once the second interaction had been completed the participant will answer the same questionnaire regarding that interaction technique. Participants will also be timed for their completion of each task. The measure chosen for this comparison evaluation is the system usability scale (SUS) [5], which will give an overall score of both interactions' usability. Together with the SUS participants are also asked how fun they would rate both systems as well as if they felt like they had a superpower while interacting. There will then be a free text question in this questionnaire that will ask the participant to expand on their answers to the fun rating and if they felt they could relate their experience to anything they had seen before. This last question will allow us to check what kind of legacy bias is present in both interactions. Further details on the procedure can be found in section 6.

4 Gesture Elicitation Study

A gesture elicitation study was conducted with 20 participants. The aim of this study is to determine a consensus set of gestures for both travel via flight and selection and manipulation via telekinesis. 12 referents for flight [Table 4] and 11 referents [Table 3] for telekinesis were defined based on the task decompositions offered by Bowman et al. [3].

4.1 Procedure

Participants were recruited based largely on convenience sampling around the campus of Aalborg University Copenhagen. When a participant had been recruited, they were led to a controlled lab space where the study could be held. First, the participant was asked to read the introduction on the consent form which can be seen in appendix A. The introduction consisted mostly of explaining the meaning behind the study they were about to partake in and what the procedure of the test would be. The introduction explained in broad strokes what gesture elicitation is, why I had asked them to participate and what my motivations are for conducting the study. Additionally, informing them that the session would be audio and video recorded. Once the participant had read the introduction they were asked if they had any questions or needed clarifications on any points. When that had been resolved they were asked to fill out the consent form which also includes some demographical questions.

In this GES the user would not have any equipment that would be part of the implementation, meaning any controllers or the HMD. This was done so users would, as much as possible, refrain from using buttons on the controller rather than performing a gesture. After the consent form had been filled out and signed, the participant was asked to stand on a mark on the floor and face one of the cameras. Each participant started with a randomised interaction meaning one half of the participants started with flying interactions, and the other half started with telekinesis interactions. Referents were then spoken aloud to the participant. Participants were allowed to ask for clarifications to the referent if so needed. If the participant needed clarification the test conductor would strictly refrain from performing any gestures in order to clarify what was meant by the referent. The entirety of the elicitation study was recorded with two video cameras, one facing the participant from the front and one in profile to the participant, this ensured that all angles of the participant gestures were captured for subsequent analysis. Once the participant had performed gestures for all the referents they were asked a follow-up question if they took any inspiration from previous experiences when they formulated their gestures. Some participants proposed multiple gestures for a referent, in that case, the participant was asked to choose a favourite from those gestures. The favourite would be the one entered into the data set. Finally, after supplying a gesture to all referents, participants were asked if they drew any inspiration from anything specific in order to formulate their gestures. The data would be analysed through observation, meaning that all video clips would be qualitatively analysed and the gestures participants performed would then be entered into a data set by hand.

Apparatus

Participants were recorded using two Canon EOS 1D DSLR cameras. One of the cameras was connected to a laptop PC to monitor the framing of the video. The EOS utility software was used to start the recording, as well as ingest formatted video.

4.2 Results

After all video clips had been analysed and entered into a data set, the gestures were ready to be analysed. The methods for analysing the gestures will be the number of agreeing participants for each gesture together with the agreement rate for each gesture in the consensus set.

4.2.1 Results for Telekinesis

The results for the telekinesis chosen gestures can be found in table 3. This table was formulated from the full results that can be seen in appendix B. Some referents had competing most chosen gestures, meaning that some gestures are tied for being the most agreed-upon gesture. But for the sake of creating a coherent set of interactions that would not clash with other gestures, these were chosen as a compromise.

Referent	**Most chosen gesture**	**ID**	**Count**	**AR**
Specify	Point (open palm)	l3	10	0.43
Confirm	Grab	m5	7	0.19
Move up	Move arm up (stick metaphor)	n2	10	0.35
Move left/right	Move arm left/right (stick metaphor)	o2	10	0.35
Move away	Extend arm (joystick metaphor)	p4	5	0.13
Move closer	Retract arm (joystick metaphor)	q4	10	0.27
Hold	Other hand, palm up, held there	r1	5	0.14
Rotate X (pitch)	Other hand, in fist at side, wheel motion	s5	5	0.11
Rotate Y (yaw)	Other hand, in fist at bottom, wheel motion	t5	5	0.12
Rotate Z (roll)	Main hand turn clockwise/counter clockwise	u4	8	0.22
Release	Open palm	v1	10	0.30

Table 3: Telekinesis referents and chosen gestures (ID = gesture identifier, AR = agreement rate)

The referents that have competing gestures are *p4* and *p6*, *r1* and *r6*, and *t5* and *t6*. *p4* ”Extend arm” was chosen over *p6* ”Palm open facing away, extending arm” for the referent ”Move away” because the majority had chosen *m5* ”Grab” as confirmation of selection as well as *v1* ”open palm” had been chosen as the method of releasing the object. In this case, it would be hard to distinguish, from a system design perspective, how *p6* ”Palm open facing away, extending arm” and *v1* ”Open palm” are different from each other. Additionally, using *m5* ”grab” as the method of continuing the interaction with the object, in other terms holding the object, would give a suitable interaction flow. Meaning that users start the interaction by grabbing the object, continue the interaction by having their hand held closed and end it by releasing the object. Using *p6* Palm open facing away, extending arm” in the middle of that interaction, would be hard to distinguish when implementing the system, when the gesture for releasing the object is ”open palm”

r1 ”Other hand, palm up, held there” was chosen over *r6* ”Squeeze hand” for similar reasons. Another gesture for the referent confirm was *m3* ”squeeze, hold hand” which was performed by 3 participants. Choosing *r1* over *r6* opens up the possibility of confirming one’s selection by squeezing the hand into a fist or grabbing, which brings the number of participants in agreement to 10. Merging the two gestures would also increase the agreement rate from 0.19 to 0.30 Additionally, from a usability standpoint having the option to either have your hand semi-closed or fully closed and still interacting with the object would result in fewer errors than trying to distinguish between a semi-closed hand and a fist for two different interactions.

t5 "other hand, in fist at bottom, wheel motion" was chosen over *t6* "Other hand grab and turn from the bottom" because *t5* shares a similarity with *s5* "other hand, in fist at side, wheel motion". Having similar gestures improves the guessability of gestures which in the end improves the usability of the whole system.

For object translation in relative X and Y axes, participants indicated that the object would be attached to the hand as if it was on the end of a long stick held in the hand. This is what is meant by 'stick metaphor' in table 3. They said that the object would follow along to wherever their hand was pointing with some delay, as if the stick they were holding the object with, is flexible.

Figure 4 depicts all the telekinesis referents. The bars are colour-coded so green represents a referent with a high agreement rate (above 0.3 [30]), and yellow represents a medium agreement rate (between 0.3 and 0.1). As can be seen from the figure none of the agreement rates are below 0.1, which means that the interaction should present a relatively intuitive and guessable experience as a whole [30]. Figure 6 shows a rendering of the gestures chosen.

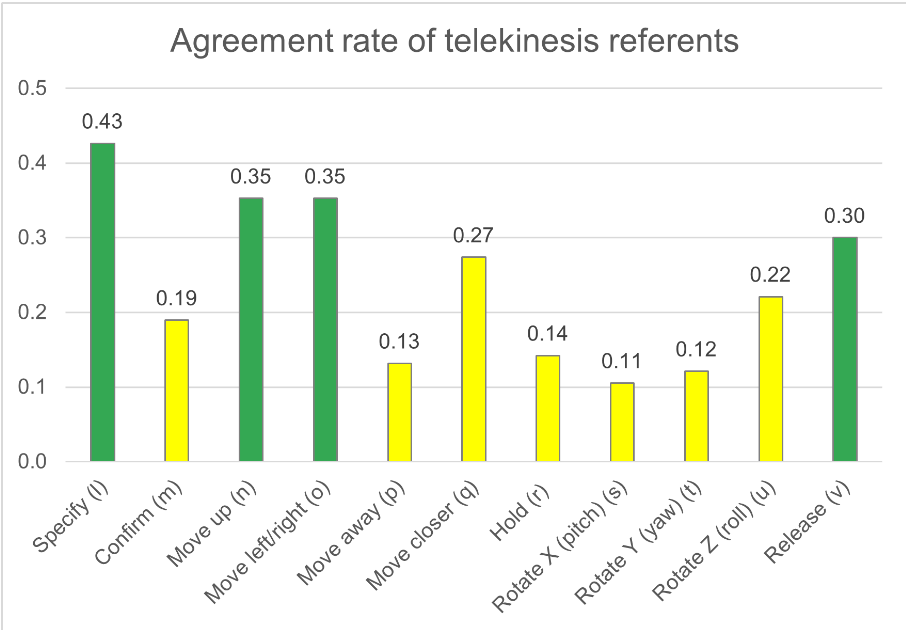


Figure 4: Agreement rates of telekinesis visualised

Participant answers to the question if they drew inspiration from anything while formulating their gestures were not uniform. Two participants mentioned the X-Men™ specifically the Magneto character. Two participants mentioned 'The Force' from Star Wars™ , 6 participants said that they did not draw inspiration from anything specific. The rest mentioned different topics, such as Harry Potter™ Legend of Zelda™ and PORTAL developed and published by Valve, etc.

4.2.2 Results for Flight

The chosen gestures for flying can be found in table 4. Along with the amount of agreeing gestures suggestions in agreement for a given gesture, their coding and individual agreement rates. The full results including referents and a more elaborate description of the suggested gestures can be seen in appendix B. Contrary to the elicited telekinesis gestures, flying gestures had an overall poor agreement rate in all but the referent for turning (j). This does bring up some considerations for how and what should be implemented for a final evaluation.

Referent	**Most chosen gesture**	**ID**	**Count**	**AR**
Engage fly mode	Small hop	a7	5	0.09
Fly Up	Both arms extended upward, hands in fists	b1	4	0.11
Fly down	Both arms extended down, hands in fists	c1	4	0.08
Fly forward	Both arms forward, hands in fists	d1	5	0.14
Increase forward speed	Thrust arms forward, hands in fists	e5	5	0.08
Decrease forward speed	Retract arms towards the body, hands in fists	f1	4	0.09
Hold speed	Hold the lean to the desired speed	g4	6	0.14
Stop and hover	Palms open towards the ground	h1	7	0.20
Strafe	Arm extension opposite side, open palm	i5	6	0.13
Turn	Turn whole body	j1	17	0.72
Land and stop	Ground collision	k2	9	0.22

Table 4: Flying referents and gestures elicited

Figure 5 depicts all the flying agreement rates for each referent. What is immediately apparent is how many of the consensus sets are below or close to 0.1 AR which denotes a low agreement. It is possible that extraneous factors, such as the participant's lack of knowledge or expertise with flying in a virtual environment, contributed to the low agreement rates for flying gestures. Or that participants had either no comparable or a wider range of experiences that they drew inspiration from.

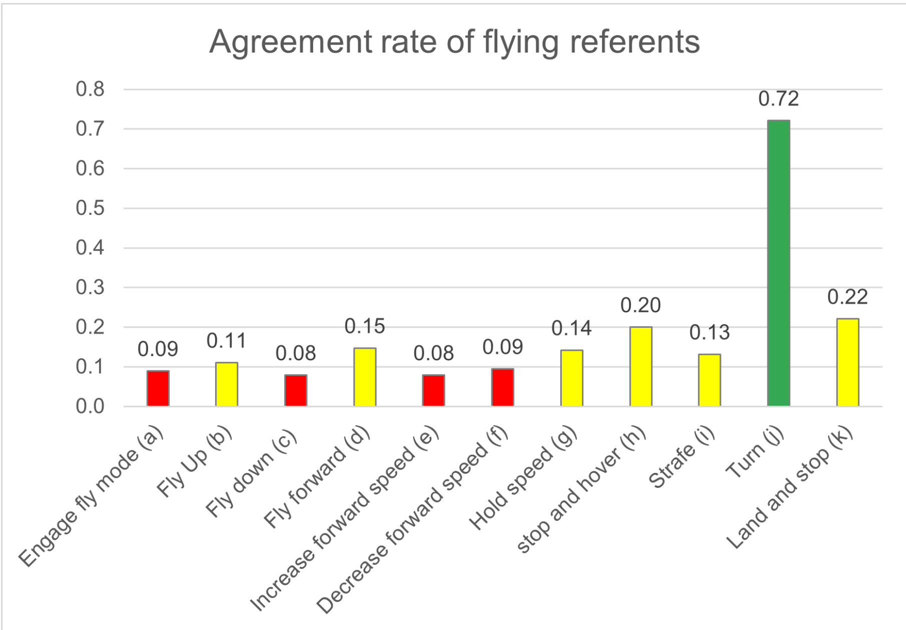


Figure 5: Agreement rates of flying visualised

I have chosen to concentrate on the results for selection and manipulation gestures in this thesis notwithstanding the possible causes for the low results of flight. Given that the telekinesis consensus sets have much higher agreement rates, I think they would offer more important insights into how consumers engage with virtual worlds. Hopefully resulting in the ability to provide a more thorough and substantial implementation of nonisomorphic selection and manipulation to understand their implications for the creation of future VR interfaces.

5 Design & Implementation

After having settled that nonisomorphic selection and manipulation in virtual environments should be the focus of the final evaluation of this thesis, work could begin on implementing the gestures. The interactions will be implemented in the Unity3D game engine. Steam VR will facilitate basic integration from Unity3D to an HMD [25]. In essence, the telekinesis interaction can be described as a nonisomorphic 3D selection and manipulation technique. The technique needs to employ 6 degrees of freedom (6-DOF) manipulation of objects. The selection of objects will employ a 2-DOF ray-casting technique. This selection technique is also well established according to LaViola et al. [18].

figure 6 shows all of the telekinesis gestures that participants performed in the GES. 1 is point (open palm), where users will point their hand at an object they wish to interact with. 2 is grabbing the desired object. 3 is translating the object up and down, by pointing the controller in a given direction the user can translate objects in relative X and Y axes. 4. is moving an object closer to or away from the user, here users will simply extend their arm to move the object further away and pull their arm closer to move objects closer to them. 5 is rotating the object on the Z axis. Here users will simply turn the hand interacting with the object clockwise or counterclockwise. 6. is holding the object in place, here users will point their open palm of their off-hand at the object and it will freeze in position until interacted with again. 7. is rotating the object on the X-axis (pitch). Users will grab with their off-hand and pull it up and over their main hand in a circle to pitch it up or move it down and under the main hand to pitch down. 8. is rotating the object around the Y axis. Similarly, users will grab with their off-hand but then move it around to the left or the right of the main hand to yaw the object in the desired direction.

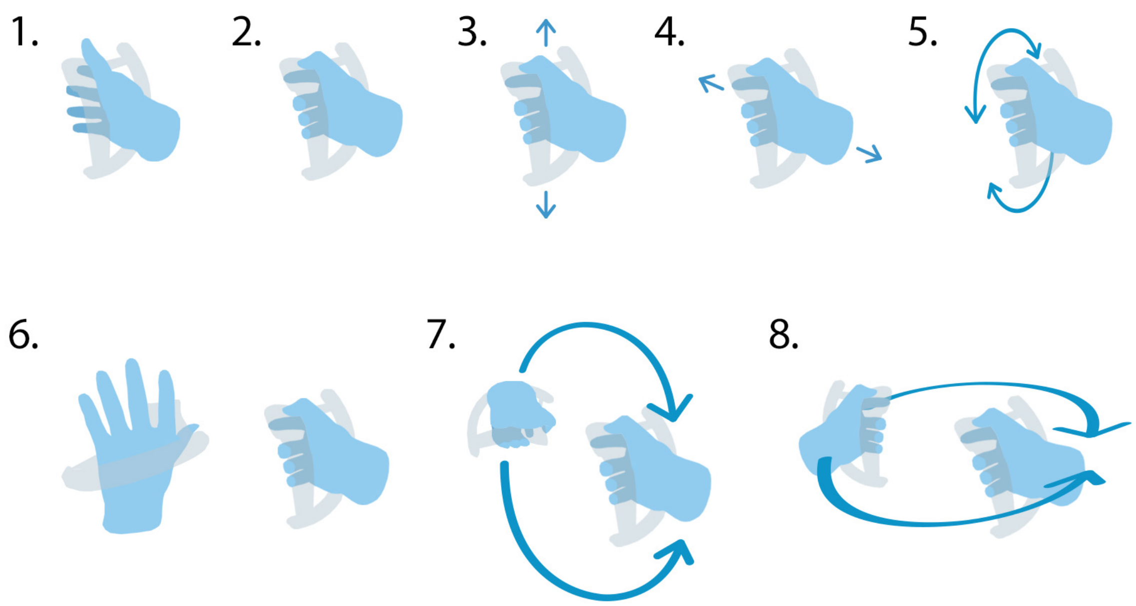


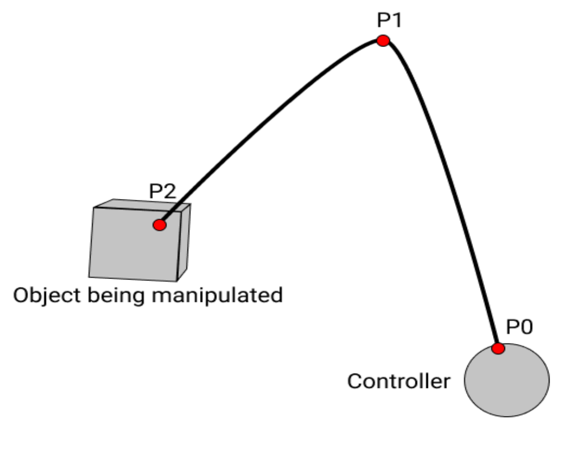
Figure 6: Chosen gestures for selection and manipulation

5.1 Translation

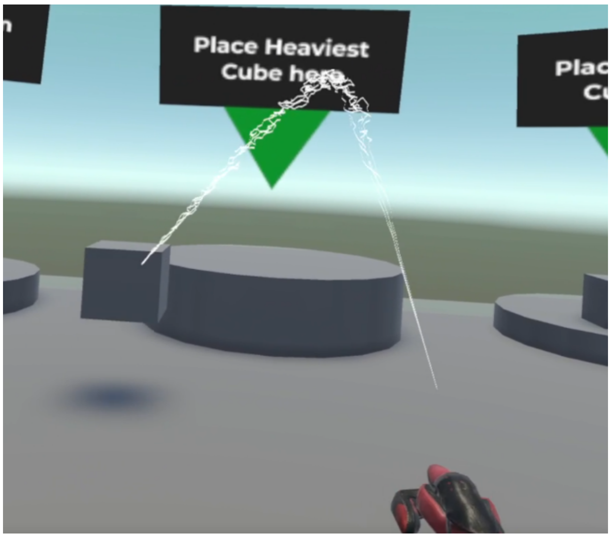
To start interacting with an object participants in the GES elected to point at the object with an open palm, and confirm their selection by doing a grabbing motion with their fingers. Steam VR has an input system that listens for different controller interactions. Using this it can activate certain scripts when one or several conditions for user input is met. To start interacting with an object the user will have to satisfy the *Grab_pinch* condition which relates to having all fingers in contact with the controller.

Most participants in the GES expressed that when moving the objects around, the object would move as if it was connected to the hand with a flexible rod. One such selection and manipulation technique that partially fits most of these requirements can be found on the unity asset store [13]. With some modifications to user feedback, rotation and user-relative z-axis translation, this will serve as the foundation for the selection and manipulation. In essence, the asset uses controller vectors and applies a force for the difference in where the currently interacted object is and where it is supposed to be. Therefore, the object has a feeling of weight by the way of actually including the *rigidbody* variables in the calculation of how an object is manipulated.

However, the user lacks some feedback on the system state of their telekinetic powers, to create that an arc was implemented that gives the user a better sense of the direction the object is being pulled in. The design of this arc was adapted from a previous project that I was part of [7]. A line renderer is attached between the player's virtual and the object being manipulated following a quadratic bezier curve. The three points of the curve are respectively, the virtual hand position (P0), the object being manipulated (P2) and a point equal distances from both (P1). The middle point is reliant on the direction the virtual hand is pointing, and changes position based on the direction that the object is being pulled in. In essence, if the user moves the object in a given direction it will appear as though a flexible rod is connecting the virtual hand and the object. Figure 7 shows an illustration of the arc and an in-engine screenshot [7].



(a) Telekinesis arc illustrated



(b) In-engine screen shot

Figure 7: (Adapted from Dyrholm et al. [7])

5.2 Rotation

For a user to rotate the object they are manipulating in all three degrees (pitch, yaw and roll) they will also have to engage in bi-manual interaction. The first rotation implemented was 'roll'. Here users indicated that they would turn the hand that they are manipulating the object with, in a clockwise or counterclockwise rotation.

```
void Update()
{
//[...]
    if (!otherHand.isRotating && !telekinesis.m_ActiveObject.frozen)
    {
        GameObject ActiveGO = telekinesis.m_ActiveObject.gameObject;

        Vector3 playerToObject = ActiveGO.transform.position - player.transform.position;
        float rotationAngle = transform.rotation.eulerAngles.z;
        if (rotationAngle > 180)
        {
            rotationAngle -= 360;
        }

        if (Math.Abs(rotationAngle) > 60)
        {
            if (rotationAngle > 0)
            {
                rotationAngle -= 60;
            }
            if (rotationAngle < 0)
            {
                rotationAngle += 60;
            }
            ActiveGO.transform.RotateAround(ActiveGO.transform.position,
                playerToObject, rotationAngle * 2 * Time.deltaTime);
        }
    }
//[...]
}
```

Listing 1: Roll implementation

There is one liberty taken in this script, being that the object only starts rolling when the user's controller roll exceeds a certain limit, this being 60 degrees of rotation. When that is exceeded the roll of the controller is multiplied by two and added every second to the object. Meaning if the controller was held at 62 degrees relative roll, the object would rotate 4 degrees every second. The roll rotation is blocked from executing when the user is engaging with the bi-manual rotation interaction. This was done because overlapping rotations would cause an undesirable outcome where the object could suffer from gimbal lock and sporadic rotations.

Moving on to pitch and yaw. In these rotations, the user would engage the hand that is not currently manipulating an object, referred to as the off-hand. As stated in table 3 users would grab with their off hand and do a wheel motion around their main hand controller. The implementation of this can be seen in listing 2

```
private Vector3 startPos;
private Quaternion currentRot;
private Transform otherHandObject;

void Update()
{
//[...]
    if (SteamVR_Actions._default.GrabGrip.GetStateDown(inputSource) &&
    controllerAsignment == ControllerAsignment.offHand)
    {
        //If this is the off hand, get initial data on the object
        GrabbedForRotation();
    }

    if (controllerAsignment == ControllerAsignment.offHand && isRotating)
    {
        //Turn off telekinesis on this hand so an object isn't grabbed by mistake
        telekinesis.enabled = false;
        //Start Rotating
        Rotate();
    }
//[...]
}

public void Rotate()
{
    //Get the direction from this controller to the other
    Vector3 handDirection = Vector3.Normalize(transform.position -
        otherHand.transform.position);

    //Rotate the object
    otherHandObject.rotation = Quaternion.FromToRotation(startPos, handDirection)
        * currentRot;
}

public void GrabbedForRotation()
{
    if (controllerAsignment == ControllerAsignment.offHand)
    {
        // Get the rotation and starting pos for the grabbed object from the other hand
        otherHandObject = otherHand.telekinesis.m_ActiveObject.transform;
        startPos = Vector3.Normalize(transform.position - otherHand.transform.position);
        currentRot = otherHandObject.rotation;
        isRotating = true;
    }
}
```

Listing 2: Pitch and yaw implementation

To control the pitch and the yaw of the object, users will grab with their off hand and do a circular motion to move the object. In the GES users demonstrated that, by doing a wheel motion with their off-hand. To implement this the off-hand controller has to know the position of the main hand controller and get a direction from those positions *startPos*. The difference between that direction and a constantly updated direction *handDirection*, is used to calculate how far the object *otherHandObject* has to rotate. Figure 6 (8.) Depicts a graphical representation of how a user controls an object's yaw.

5.3 GoGo Hand

To properly gauge the viability of gesture elicitation for nonisomorphic interaction, some established control for selection and manipulation will be implemented [17]. The GoGo hand first proposed by Poupyrev et al. in 1996 [22, 18] is a direct and nonlinear mapped 3D selection and manipulation technique. This technique allows the user to extend their virtual arm's length beyond their physical reach. Thus allowing the user to manipulate remote objects. For the user to "grow" their virtual arm the user simply has to extend their real hand out or bring it closer [18].

The position of the virtual hand is often denoted by a 3D model of a hand in turn providing visual feedback to the user of the position of the virtual hand. Different mapping functions can be used for the extension of the user's arm, which can be chosen by the designers to fit the application's needs. Regardless of an object's proximity to the user, the GoGo hand approach provides direct and seamless manipulation of virtual items. With its 6-DOF manipulation capability, users may push nearby things farther away or pull far-off objects closer. It's crucial to keep in mind that the GoGo approach still has a finite maximum reaching distance. The approach amplifies minor hand movements as the user's hand moves farther away, resulting in bigger movements of the virtual hand. The accurate placement of items at a distance becomes more difficult due to this amplification effect [18].

The GoGo approach has been tested in a number of experiments, including those by Bowman and Hodges [4] and Bhomwick et al. [2]. According to this research, users had no substantial problems comprehending or employing the technique. It is important to consider, nevertheless, that the GoGo approach often performs worse in selection tasks than ray-casting since it calls for 3-DOF control rather than 2-DOF. Despite this drawback, the GoGo hand technique has demonstrated promise in aiding natural 3D manipulation in virtual environments [18].

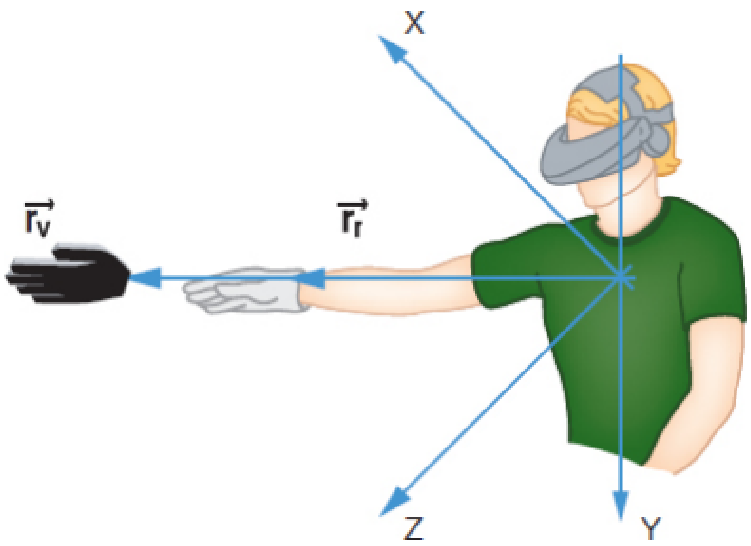


Figure 8: Visual representation of GoGo hand, $\vec{r_v}$ is the scaled vector of a users reach, $\vec{r_r}$ is the physical user hand position. (Adapted from [18])

The GoGo hand implementation was directly adapted from the ISUE lab implementation of the GoGo hand implementation in the Unity3D engine [16]. Khaloo is the only contributed author of the 3D Interactions repository, however, the Interactive Computing Experiences Research Cluster (ICE, formerly ISUE) is the owner of the repository. Evidently, the lab associated with LaViola et al. [18] and credit the publication on the publication website [14], as well as Poupyrev, who is credited with the original design for the GoGo hand [22]. In short, it seems that this implementation is closest to the interaction technique described by LaViola et al.

The implementation of the GoGo hand is relatively straightforward. A user starts with a model of their hand with non-scaled interaction. The user will then press a button to select a starting point. Once the starting point has been selected the user's hands will be scaled taking into account that starting point.

```
        var pose = new SteamVR_Utils.RigidTransform(poses[i].mDeviceToAbsoluteTracking);
        var HMDpose = new SteamVR_Utils.RigidTransform(
            poses[(int)EIndex.Hmd].mDeviceToAbsoluteTracking);

        if (origin != null)
        {
            transform.position = origin.transform.TransformPoint(pose.pos);
            transform.rotation = origin.rotation * pose.rot;
        }
        else
        {
            var distance = Vector3.Distance(HMDpose.pos, pose.pos);

            if (distance > threshold)
            {
                if (initPose == Vector3.zero)
                {
                    Debug.LogError("Initiate controller Pos");
                    transform.localPosition = pose.pos;
                    transform.localRotation = pose.rot;
                    return;
                }

                float k = 25;
                var diffPos = pose.pos - initPose ;
                diffPos *= (1f + k*Mathf.Pow(distance,2));
                pose.pos += diffPos;
            }
            transform.localPosition = pose.pos;
            transform.localRotation = pose.rot;
        }
    }
```

Listing 3: GoGo hand main implementation

Listing 3 shows the main implementation of the GoGo hand in C#. The origin is a *Transform* type, that holds a relative position to the parent object of the hand. In this case the SteamVR Objects container. Code is blocked from executing if the *initPose* variable has not been set. Once it has been set by the user the hand position can be scaled accordingly. *distance* is a vector of the difference between the absolute transform position of the VR player GameObject, called the pose, and the hand pose. *diffPos* is also a vector denoting the distance and direction of the hand position to the user-set position. This vector is then multiplied by 1 plus k times *distance* squared. This means the further the real hand gets from the position set by the user, the virtual hand will get exponentially further away.

To manipulate objects upon collision with an object and button confirmation by the user a Rigid Joint object will be added to the virtual hand with an extreme break threshold. This simulates the object being 'attached' to the user's hand. Then to further manipulate and rotate the object the user will then simply have to rotate the wrist.

One addition was made to the original GoGo implementation. It was deemed necessary to allow users to reset the *initPose* vector to 0. During in-house testing of the implementation, it quickly became clear that if one would want to either have more precision in the position of the virtual hand or reach objects further away, a new *initPose* position needs to be set. Therefore it was added that if users press a button it would zero out *initPose* allowing them to set a new one.

5.4 Task Design

For users to report accurately on the performance of Telekinesis and GoGo hand, they will need an environment to interact with. Additionally, to ensure that users explore all the interaction possibilities of both interaction techniques some tasks will need to be established. The user will be placed on a square pedestal raised slightly above the task area. This was done to minimise the possibility of two objects occluding each other in any of the coming tasks. Additionally, a directional light was added to the scene pointing at a 90° angle perpendicular to the ground plane. This helps provide some feedback to the user on the position of the object being manipulated when it is held in the air by it's shadow being directly under it [18].

The first task is to get a feeling for the interaction. Here users will be given a set time where they can explore all the functionality of the specific interaction technique, hopefully building some form of familiarity with the interaction. A timer will be started via a button press initiated by the conductor, which in turn will instantiate the training objects. Once the timer reaches the specified time the training objects will be destroyed automatically. This ensures that all participants have the same amount of training.

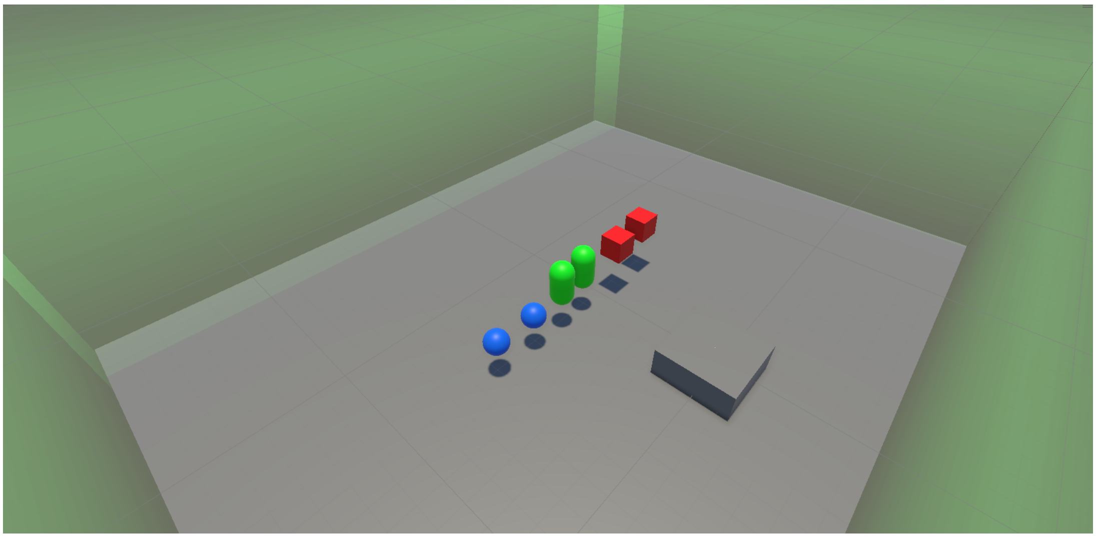


Figure 9: Task environment with training objects visible

The first task that users will be presented with is a positioning task. This task was partially adapted from Frees and Kessler [9], also included in a collection for evaluating selection and manipulation techniques in by VR Bergström et al. [1]. To complete the task the user will pick up a sphere and place it into a cubical boundary. Once the sphere is completely enveloped by the boundary, the boundary and the sphere will be destroyed. A new sphere will be instantiated in front of the user, and a new boundary will be instantiated in a new position. The boundaries will get progressively smaller, starting from 3m to a side, and finally 0.8m to a side. The sphere is always 0.5m in diameter. The user has to place the sphere in the boundary six times to complete the task. The task is started by a button press by the conductor which simultaneously starts a timer, the timer is automatically stopped once the task is completed. Figure 10 shows all the boundaries activated, in the test environment along with the sphere.

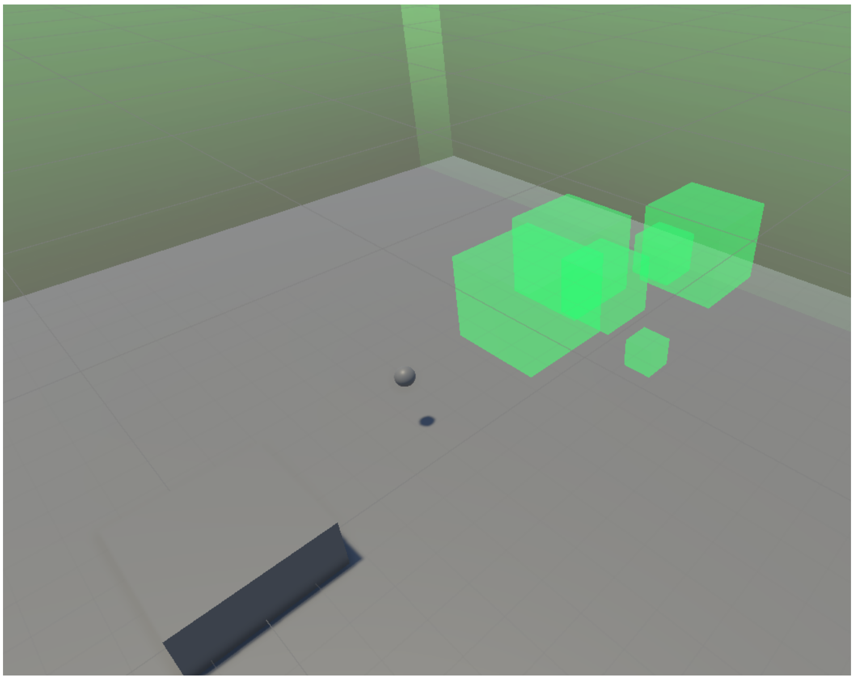


Figure 10: First task, with all boundaries activated

The second task that users will complete is a docking task. Inspiration was taken from various tasks described by Bergström et al. [1]. The task will be a mix of non-orientation-specific docking tasks and semi-orientation-specific docking tasks. This means that participants will have some objects that will not require any rotation from the beginning and some objects that can be docked in two orientations.

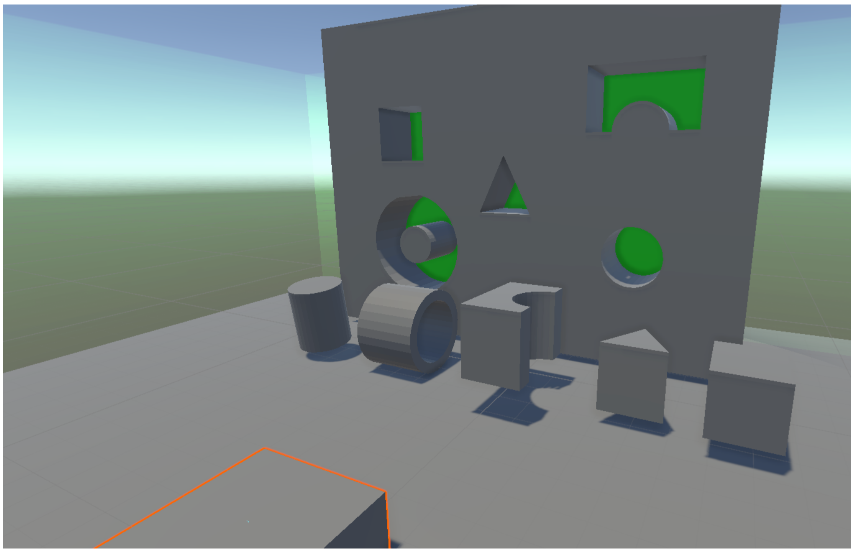


Figure 11: Second task, player pedestal highlighted in orange outline

Users will be presented with a board with various cutouts in different shapes, as well as objects fitting those shapes [Figure 11]. The objects will be placed in such a way that the user will have to rotate most objects on all axes (pitch, roll and yaw). For some objects, it will only be necessary to rotate the object on the x-axis (pitch), for it to be in the correct orientation to be inserted. Some objects require a rotation on all axes. Additionally, the user will need to perform translations for all objects on all axes to insert the objects into the board. All these together will ensure that the user will use all the telekinesis gestures.

When the object has been fully placed into its corresponding slot the object will turn from grey to green, giving the user feedback that the object is correctly placed and they can move on to the next. The objects will be spawned by a button press by the test conductor and a timer will similarly be stopped automatically once all objects are correctly placed. This task was also chosen for its simplicity in explanation as well as most users might recognise the task without much introduction. This will help ensure that no users are confused by the task design and the focus will only be on the interaction technique.

6 Evaluation

6.1 Procedure

This evaluation of both GoGo and telekinesis will follow a within-subjects experiment design. What interaction technique users start with will follow a switching structure, meaning participant 1 will start with telekinesis and participant 2 will start with GoGo and so on.

Firstly participants were told a short introduction of what the project was about and a brief agenda of the test. Participants were then instructed to input some demographic data on an electronic questionnaire, namely age and gender. A paper version of the questionnaire can be found in appendix C. After filling out the demographic data, users were given a short introduction to the interaction technique they will start with. This introduction is a short overview of how the interaction works, and how the participants can perform the different translations and rotations. The introduction to telekinesis follows the same structure as table 3 in the way that they are outlined.

Once this introduction was complete users were given the HMD, the controllers and the task scene was launched. Participants were told they would be given a short amount of time to practice the interaction technique before having to complete any tasks. The exact amount of time was 4 minutes. This training time was given because it was deemed sufficient to allow participants to perform all the actions as well as not being so long that the participants get bored and to keep the experiment time short. Participants were encouraged to ask questions about the interaction if something felt unclear regarding or they could not remember the gestures.

When the training time was complete the users were told what the first task (the positioning task) would entail as well as mentioning that they will be timed, but to complete the task at a pace that they were comfortable with. Once they had completed the positioning task their completion time was noted on the electronic questionnaire.

Participants were then introduced to the docking task and shown the board before their time was started. Similarly, users were told that they would be timed but to complete the task at a comfortable pace. Again once all objects had been placed correctly, their time would be noted.

Participants would then be asked to remove the HMD and fill out the first part of the questionnaire, when that was completed the participants would then be given the introduction to the second interaction technique. If this was the GoGo interaction technique, they would be introduced to the controls of creating the starting point, how to reset it and how the scaling works from then on. Then they were told how to pick up objects by having their hand collide with the object and then pressing the trigger. Then they would put on the HMD once more, complete the training and the two tasks. When all tasks were completed they would remove the HMD and complete the last part of the questionnaire which marks the end of the experiment.

Aparatus

A desktop computer running Windows 10 and equipped with an AMD Ryzen 5950X, an NVidia RTX 3080ti GPU, and 32GB of RAM was used. The display on the Valve Index HMD was powered by SteamVR. The participant interacted with the interaction techniques using the Valve Index controllers. The participants filled out the electronic questionnaire on a laptop PC.

6.2 Measures

The main measure for the viability of telekinesis from gesture elicitation is the system usability scale (SUS) by Brooke [5]. SUS is described as a "Quick and dirty" scale for measuring the general usability of a system. It consists of 10 5-point Likert scale questions with positive and negative statements. Individual scores are treated by subtracting 1 from positively inclined questions. For negatively inclined questions, the participant scale position is subtracted from 5. The answers are then summed after this treatment and multiplied by 2.5. The result is a scale from 0-100 denoting usability. Brooke writes that from testing multiple systems, it can be said that a system usability score above 68 denotes above-average usability [5]. Additionally, participants will, as mentioned before, be timed on the tasks they have to complete.

The final part of both questionnaire sections has some custom measurements. The first of these is a 5-point Likert scale question with the statement "I felt like I had a supernatural power". This question was formulated to gauge how users felt about the interaction technique and if it felt supernatural to them. Furthermore, this question also implies that they had some connection or presence in the virtual environment with the interaction technique if they indicate agreement with the statement. The next question asks users to rate how fun they thought the interaction was on a scale of 1-10. Because of fun is a very subjective feeling it was deemed necessary to offer participants some more granularity in their response. This was also followed up by a free-text response allowing them to expand on their answer to how fun they rated the interaction technique. The final question is also a free-text question asking them if they felt they could relate their experience to anything they had seen before. This free-text question can help gauge the amount of legacy bias the participants felt was present in the interaction.

6.3 Results

20 participants were gathered for the final evaluation, 17 male and 3 female. 9 of those participants were also part of the preliminary gesture elicitation study. The results in their entirety can be found in appendix D. One of the main focuses of this thesis is to gauge the viability of gesture elicitation for nonisomorphic interaction in VR. One of the ways this was measured was through the SUS. In figure 12 a visual representation of the SUS scores can be seen. The SUS scores were treated as per the instructions of Brooke [5] for both telekinesis and GoGo.

From there the data was analysed through the Shapiro-Wilk test to check for a normality. Both telekinesis ($p = 0.08$) and GoGo ($p = 0.67$) had p values above the chosen alpha value ($\alpha = 0.05$) and could therefore be treated as normal data. A parametric test could then be used to test if there is a statistically significant difference between the SUS scores of telekinesis and GoGo. Telekinesis scored a mean SUS value of 65.5 (Median = 65, SE = 4.29) and GoGo scored a mean SUS value of 81.1 (Median = 81.2, SE = 2.90). Brooke states that a system with a SUS above 68 can be determined as performing, usability-wise, above average [5]. From that, it can be concluded that the telekinesis interaction has below-average usability and the GoGo hand has above-average usability. Performing a Cohens's d effect measurement [8] also shows that there is a large reported difference between the two means ($d = 0.958$)

The related two-sample t-test was used to determine if there is a significant difference. The test was chosen because users have to try both conditions, selection and manipulation with telekinesis and with GoGo [8]. The null hypothesis can be established as there is no significant difference in usability between the two interaction techniques. H1 is that there is a significant difference between the two. The paired sample t-test reveals that there is a significant difference with the results showing a statistically significant difference ($t(19) = 3.789$, $p = 0.0012$). Overall it can be said that users generally found the GoGo interaction technique to be more usable than the telekinesis interaction technique.

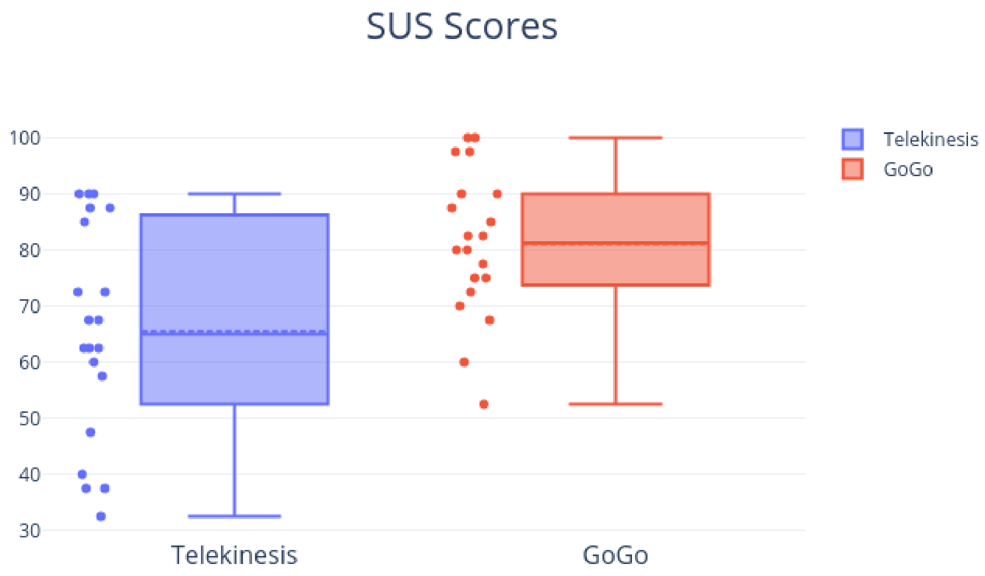


Figure 12: SUS scores (solid line = mean, dashed line = median)

Figure 13: Participant fun rating (solid line = mean, dashed line = median)

Participants were also asked to rate how fun they thought each interaction technique was on a scale of 1-10. 1 being not fun at all and 10 being very fun to interact with. Figure 13 depicts the results. Telekinesis scored a mean of 7.75 (Median = 7.5, SE = 0.39) and GoGo scored a mean of 7.85 (Median = 8, SE = 0.32). With this in mind, a non-parametric statistical test should be performed to test for any significant difference. A Wilcoxon signed rank test was conducted to compare the fun ratings of the

Telekinesis and GoGo groups. The test revealed that there was no significant difference between the two fun ratings (W = 63.0, p = 0.793). The range of fun ratings was the same for both groups (6), and the minimum and maximum values were also similar (Telekinesis: 4 and 10, GoGo: 4 and 10). These results provide some indication that participants felt that both interaction methods were equally fun.

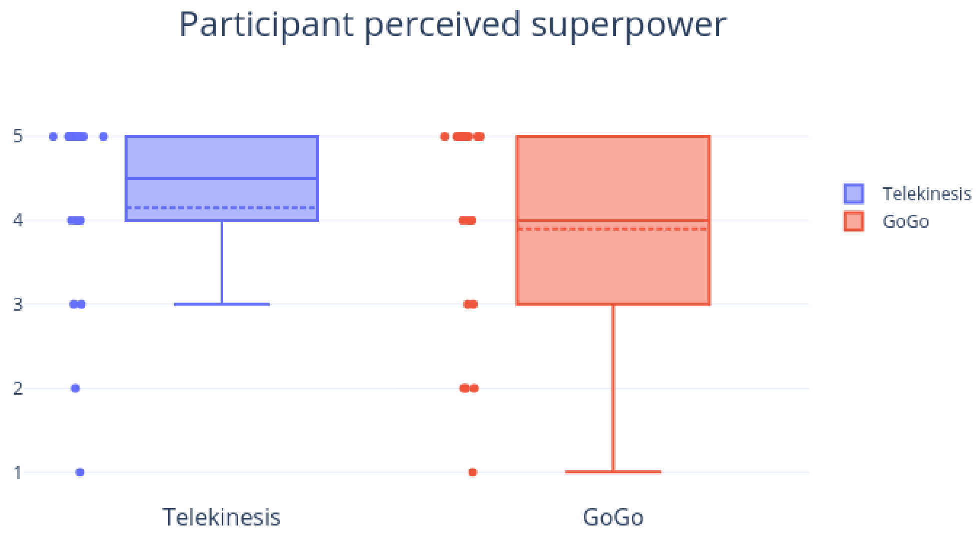


Figure 14: Participant answers to "I felt like I had a superpower" (5 = strongly agree, 1 = strongly disagree) (solid line = mean, dashed line = median)

Participants responded to the 5-point Likert scale question "I felt like I had a superpower" after using each interaction technique. Telekinesis had a mean of 4.15 (Median = 4.5, SE = 0.25) and GoGo had a mean of 3.9 (Median = 4, SE = 0.29) A Wilcoxon signed rank test reveals that there is no significant difference between the two results (W = 38.5, p = 0.61).

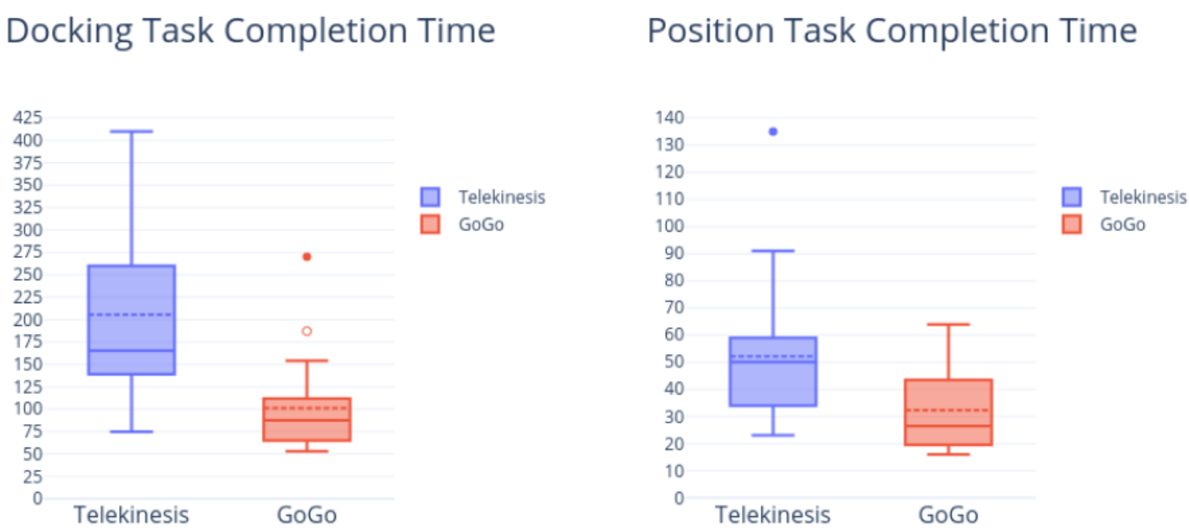


Figure 15: Participant completion time in both tasks (in seconds) (solid line = mean, dashed line = median)

Figure 15 represents user completion times in both tasks. The completion times of the two interaction techniques were compared using a Wilcoxon signed-rank test.

For the Telekinesis technique, the mean completion time for the position task was 52.1 seconds (SE = 5.897), with a standard deviation of 26.376. The range of completion times ranged from 23 to 135 seconds. In the docking task, the mean completion time was 205.3 seconds (SE = 21.035), with a standard deviation of 94.073. The range of completion times was from 75 to 410 seconds.

For the GoGo technique, the mean completion time for the position task was 32.25 seconds (SE = 3.606), with a standard deviation of 16.127. The range of completion times ranged from 16 to 64 seconds. In the docking task, the mean completion time was 101.25 seconds (SE = 11.755), with a standard deviation of 52.570. The range of completion times was from 53 to 270 seconds.

The Wilcoxon signed-rank test yielded a statistically significant difference in completion times between the Telekinesis and GoGo techniques (Position task: $W = 9.5$, $p = 0.00036$) (Docking task: $W = 10.0$, $p = 0.00039$). Overall, these findings indicate that participants achieved significantly faster completion times with the GoGo technique compared to Telekinesis for both the position and docking tasks.

7 Discussion

Supernatural interaction has the potential to be the most useful selection and manipulation technique for VR. Aside from being appealing to users with their novelty, they can also be used to complete complicated tasks that natural or isomorphic interaction cannot. One of the larger questions within supernatural interaction is how to design them. Since we do not have any real-life experiences to draw inspiration from, supernatural interaction techniques need to be designed from the ground up. It can therefore be a difficult task to create interactions that feel natural and are usable. Here gesture elicitation can provide relief. By asking users directly instead of researching various designs, interactions that feel natural can be directly extracted from the end users. Additionally, one of the main points of creating a gesture elicitation study is to improve the guessability of any specific interaction. This thesis aimed to not only conduct a gesture elicitation study but to measure the usefulness of the elicited gestures for selection and manipulation.

The results of the final evaluation proved insightful in several ways. Firstly it is evident that GoGo had a higher usability score than telekinesis and telekinesis had a sub-average usability (< 68). Several reasons could explain this difference. One relevant discussion point is the way users can rotate objects, which is substantially different between the two interaction techniques. The GoGo hand, having the ability to rotate an object in a 1:1 mapping of the user's wrist movements is evidently more intuitive than the method of rotation for telekinesis. Substantiated by participant answers to the first free-text question: *"Please explain in a few words why you answered in the way you did to the question above [Fun rating]"*. Some examples of how participants described GoGo are: *"Even though the previous run was really fun too, this felt much better"* and: *"The interaction is extremely intuitive and comes so naturally, but it doesnt feel as entertaining as the previous version"* and: *"Really nice you can rotate objects like you would normally yourself."* [Appendix D]. These quotes fit the overall sentiment quite well.

One thing to note about the results of the SUS evaluation is that the spread of the scores for telekinesis is far wider than for GoGo, this spread is very visible in figure 12. Also visible in the figure is that there is a noticeable gap between the middle scores and the higher scores. There are no scores between 72.5 and 85. 4 out of those 6 observations that scored Telekinesis 85 or above are also in the fastest 50% to complete both tasks. It was observed that these participants had a better grasp of rotation with telekinesis, also evident in their relatively quick completion times. This could indicate that if participants had more time to get familiar with telekinesis it would have scored higher on usability. This is further supported by some comments the participants had after the end of the experiment and in the free-text responses on telekinesis, for instance: *"It [telekinesis] was quite a bit harder to control the rotation but i got the hang of it at the end and then it felt like more of a challenge to overcome.* and: *"[...] with a bit of training, I think it will become a natural way of interacting."* and: *"I felt like I wasn't very adept at using the control system; perhaps with more practice it would feel more enjoyable."* [Appendix D]. However, this division in SUS scoring might also be an artefact of the relatively low sample size ($n = 20$).

Another thing of note in the results is that even though there was a significant difference in SUS scores between the two interaction techniques, participants rated both interactions equally fun. This would mean that participants felt that even though telekinesis was less usable they still had fun interacting with it, despite frustrations stemming from the sub-average usability. Participant answers to the free-text question asking on elaboration on their rating of fun for telekinesis, contain answers such as: *"It´s not often you can find ways in real life to lift objects in a distance, so it was pretty fun to feel like a superhero."* and: *"The delay in the objects moving to wherever was pointed really gave them a sense of weight, which made the entire experience quite fun."* [Appendix D]. Not all were in agreement with these statements, one participant wrote: *"The other system [GoGo] was better"* [Appendix D]. This participant gave telekinesis a SUS score of 62.5 but still gave the interaction technique an 8 on the perceived fun scale. This participant gave GoGo an SUS score of 97.5 and a fun rating of 8. Another participant who gave telekinesis an SUS score of 32.5 also gave a 7 on the perceived fun scale, while giving GoGo an SUS score of 75 and a fun rating of 8. This further supports the claim that even though participants had usability difficulties they still enjoyed the interaction. This could be explained in three ways. (1) Telekinesis' fun and usability ratings do not have an effect on each other in this evaluation. (2) The telekinesis fun results were being affected by the sub-average usability, but telekinesis was inherently more fun to interact with. (3) Telekinesis was not so unusable that it affected fun, meaning that usability first starts having an effect on the fun of a system at a lower usability score than what was measured for telekinesis. It is important to mention 'fun' is a very subjective feeling and that the perceived fun rating does not have any academic support in this thesis, which could have influenced participant answers. Some participants could have weighed more heavily on usability being necessary for a system to be fun. Others might have seen it as a challenge and had drawn fun from that, as was mentioned by one of the participants, displayed in the paragraph above. For a future iteration of this thesis, this should be remedied and scientific methods for measuring fun should be explored.

Participants were also asked if they had participated in the GES prior to participating in the final evaluation. 11 participants did not participate in the GES, while 9 did participate. Having participated in the GES prior to the evaluation could have influenced participant answers somewhat. If a participant had suggested one gesture for a specific referent, they would be able to recognise it and have an easier time completing the tasks and understanding how the interaction works. However, analysing the mean differences between the two groups there does not exist a large difference in any of the measures except for participant answers to "I felt like i had a superpower" for GoGo and fun ratings for GoGo [Appendix E]. However, the only groups that are of interest to this study are the differences between did and did not participate in telekinesis interaction, because the GES only concerned telekinesis.

There are some considerations for conducting a GES for virtual reality applications. There exist many different takes on presenting a referent to a user while conducting a GES [30, 31, 29, 21]. The approach in this thesis is in the bare-bones range on the spectrum of referent displaying methods that were investigated. Participants in this study were presented with referents orally and would perform gestures only with their hands. Ortega et al. [21] performed the GES with participants wearing an HMD and in a VE. Here they were presented with the referents through text and an animation of an object performing the motion of the referent. If the same method for displaying referents was implemented in this thesis, some user-error could have been avoided. It was observed during the final evaluation that many participants had difficulty performing pitch and yaw rotations of objects. Since the gesture elicited from participants in the GES was the off-hand doing a wheel motion around the grasping hand, rotation had to be based on the positions of the two hands in relation to each other and not the object being manipulated. Many participants would try to yaw the object, by pulling their off-hand away from their main hand in a straight line. The object would not rotate of course, because the vector direction from the main hand to the off hand would not change. It can therefore be speculated that, if participants had a better sense of scale and a virtual object they could see during the GES, another gesture might have been elicited. This in turn could have improved the overall design of rotations.

It was deemed advantageous to have users perform gestures without the knowledge of what input device they had available and were therefore not given one. The idea was that participants would be more likely to perform actual gestures, instead of using button presses. Buttons can be very useful methods of controlling a system but can be less intuitive than performing a gesture. A button labelled 'A' does not inherently convey any meaning. Participants were told that they would be performing gestures for a

VR application, so some participants would have an idea of what user inputs would be available on a VR controller. This is also evident from the results of the GES, where the gesture labelled *r2* "Button press" was performed by 4 different participants for the referent 'Hold'. It should also be noted that the chosen gesture *r1* "other hand, palm up, held there" was performed by 5 participants. Meaning that gesture *r2* "Button press" could have easily been a contender for the chosen gesture for that referent. But the assumption that having users focused more on gestures instead of system control through buttons is not substantiated in this thesis. However, an example of a GES for supernatural/nonisomorphic interaction where users were also given a controller could not be found. It is only speculation if there would have been more button-related gestures performed if users were also given a controller but for this GES it can be said that no gestures involving button presses won out. I, however, feel confident in stating that using one's whole hand in a grabbing gesture to pick up an object, is more natural than pressing a button, even though it might be more usable.

It can also be discussed if the tasks that participants had to complete were less focused on precision and instead had some elements where precision was not the goal of the task. Imagining having participants demolish a building using either interaction technique might have influenced the usability results significantly. Since it was precision using telekinesis that participants had the most difficulty with especially rotation. Creating tasks such as these for a second iteration of this thesis would probably provide some interesting results and insight into the strengths and weaknesses of both interaction techniques. In essence, the use case of the interaction should be examined more carefully in a future iteration.

In terms of legacy bias, there seems to be a lot present in telekinesis assuming the answers to the last free-text question *"Did you feel any similarity between the system you just interacted with and something you have seen before (This could be a game, movie, TV show, comic book etc.)"* is any indication of that. Not just for telekinesis but for both interaction techniques. For telekinesis, X-Men™ was mentioned by 5 participants. The movie Minority Report was mentioned twice and Star Wars™ was also mentioned by three participants. Three participants did not indicate that they could specifically relate their experience with telekinesis to any experience. For GoGo, the most mentioned experience was the Fantastic Four™ mentioned by 5 participants and The Incredibles™ was mentioned by 4 participants. However, 7 participants felt that they could not relate their experience to anything specific. These entries are evidence towards legacy bias being a much larger presence in telekinesis than in GoGo. Coupled together with telekinesis having a lower usability than GoGo, there is reason to believe that telekinesis has fallen into a local minima which can happen when legacy bias influences gesture elicitation [Section 2.5.1]. This may not be the sole reason for the sub-average usability score of telekinesis but could be one of the contributing factors among others described in this section. Legacy bias could however also be a positive influence on the telekinesis interaction technique if one follows the advice by Köpsel and Nikola [17]. For future work within this subject, it would be interesting to see if employing some of the methods, described in section 2.5.1, for reducing legacy bias in GES' and if the reduction in legacy bias influences the usability of supernatural interaction.

In the GES, flight had quite poor agreement rates. All except one referent had an agreement rate above 0.3 which denotes a high agreement [30]. If almost all of the referents had this relatively low agreement it can be said that the gestures would not draw from any of the benefits of gesture elicitation. Reasons for this low agreement rate can only be speculated on in this thesis. Locomotion in 3 dimensions is something that is quite far removed from any real-life experiences that any person has. Flight in the real world requires either a vehicle or specialised equipment. While something like telekinesis still has some likeness to the real world. When we pick up an object in the real world and move the hand grabbing it up, the object moves up. The same is true for GoGo and telekinesis. In flight, this same connection does not exist unless one would make a GES where all participants were trained pilots.

The gesture elicitation study gathered some truly interesting results. From a personal point of view, the GES provided some novel gestures for interaction, that I would not have thought of. And from an interaction designer's point of view, the method can be advantageous to employ early in any design process. However, It can be speculated that one could find a middle ground between this participatory design approach and an internal design approach, instead of relying solely on participant gestures. Here the GES could be used to gather inspiration, rather than being the first and final answer to how an interaction should be designed.

This thesis might serve as a stepping stone to answering the much bigger question of how we make natural feeling supernatural interaction. Or if it can be answered with certainty at all, given the self-contradictory nature of quantifying an interaction as a natural supernatural interaction. To answer that question it will take multiple iterations and far too many methods of data gathering than is tenable for one thesis.

8 Conclusion

To answer the broader research question "How can gesture elicitation help create supernatural/nonisomorphic interaction techniques and how do these compare to already established techniques?" several more iterations of this thesis are needed. The question that this thesis is able to provide some answers to would be: "How can gesture elicitation help create a supernatural interaction technique and how does this compare to the established interaction technique GoGo?". This research question provides a more narrow and focused question that this thesis will be able to provide some answers to. Taking a starting point in the first broader research question; travel and selection and manipulation were investigated in the realm of supernatural/nonisomorphic interaction. Supernatural interaction can be very powerful, by being more intuitive and more useful [18]. One contribution this paper offers to the gesture elicitation community is using LaViola et al. [18] task decompositions in specifying referents for travel and selection and manipulation. The individual tasks for travel and selection and manipulation were broken down into their components [Section 2.1 & 2.2]. These decompositions serve as the foundations for the referents used in the GES. The subtasks for selection and manipulation are; Selection, positioning and release. These were then broken down into further sub-tasks and used to create specific referents [Table 1]. Similarly, travel consists of the tasks: Direction/target selection, velocity/acceleration selection and input conditions. These are then broken down into sub-tasks that served as the referents for supernatural travel (flight) [Table 2]. Using these task decompositions was useful in the sense that they encompass all the tasks and sub-operations needed for the full interaction suite, making it easier to define referents.

A GES was performed with 20 participants. Video recordings of participant gestures were analysed and entered into a data set. An analysis of agreement rate was then performed and a consensus set was created from the elicited gestures. Overall agreement is quite high in telekinesis but quite low in flight. It was deemed necessary to exclude flight from the full implementation due to these low agreement rates. Fully implementing a travel technique that would not draw any of the benefits from gesture elicitation is untenable for this thesis and lies outside the scope. Nevertheless, the consensus set for both interactions was created. These consensus sets are also one of the contributions of this thesis which, in some of the literature, is the final contribution and result of their studies [11, 2, 27]. In future work, the consensus sets for both telekinesis [Table 3] and flight [Table 4] can be used to design improved versions of the implementations in this thesis. Telekinesis was implemented alongside an established interaction technique, GoGo hand [22, 18]. To evaluate the two interaction techniques comparatively, a questionnaire was formed using the system usability scale [5] with the addition of some custom items. These items provided insight into how fun participants thought each interaction technique was, if they felt like they had a superpower and if they could relate their experience to something they have experienced before.

The resulting evaluation ($n = 20$) gave valuable insight into how telekinesis designed through gesture elicitation can compare to the established interaction technique GoGo. Telekinesis scored a mean of 65.5 (median = 65, SE = 4.29). GoGo scored a mean of 81.1 (median = 81.2, SE = 2.90). A paired sample t-test showed there was a significant difference between the two samples ($t(19) = 3.789$, $p = 0.0012$). For participant fun ratings, telekinesis mean rating was 7.75 (Median = 7.5, SE = 0.39) and GoGo mean rating was 7.85 (Median = 8, SE = 0.32). A Wilcoxon signed rank test showed that there was not enough evidence to conclude that there is a significant difference between the two samples ($W = 63.0$, $p = 0.793$). Participant answers to if they felt like they had a superpower, for telekinesis was a mean of 4.15 (Median = 4.5, SE = 0.25) and GoGo had a mean of 3.9 (Median = 4, SE = 0.29). A Wilcoxon signed rank test showed that there was not enough evidence to conclude that there is a significant difference between the two samples either ($W = 38.5$, $p = 0.61$). Participant completion time for the first task, the positioning task, using telekinesis was a mean of 52 seconds (SD = 26.4) and GoGo had a mean completion time of

32 seconds (SD = 16.1). For the second task, the docking task, participants had a mean completion time of 205 seconds (SD = 94.1) using telekinesis. Participant completion time using GoGo was a mean of 101 seconds (SD = 52.6). Both completion times were found to be significantly different from each other (Position task: W = 9.5, p = 0.00036) (Docking task: W = 10.0, p = 0.00039).

It can be concluded that telekinesis performed sub-average (< 68 [5]) and had lower usability than GoGo. Furthermore, completion times were also significantly higher for participants using telekinesis than for GoGo. However, not enough evidence could be found to suggest that there was a significant difference in fun, despite the relatively low usability score of telekinesis. This is further supported by participants' answers to the elaborative question about their rating of fun. This means there is a good opportunity for nonisomorphic selection and manipulation designed through gesture elicitation, to be very engaging. If the telekinesis interaction technique was used as the basis for the initial design and subsequently improved through more user studies it could in theory be a very usable and engaging form of interaction.

This thesis also explored how the current literature uses GES and how a GES can be used to create supernatural selection and manipulation techniques. The analysis investigated gesture elicitation's strengths and weaknesses as well as how to conduct a gesture elicitation study. The possible detriments and benefits of legacy bias were also investigated. Several opinions differ on the topic, some stating that legacy biased results can fall into a local minima and never find the best gesture because of it [19]. Others state that in novel interfaces, legacy bias improves the adoption of new interaction techniques by giving users a reference point [17].

The answer to the question of whether legacy bias is a detriment or benefit to gesture elicitation cannot be concluded in this thesis. However, from the results gathered it is evident that the telekinesis interaction technique had similar ratings of fun to the GoGo interaction technique. Legacy bias was evidently more present in telekinesis when looking at participant free-text answers, where only 3 participants indicated that they could not relate their experience to anything they had previously seen. Compared to 7 participants who indicated that they could not relate their experience to anything specific while using GoGo. Although opinions differed on exactly what experience participants could relate telekinesis to, this combination suggests that telekinesis does not have to be as usable as GoGo to be as fun to interact with. Whether this result is caused by legacy bias being more present in telekinesis cannot be concluded. However, it can be hypothesised that using a supernatural power that one has seen from graphic or digital media can make a more engaging interaction technique than the more utilitarian interaction techniques.

For future work within this field, it can be suggested that for supernatural interaction it might be beneficial to give a more detailed referent display. This could result in participants providing gestures that are more context-appropriate. It would also be interesting to see if using some of the methods for reducing legacy bias, a consensus set could be formed that has a higher usability. This would also provide further insight into questions regarding the detrimental or beneficial effects of legacy bias.

In essence, this thesis has taken another step in the direction of creating usable and natural supernatural selection and manipulation in VR. It has provided insight into how gesture elicitation can be used for designing such interaction techniques. Additionally, evidence towards a suitable method for conducting a GES for supernatural interaction is presented. Secondly, this thesis provided insight into how a supernatural interaction designed from the results of a GES, compares to an established nonisomorphic interaction technique. Further research is needed to find a definitive answer to the 'best' method of performing supernatural interactions in VR, but this thesis serves as a step in that direction by providing the findings needed to answer the question "How can gesture elicitation help create a supernatural interaction technique and how does this compare to the established interaction technique GoGo?".

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Appendices

A Consent form

Consent Form

For my master thesis I am researching the possibility of creating natural super-human interaction in VR. To do this I will use a technique called a gesture elicitation study, which you will participate in today. The aim of this study is for you to imagine gestures for two interactions, telekineses and flight. During the study I will tell you a specific interaction you have to do. It is on you to imagine a gesture that you feel is most appropriate for that interaction. For instance i will say, "move the object up" and you will then have to imagine what gesture goes with that interaction and perform it.

During the session you will be recorded for both video and audio. The recordings of this study will not be shared with anyone, will only be used for internal research purposes. The recordings will be analysed and labeled based on the gestures you perform. These gestures will then form the basis of a fully implemented gesture set. Additionally the recordings will not be shown to anyone outside of myself, supervisor Niels Christian Nilsson and exam censor.

When these have been implemented I will be testing those interaction's usability. Therefore I would like to ask you to come back once the implementation is done and try out the interactions.

Thank you for your time and participation in the test of my master thesis
Now, please fill out the details below.

*Required

1. Age *

____

2. Gender *

Mark only one oval.

( ) Male
( ) Female
( ) Prefer not to say
( ) Other: ______________________

3. I consent to having both audio and video recorded during my participation in this study. *

   Mark only one oval.

   - Yes
   - No

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

   Mark only one oval.

   - Yes
   - No

5. I understand that all personal information will be treated confidentially. *

   Mark only one oval.

   - Yes
   - No

6. I accept that the audio and video recording of this session as well as any personal data will be stored in accordance with GDPR regulations *

   Mark only one oval.

   - Yes
   - No

7. I would like to participate in a future usability study (If yes please fill out contact details below) *

Mark only one oval.

- Yes
- No

8. Full name and email:

9. Date & Signature

B Elicitation study results

a1	2	**b1**	**4**	**c1**	**4**	**d1**	**5**	e1	3	**f1**	**4**	g1	3	**h1**	**7**	i1	2	**j1**	**17**	k1	2
a2	1	b2	1	c2	1	d2	2	e2	1	f2	1	g2	1	h2	6	i2	2	j2	1	**k2**	**9**
a3	1	b3	1	c3	1	d3	2	e3	1	f3	1	g3	1	h3	1	i3	2	j3	2	k3	1
a4	3	b4	1	c4	1	d4	4	**e4**	**5**	f4	3	**g4**	**6**	h4	1	i4	2			k4	2
a5	1	b5	1	c5	1	**d5**	**5**	e5	2	f5	3	g5	1	h5	2	**i5**	**6**			k5	3
a6	2	**b6**	**4**	**c6**	**4**	d6	1	e6	1	f6	3	g6	4	h6	1	i6	1			k6	2
a7	**5**	**b7**	**4**	c7	2	d7	1	e7	2	f7	1	g7	1	h7	2	i7	4			k7	1
a8	1	b8	1	c8	1			e8	1	f8	1	g8	3			i8	1				
a9	2	b9	3	c9	2			e9	1	f9	3										
a10	2			c10	2			e10	1												
c11	1			e11	1																
e12	1																				
AR		AR		AR		AR		AR		AR		AR		AR		AR		AR		AR	
0.0895		0.1105		0.0789		0.1474		0.0789		0.0947		0.1421		0.2000		0.1316		0.7211		0.2211	

Table 5: Gesture occurrences and agreement rate for flying referents

l1	9	m1	4	n1	2	o1	2	p1	1	q1	1	r1	5	s1	2	t1	1	u1	3	v1	10
l2	1	m2	1	n2	10	o2	10	p2	1	q2	1	r2	4	s2	1	t2	1	u2	1	v2	2
l3	10	m3	3	n3	7	o3	7	p3	3	q3	3	r3	1	s3	1	t3	1	u3	5	v3	5
		m4	1	n4	1	o4	1	p4	5	q4	10	r4	1	s4	1	t4	1	u4	8	v4	1
		m5	7					p5	2	q5	3	r5	1	s5	5	t5	5	u5	2	v5	2
		m6	4					p6	5	q6	2	r6	5	s6	4	t6	5	u6	1		
								p7	2			r7	2	s7	1	t7	1				
								p8	1			r8	1	s8	1	t8	1				
														s9	3	t9	3				
														s10	1	t10	1				
AR		AR		AR		AR		AR		AR		AR		AR		AR		AR		AR	
0.4263		0.1895		0.3526		0.3526		0.1316		0.2737		0.1421		0.1053		0.1211		0.2211		0.3000	

Table 6: Gesture occurrences and agreement rate for telekinesis referents

Engage fly mode	Thrust both arms upward, hands in fists	a1	One arm lifted up, hand in fist	a2	arms extended to either side hands in fists	a3	Arms to either side open palm give one wave with both arms.	a4	Arms in fron, hands in fists	a5	Jump up one arm lifted above the head, hand in fist	a6	Small hop	a7	Arms thrust above head open palms	a8	Arms to either side open palm facing towards the ground, small hop	a9	open palms, quick thrust downwards.	a10				
Fly Up	Both arms extended upward, hands in fists	b1	button press	b2	head gaze up	b3	waving arms open palm	b4	lean back arms in fron, hands in fists	b5	One arm up lifted above the head, hand in fist	b6	Both arms down the side, palms open pointing towards the ground	b7	waving arms open palm, hands in fists at either side	b8	Look up	b9						
Fly down	Both arms extended down, hands in fists	c1	button press	c2	head gaze down	c3	both arms down at the sides open palm	c4	Lean forwards arms in front, hands in fists	c5	One arm down, hand in fist	c6	Both arms raised above the head, open palms, pointing up	c7	Swim move waving arms up	c8	Look down	c9	Close palms, the amount the palms are closed determines how fast you fall (fully closed, max fall)	c10	Look down, bend one leg	c11		
Fly forward	Both arms forward, hands in fists	d1	look forward (head gaze)	d2	lean forward holding arms out to the side	d3	One arm forward, hand in fist	d4	Arms extended behind the body, palms open pointing backwards	d5	Swimming motion forward	d6	Lean forwards arms down at the side	d7										
Increase forward speed	Fully extend arms forward, hands in fists (Accelerator pedal)	e1	lift arm up with hand squeeze	e2	Joystick up	e3	leaning forward	e4	thrust arms forward hands in fists (one thrust moves 1 tick up in speed)	e5	Thrust one arm forward hand in fists, (one thrust moves 1 tick up in speed)	e6	Fully extend one arm, hand in fist (accellerator pedal	e7	Rigourus swim motion forward	e8	Squeeze hands into fists (accelerator pedal)	e9	thrust arms behind the body hands in fists	e10	Open palms behind the body fully, the amount open determines the acellaration (fully open, max acceleration)	e11	leaning forward, arm out in front	e12
Decrease forward speed	Retract arms towards the body, hands in fists (accelerator pedal)	f1	lower arm with hand squeeze	f2	joystick down	f3	lean back holding arms out to the side	f4	Retract one arm, hand in fist, (accelerator pedal)	f5	Both hands extended in front of the body, palms open pointing forward	f6	Swim motion backwards	f7	Retract one arm from both arms fully extended	f8	Lean forwards arms down at the side	f9						
Hold speed	Arms extended to desired speed, hands in fists	g1	open palm	g2	button press	g3	hold the lean to the desired speed	g4	Arms extended to desired speed, hands in fists, rotate hands forwarf	g5	One arm extended to desired speed, hand in fist.	g6	Swim motion in intervals to reach desired speed	g7	Arms extended behind the body, palms open pointing backwards	g8								
stop and hover	Palms open towards the ground	h1	stand in neutral position after lowering speed	h2	stand in a neutral position arms extended to either side open palm	h3	arms in front open palms	h4	Arms at the side, semi closed fists pointing down	h5	Swim motion upwards at regular intervals	h6	Arms held out to the side, elbows bent in front, palms open facing towards the ground	h7										
Strafe	Extend one arm to the side they want to go	i1	Joystick	i2	extend both arms towards the desired direction	i3	lower arm towards the desired direction, elevate arm opposite desired direction	i4	Extend one arm to the opposite side they want to go to, open palm, angle determines how fast the strafe is	i5	Swim motion pushing to the opposite side they want to go to	i6	Lean towards the side they want to go to	i7	Extend one arm in the opposite direction they want to go to, open palms	i8								
Turn	Turn whole body	j1	turn hands in a steeting wheel motion, hands in fists	j2	Point open palms in opposite directions, on opposite sides of the center of gravity	j3																		
Land and stop	open palms arms at the sides	k1	ground collision	k2	Ground collision open palms	k3	small hop	k4	Ground collision, hands in fists	k5	Crouch	k6	Ground collision open palms, quick thrust downwards	k7										
Specify	Point	l1	Head gaze	l2	Point (open palm)	l3																		

Confirm	index squeeze	m1	button press	m2	squeeze hold hand	m3	pinch, index and thumb	m4	Grab	m5	Jab hand forward	m6								
Move up	Move arm up index finger extended (stick metaphor)	n1	Move arm up, hand in fist (stick metaphor)	n2	Move arm up, palm open towards the given direction	n3	Move arm up open hand	n4												
Move left/right	Move arm left/right index finger extended (Stick metaphor)	o1	Move arm left/right (Stick metaphor)	o2	Move arm left to right, palm open towards the given direction	o3	Move arm left and right open hand	o4												
Move away	Extend arm, squeeze index finger (joystick metaphor)	p1	Extension from middle point	p2	Joystick up	p3	Extend arm, hand in fist (joystick metaphor)	p4	Thrust arm forward hand in fist, push based from the force of the fist	p5	Palm open facing away, extending arm	p6	Thrust arm forward hand open, moves continuously away after thrust	p7	Extend arm open hand joystick metaphor	p8				
Move closer	Retract arm, squeeze index finger	q1	Retracting from middle point	q2	Joystick down	q3	Retract arm, hand in fist (joystick metaphor)	q4	palm open facing inwards, retracting arm	q5	Retract arm open hand (joystick metaphor)	q6								
Hold	Other hand, palm up, held there	r1	Button press	r2	open palm, dwell time, pointed at the object	r3	other hands twist locking motion	r4	sharp rotation movement (locking motion)	r5	Squeeze hand	r6	Let hand fall to neutral position	r7	Quick shake of the hand up and down	r8				
Rotate X (pitch)	Flick wrist up/down	s1	Tilt wrist up down (joystick metaphor)	s2	open palm swipe from up or down	s3	joystick up and down	s4	other hand in fist pointed towards the side of the object with second hand, wheel motion	s5	other hand, grab and turn from the side	s6	Other hand close fist pointed straight towards the object swiping motion up and down	s7	Make a hook gesture with the index finger of the main hand, wheel motion	s8	Hold position on object, main hand grab from side and rotate hand in the desired direction	s9	Use both hands and grab on either side	s10
Rotate Y (yaw)	Flick wirst left/right	t1	Wriggle wrist back and forth (joystick metaphor	t2	open palm swip from left or right	t3	joystick left right	t4	hand in fist pointed towards the bottom of the object with second hand, wheel motion	t5	Other hand grab and turn from the bottom	t6	other hand closed fist pointed straight towards the object swiping motion left and right	t7	Make a hook gesture with the index finger of the main hand, wheel motion	t8	Hold position on object, main hand grab from below and rotate hand in the desired direction	t9	Use both hands an grab on either side, move hands around the object	t10
Rotate Z (roll)	Rotate hand	u1	grab and rotate on a centra pivot point	u2	hand in fist pointed towards the front of the object with second hand, wheel motion	u3	main hand turn clockwise/count er clockwise	u4	Other hand grab from front and turn clockwise/count er clockwise	u5	Make a hook gesture with the index finger of the main hand, wheel motion	u6								
Release	Open palm	v1	Release index finger	v2	Small squeeze	v3	Let hand fall down to a neutral position	v4	Swipe arm away	v5										

Starting condition	Referent Participant ID	Engage fly mode (a)	ID	Fly Up (b)	ID	Fly down (c)	ID	Fly forward (d)	ID	Increase forward speed (e)	ID
Fly start	4198	Thrust both arms upward, hands in fists	a1	Both arms extended upward, hands in fists	b1	Both arms extended down, hands in fists	c1	Both arms forward, hands in fists	d1	Fully extend arms forward, hands in fists (Accelerator pedal)	e1
Telekinesis start	4200	One arm lifted up, hand in fist	a2	button press	b2	button press	c2	look forward (head gaze)	d2	lift arm up with hand squeeze	e2
Fly start	4202	Thrust both arms upward, hands in fists	a1	Both arms extended upward, hands in fists	b1	Both arms extended down, hands in fists	c1	Both arms forward, hands in fists	d1	Fully extend arms forward, hands in fists (Accelerator pedal)	e1
Telekinesis start	4204	arms extended to either side hands in fists	a3	head gaze up	b3	head gaze down	c3	look forward (head gaze)	d2	Joystick up	e3
Fly start	4206	Arms to either side open palm give one wave with both arms.	a4	waving arms open palm	b4	both arms down at the sides open palm	c4	lean forward holding arms out to the side	d3	leaning forward	e4
Fly start	4208	Arms in fron, hands in fists	a5	Lean back arms in fron, hands in fists	b5	Lean forwards arms in front, hands in fists	c5	Both arms forward, hands in fists	d1	thrust arms forward hands in fists (one thrust moves 1 tick up in speed)	e5
Telekinesis start	4210	Jump up one arm lifted above the head, hand in fist	a6	One arm up lifted above the head, hand in fist	b6	One arm down, hand in fist	c6	One arm forward, hand in fist	d4	Thrust one arm forward hand in fists, (one thrust moves 1 tick up in speed)	e6
Fly start	4212	Small hop	a7	One arm up lifted above the head, hand in fist	b6	One arm down, hand in fist	c6	One arm forward, hand in fist	d4	Fully extend one arm, hand in fist (accellerator pedal	e7
Telekinesis start	4214	Small hop	a7	Both arms down the side, palms open pointing towards the ground	b7	Both arms raised above the head, open palms, pointing up	c7	Arms extended behind the body, palms open pointing backwards	d5	leaning forward	e4
Fly start	4216	Arms to either side open palm give one wave with both arms.	a4	waving arms open palm, hands in fists at either side	b8	Swim move waving arms up	c8	Swimming motion forward	d6	Rigourus swim motion forward	e8
Telekinesis start	4218	Small hop	a7	One arm up lifted above the head, hand in fist	b6	One arm down, hand in fist	c6	One arm forward, hand in fist	d4	Fully extend one arm, hand in fist (accellerator pedal	e7
Telekinesis start	4223	Arms thrust above head open palms	a8	Both arms extended upward, hands in fists	b1	Both arms extended down, hands in fists	c1	Both arms forward, hands in fists	d1	thrust arms forward hands in fists (one thrust moves 1 tick up in speed)	e5
Fly start	4225	Arms to either side open palm facing towards the ground, small hop	a9	Look up	b9	Look down	c9	Arms extended behind the body, palms open pointing backwards	d5	Squeeze hands into fists (accelerator pedal)	e9
Telekinesis start	4227	Jump up one arm lifted above the head, hand in fist	a6	One arm up lifted above the head, hand in fist	b6	One arm down, hand in fist	c6	One arm forward, hand in fist	d4	Fully extend arms forward, hands in fists (Accelerator pedal)	e1
Fly start	4229	Small hop	a7	Look up	b9	Look down	c9	Lean forwards arms down at the side	d7	thrust arms behind the body hands in fists	e10
Telekinesis start	4231	Arms to either side open palm facing towards the ground, small hop	a9	Both arms down the side, palms open pointing towards the ground	b7	Close palms, the amount the palms are closed determines how fast you fall (fully closed, max fall)	c10	Arms extended behind the body, palms open pointing backwards	d5	Open palms behind the body fully, the amount open determines the acellaration (fully open, max acceleration)	e11
Fly start	3141	Arms to either side open palm give one wave with both arms.	a4	Both arms extended upward, hands in fists	b1	Both arms extended down, hands in fists	c1	Both arms forward, hands in fists	d1	leaning forward	e4
Telekinesis start	3142	open palms, quick thrust downwards.	a10	Both arms down the side, palms open pointing towards the ground	b7	Close palms, the amount the palms are closed determines how fast you fall (fully closed, max fall)	c10	Arms extended behind the body, palms open pointing backwards	d5	leaning forward	e4
Fly start	3143	Small hop	a7	Both arms down the side, palms open pointing towards the ground	b7	Both arms raised above the head, open palms, pointing up	c7	Arms extended behind the body, palms open pointing backwards	d5	leaning forward	e4
Telekinesis start	3145	open palms, quick thrust downwards.	a10	Look up	b9	Look down, bend one leg	c11	lean forward holding arms out to the side	d3	leaning forward, arm out in front	e12

Decrease forward speed (f)	ID	Hold speed (g)		stop and hover (h)	ID	Strafe (i)	ID	Turn (j)	ID	Land and stop (k)	ID
Retract arms towards the body, hands in fists (accelerator pedal)	f1	Arms extended to desired speed, hands in fists	g1	Palms open towards the ground	h1	Extend one arm to the side they want to go	i1	Turn whole body	j1	open palms arms at the sides	k1
lower arm with hand squeeze	f2	open palm	g2	stand in neutral position after lowering speed	h2	Joystick	i2	Turn whole body	j1	ground collision	k2
Retract arms towards the body, hands in fists (accelerator pedal)	f1	Arms extended to desired speed, hands in fists	g1	stand in neutral position after lowering speed	h2	extend both arms towards the desired direction	i3	Turn whole body	j1	ground collision	k2
joystick down	f3	button press	g3	stand in neutral position after lowering speed	h2	Joystick	i2	Turn whole body	j1	ground collision	k2
lean back holding arms out to the side	f4	hold the lean to the desired speed	g4	stand in a neutral position arms extended to either side open palm	h3	lower arm towards the desired direction, elevate arm opposite desired direction	i4	Turn whole body	j1	ground collision	k2
retract arms towards the body, hands in fists (accelerator pedal)	f1	Arms extended to desired speed, hands in fists, rotate hands forwarf	g5	arms in front open palms	h4	extend both arms towards the desired direction	i3	turn hands in a steeting wheel motion, hands in fists	j2	Ground collision open palms	k3
Retract one arm, hand in fist, (accelerator pedal)	f5	One arm extended to desired speed, hand in fist.	g6	Palms open towards the ground	h1	Extend one arm to the opposite side they want to go to, open palm, angle determines how fast the strafe is	i5	Turn whole body	j1	open palms arms at the sides	k1
Retract one arm, hand in fist, (accelerator pedal)	f5	One arm extended to desired speed, hand in fist.	g6	Palms open towards the ground	h1	Extend one arm to the opposite side they want to go to, open palm, angle determines how fast the strafe is	i5	Turn whole body	j1	small hop	k4
Both hands extended in front of the body, palms open pointing forward	f6	hold the lean to the desired speed	g4	Arms at the side, semi closed fists pointing down	h5	Extend one arm to the opposite side they want to go to, open palm, angle determines how fast the strafe is	i5	Point open palms in opposite directions, on opposite sides of the center of gravity	j3	Ground collision, hands in fists	k5
Swim motion backwards	f7	Swim motion in intervals to reach desired speed	g7	Swim motion upwards at regular intervals	h6	Swim motion pushing to the opposite side they want to go to	i6	Turn whole body	j1	ground collision	k2
Retract one arm, hand in fist, (accelerator pedal)	f5	One arm extended to desired speed, hand in fist.	g6	stand in neutral position after lowering speed	h2	Extend one arm to the side they want to go	i1	Turn whole body	j1	small hop	k4
Retract arms towards the body, hands in fists (accelerator pedal)	f1	Arms extended to desired speed, hands in fists	g1	stand in neutral position after lowering speed	h2	Lean towards the side they want to go to	i7	Turn whole body	j1	ground collision	k2
Both hands extended in front of the body, palms open pointing forward	f6	Arms extended behind the body, palms open pointing backwards	g8	Arms held out to the side, elbows bent in front, palms open facing towards the ground	h7	Lean towards the side they want to go to	i7	Turn whole body	j1	Crouch	k6
Retract one arm from both arms fully extended	f8	One arm extended to desired speed, hand in fist.	g6	Arms at the side, semi closed fists pointing down	h5	lower arm towards the desired direction, elevate arm opposite desired direction	i4	Turn whole body	j1	ground collision	k2
Lean backwards arms down at the side	f9	Arms extended behind the body, palms open pointing backwards	g8	stand in neutral position after lowering speed	h2	Extend one arm to the opposite side they want to go to, open palm, angle determines how fast the strafe is	i5	Turn whole body	j1	ground collision	k2
Both hands extended in front of the body, palms open pointing forward	f6	Arms extended behind the body, palms open pointing backwards	g8	Palms open towards the ground	h1	Extend one arm to the opposite side they want to go to, open palm, angle determines how fast the strafe is	i5	Point open palms in opposite directions, on opposite sides of the center of gravity	j3	Ground collision, hands in fists	k5
lean back holding arms out to the side	f4	hold the lean to the desired speed	g4	Arms held out to the side, elbows bent in front, palms open facing towards the ground	h7	Lean towards the side they want to go to	i7	Turn whole body	j1	ground collision	k2
lean back holding arms out to the side	f4	hold the lean to the desired speed	g4	Palms open towards the ground	h1	Extend one arm in the opposite direction they want to go to, open palms	i8	Turn whole body	j1	Ground collision open palms, quick thrust downwards	k7
Lean backwards arms down at the side	f9	hold the lean to the desired speed	g4	Palms open towards the ground	h1	Extend one arm to the opposite side they want to go to, open palm, angle determines how fast the strafe is	i5	Turn whole body	j1	Ground collision, hands in fists	k5
Lean backwards arms down at the side	f9	hold the lean to the desired speed	g4	Palms open towards the ground	h1	Lean towards the side they want to go to	i7	Turn whole body	j1	Crouch	k6

Specify (l)	ID	Confirm (m)	ID	Move up (n)	ID	Move left/right (o)	ID	Move away (p)	ID	Move closer (q)	ID
Point	l1	index squeeze	m1	Move arm up index finger extended (stick metaphor)	n1	Move arm left/right index finger extended (Stick metaphor)	o1	Extend arm, squeeze index finger (joystick metaphor)	p1	Retract arm, squeeze index finger (joystick metaphor)	q1
Head gaze	l2	index squeeze	m1	Move arm up, hand in fist (stick metaphor)	n2	Move arm left/right (Stick metaphor)	o2	Extension from middle point (move arm back if fully extended, then forward	p2	Retracting from middle point	q2
Point	l1	button press	m2	Move arm up index finger extended (stick metaphor)	n1	Move arm left/right index finger extended (Stick metaphor)	o1	Joystick up	p3	Joystick down	q3
Point	l1	index squeeze	m1	Move arm up, hand in fist (stick metaphor)	n2	Move arm left/right (Stick metaphor)	o2	Joystick up	p3	Joystick down	q3
Point (open palm)	l3	squeeze hold hand	m3	Move arm up, hand in fist (stick metaphor)	n2	Move arm left/right (Stick metaphor)	o2	Extend arm, hand in fist (joystick metaphor)	p4	Retract arm, hand in fist (joystick metaphor)	q4
Point (open palm)	l3	squeeze hold hand	m3	Move arm up, hand in fist (stick metaphor)	n2	Move arm left/right (Stick metaphor)	o2	Thrust arm forward hand in fist, push based from the force of the fist	p5	Retract arm, hand in fist (joystick metaphor)	q4
Point (open palm)	l3	Grab	m5	Move arm up, hand in fist (stick metaphor)	n2	Move arm left/right (Stick metaphor)	o2	Thrust arm forward hand in fist, push based from the force of the fist	p5	Retract arm, hand in fist (joystick metaphor)	q4
Point	l1	pinch, index and thumb	m4	Move arm up, hand in fist (stick metaphor)	n2	Move arm left/right (Stick metaphor)	o2	Extend arm, hand in fist (joystick metaphor)	p4	Retract arm, hand in fist (joystick metaphor)	q4
Point (open palm)	l3	Grab	m5	Move arm up, hand in fist (stick metaphor)	n2	Move arm left/right (Stick metaphor)	o2	Extend arm, hand in fist (joystick metaphor)	p4	Retract arm, hand in fist (joystick metaphor)	q4
Point	l1	index squeeze	m1	Move arm up, hand in fist (stick metaphor)	n2	Move arm left/right (Stick metaphor)	o2	Joystick up	p3	Joystick down	q3
Point (open palm)	l3	Grab	m5	Move arm up, palm open towards the given direction	n3	Move arm left to right, palm open towards the given direction	o3	Extend arm, hand in fist (joystick metaphor)	p4	Retract arm, hand in fist (joystick metaphor)	q4
Point (open palm)	l3	Grab	m5	Move arm up, palm open towards the given direction	n3	Move arm left to right, palm open towards the given direction	o3	Palm open facing away, extending arm	p6	palm open facing inwards, retracting arm	q5
Point (open palm)	l3	Grab	m5	Move arm up, palm open towards the given direction	n3	Move arm left to right, palm open towards the given direction	o3	Palm open facing away, extending arm	p6	palm open facing inwards, retracting arm	q5
Point (open palm)	l3	Grab	m5	Move arm up, hand in fist (stick metaphor)	n2	Move arm left/right (Stick metaphor)	o2	Extend arm, hand in fist (joystick metaphor)	p4	Retract arm, hand in fist (joystick metaphor)	q4
Point (open palm)	l3	Grab	m5	Move arm up, palm open towards the given direction	n3	Move arm left to right, palm open towards the given direction	o3	Thrust arm forward hand open, moves continuously away after thrust	p7	Retract arm open hand (joystick metaphor)	q6
Point	l1	Jab hand forward	m6	Move arm up, palm open towards the given direction	n3	Move arm left to right, palm open towards the given direction	o3	Palm open facing away, extending arm	p6	Retract arm, hand in fist (joystick metaphor)	q4
Point	l1	Jab hand forward	m6	Move arm up, palm open towards the given direction	n3	Move arm left to right, palm open towards the given direction	o3	Palm open facing away, extending arm	p6	palm open facing inwards, retracting arm	q5
Point	l1	Jab hand forward	m6	Move arm up open hand	n4	Move arm left and right open hand	o4	Extend arm open hand joystick metaphor	p8	Retract arm open hand (joystick metaphor)	q6
Point	l1	Jab hand forward	m6	Move arm up, palm open towards the given direction	n3	Move arm left to right, palm open towards the given direction	o3	Palm open facing away, extending arm	p6	Retract arm, hand in fist (joystick metaphor)	q4
Point (open palm)	l3	squeeze hold hand	m3	Move arm up, hand in fist (stick metaphor)	n2	Move arm left/right (Stick metaphor)	o2	Thrust arm forward hand open, moves continuously away after thrust	p7	Retract arm, hand in fist (joystick metaphor)	q4

Hold (r)	ID	Rotate X (pitch) (s)	ID	Rotate Y (yaw) (t)	ID	Rotate Z (roll) (u)	ID	Release (v)	ID
Other hand, palm up, held there	r1	Flick wrist up/down	s1	Flick wirst left/right	t1	Rotate hand	u1	Open palm	v1
Button press	r2	Tilt wrist up down (joystick metaphor)	s2	Wriggle wrist back and forth (joystick metaphor	t2	Rotate hand	u1	Open palm	v1
Button press	r2	other hand open palm swipe from up or down	s3	open palm swip from left or right	t3	grab and rotate on a centra pivot point	u2	Open palm	v1
Button press	r2	joystick up and down	s4	joystick left right	t4	Rotate hand	u1	Release index finger	v2
Other hand, palm up, held there	r1	other hand in fist pointed towards the side of the object with second hand, wheel motion	s5	hand in fist pointed towards the bottom of the object with second hand, wheel motion	t5	hand in fist pointed towards the front of the object with second hand, wheel motion	u3	Open palm	v1
open palm, dwell time, pointed at the object	r3	other hand in fist pointed towards the side of the object with second hand, wheel motion	s5	hand in fist pointed towards the bottom of the object with second hand, wheel motion	t5	hand in fist pointed towards the front of the object with second hand, wheel motion	u3	Open palm, pointed down	v3
other hands twist locking motion	r4	other hand, grab and turn from the side	s6	Other hand grab and turn from the bottom	t6	main hand turn clockwise/counter clockwise	u4	Open palm	v1
sharp rotation movement (locking motion)	r5	other hand in fist pointed towards the side of the object with second hand, wheel motion	s5	hand in fist pointed towards the bottom of the object with second hand, wheel motion	t5	hand in fist pointed towards the front of the object with second hand, wheel motion	u3	Open palm	v1
Squeeze hand	r6	other hand, grab and turn from the side	s6	Other hand grab and turn from the bottom	t6	Other hand grab from front and turn clockwise/counter clockwise	u5	Open palm	v1
Button press	r2	Other hand close fist pointed straight towards the object swiping motion up and down	s7	other hand closed fist pointed straight towards the object swiping motion left and right	t7	hand in fist pointed towards the front of the object with second hand, wheel motion	u3	Release index finger	v2
Let hand fall to neutral position	r7	other hand, grab and turn from the side	s6	Other hand grab and turn from the bottom	t6	Other hand grab from front and turn clockwise/counter clockwise	u5	Small squeeze	v3
Squeeze hand	r6	other hand, grab and turn from the side	s6	Other hand grab and turn from the bottom	t6	main hand turn clockwise/counter clockwise	u4	Let hand fall down to a neutral position	v4
Let hand fall to neutral position	r7	other hand in fist pointed towards the side of the object with second hand, wheel motion	s5	hand in fist pointed towards the bottom of the object with second hand, wheel motion	t5	hand in fist pointed towards the front of the object with second hand, wheel motion	u3	Small squeeze	v3
Other hand, palm up, held there	r1	Make a hook gesture with the index finger of the main hand, wheel motion	s8	Make a hook gesture with the index finger of the main hand, wheel motion	t8	Make a hook gesture with the index finger of the main hand, wheel motion	u6	Swipe arm away	v5
Squeeze hand	r6	Hold position on object, main hand grab from side and rotate hand in the desired direction	s9	Hold position on object, main hand grab from below and rotate hand in the desired direction	t9	main hand turn clockwise/counter clockwise	u4	Small squeeze	v3
Squeeze hand	r6	Hold position on object, main hand grab from side and rotate hand in the desired direction	s9	Hold position on object, main hand grab from below and rotate hand in the desired direction	t9	main hand turn clockwise/counter clockwise	u4	Small squeeze	v3
Squeeze hand	r6	Hold position on object, main hand grab from side and rotate hand in the desired direction	s9	Hold position on object, main hand grab from below and rotate hand in the desired direction	t9	main hand turn clockwise/counter clockwise	u4	Swipe arm away	v5
Quick shake of the hand up and down	r8	Use both hands and grab on either side, rotating at the wrists	s10	Use both hands an grab on either side, move hands around the object	t10	main hand turn clockwise/counter clockwise	u4	Open palm	v1
Other hand, palm up, held there	r1	Flick wrist up/down	s1	Other hand grab and turn from the bottom	t6	main hand turn clockwise/counter clockwise	u4	Open palm	v1
Other hand, palm up, held there	r1	other hand in fist pointed towards the side of the object with second hand, wheel motion	s5	hand in fist pointed towards the bottom of the object with second hand, wheel motion	t5	main hand turn clockwise/counter clockwise	u4	Open palm	v1

C Implemented interaction techniques questionnaire

Did you participate in the preliminary gesture elicitation study before this test?

(1) ❍ Yes

(2) ❍ No

Gender

(1) ❍ Female

(2) ❍ Male

(3) ❍ Prefer not to say

Age

____

Filled out by conductor

This interaction

(1) ❍ A

(2) ❍ B

Test 1 time

_____

Test 2 time

_____

Please fill out the questions below regarding the interaction you just experienced.

I think that I would like to use this system frequently

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

I found the system unnecessarily complex.

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

I thought the system was easy to use.

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

I think that I would need the support of a technical person to be able to use this system.

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

I found the various functions in this system were well integrated.

(1) ❍ Strongly Disagree | (2) ❍ Disagree | (3) ❍ Neither agree nor disagree | (4) ❍ Agree | (5) ❍ Strongly Agree

I thought there was too much inconsistency in this system.

(1) ❍ Strongly Disagree | (2) ❍ Disagree | (3) ❍ Neither agree nor disagree | (4) ❍ Agree | (5) ❍ Strongly Agree

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

(1) ❍ Strongly Disagree | (2) ❍ Disagree | (3) ❍ Neither agree nor disagree | (4) ❍ Agree | (5) ❍ Strongly Agree

I found the system very cumbersome to use.

(1) ❍ Strongly Disagree | (2) ❍ Disagree | (3) ❍ Neither agree nor disagree | (4) ❍ Agree | (5) ❍ Strongly Agree

I felt very confident using the system.

(1) ❍ Strongly Disagree | (2) ❍ Disagree | (3) ❍ Neither agree nor disagree | (4) ❍ Agree | (5) ❍ Strongly Agree

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

(1) ❍ Strongly Disagree (2) ❍ Disagree (3) ❍ Neither agree nor disagree (4) ❍ Agree (5) ❍ Strongly Agree

I felt like i had a supernatural power

(1) ❍ Strongly Disagree (2) ❍ Disagree (3) ❍ Neither agree nor disagree (4) ❍ Agree (5) ❍ Strongly Agree

Please rate on a scale of 1 to 10 how fun you thought the system was to interact with

(1) ❍ 1

(2) ❍ 2

(3) ❍ 3

(4) ❍ 4

(5) ❍ 5

(6) ❍ 6

(7) ❍ 7

(8) ❍ 8

(9) ❍ 9

(10) ❍ 10

Please explain in a few words why you answered in the way you did to the question above.

____

Did you feel any similarity between the system you just interacted with and something you have seen before (This could be a game, movie, TV show, comic book etc.)

____

When you have filled out all the questions above please notify the conductor and we can begin the second part of this test

Filled out by conductor

This interaction

(1) ❍ A

(2) ❍ B

Test 1 time

_____

Test 2 time

_____

Please fill out the questions below regarding the interaction you just experienced.

I think that I would like to use this system frequently

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

I found the system unnecessarily complex.

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

I thought the system was easy to use.

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

I think that I would need the support of a technical person to be able to use this system.

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

I found the various functions in this system were well integrated.

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

I thought there was too much inconsistency in this system.

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

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

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

I found the system very cumbersome to use.

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

I felt very confident using the system.

(1) ❍ Strongly Disagree	(2) ❍ Disagree	(3) ❍ Neither agree nor disagree	(4) ❍ Agree	(5) ❍ Strongly Agree

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

(1) ❍ Strongly Disagree (2) ❍ Disagree (3) ❍ Neither agree nor disagree (4) ❍ Agree (5) ❍ Strongly Agree

I felt like i had a supernatural power

(1) ❍ Strongly Disagree (2) ❍ Disagree (3) ❍ Neither agree nor disagree (4) ❍ Agree (5) ❍ Strongly Agree

Please rate on a scale of 1 to 10 how fun you thought the system was to interact with

(1) ❍ 1

(2) ❍ 2

(3) ❍ 3

(4) ❍ 4

(5) ❍ 5

(6) ❍ 6

(7) ❍ 7

(8) ❍ 8

(9) ❍ 9

(10) ❍ 10

Please explain in a few words why you answered in the way you did to the question above.

____

Did you feel any similarity between the system you just interacted with and something you have seen before (This could be a game, movie, TV show, comic book etc.)

____

,

D Questionnaire answers

Did you participate in the preliminary gesture elicitation	Gender	Age	This interaction	Test 1 time	Test 2 time	to use this system frequently
No	Male	24	A	83	254	5
Yes	Male	37	B	31	65	2
No	Female	21	A	91	360	4
No	Male	34	B	29	102	5
No	Male	16	A	54	144	4
No	Male	28	B	17	111	4
Yes	Male	34	A	34	126	3
Yes	Male	27	B	19	88	2
Yes	Male	27	A	135	138	3
No	Male	31	B	20	71	5
Yes	Male	28	A	50	172	4
Yes	Male	27	B	41	78	5
No	Male	31	A	62	152	3
No	Male	27	B	18	72	4
Yes	Male	27	A	36	158	3
No	Male	25	B	23	56	4
Yes	Male	25	A	23	266	5
No	Female	27	B	27	101	4
No	Male	19	A	50	75	4
Yes	Female	26	B	54	187	4

I found the system unnecessarily complex.	I thought the system was easy to use.	the support of a technical person to be	functions in this system were well integrated.	much inconsistency in this system.	most people would learn to use this system very	I found the system very cumbersome to use.
2	4	1	4	1	5	2
1	4	1	4	2	5	2
3	3	2	5	1	3	4
1	5	1	4	1	5	1
2	3	3	3	2	4	2
1	5	1	4	3	5	2
2	3	1	4	2	4	3
2	4	2	4	1	4	2
1	3	2	4	1	3	2
1	5	1	5	1	5	1
2	5	1	4	2	5	1
1	5	1	5	1	2	1
3	2	4	3	4	2	4
2	4	1	4	2	4	2
4	2	4	4	1	3	2
1	4	1	5	1	5	1
2	4	1	5	2	5	1
1	4	1	4	2	4	2
1	4	1	5	1	4	1
2	4	1	5	2	5	1

I felt very confident using the system.	things before I could get going with this system.	I felt like i had a supernatural power	of 1 to 10 how fun you thought the system was
4	2	5	10
4	2	4	7
2	2	4	6
5	1	4	8
4	2	5	7
3	1	5	8
4	1	2	6
4	1	5	8
4	2	3	8
5	1	5	10
5	1	5	10
5	4	5	10
3	3	4	7
4	1	3	7
4	2	5	7
4	2	3	9
4	2	5	9
4	2	2	8
4	1	4	9
4	1	4	8

Please explain in a few words why you answered in the way you did to the question above.

It´s not often you can find ways in real life to lift objects in a distance, so it was pretty fun to feel like a superhero.

My answer is coloured by the fact that I have comparably little prior experience with VR, which possibly confers an inflated sense of novelty.

I think it was nice to use but a bit of an learning curve , so therefore a little unsure

it is smooth and easy to use

Took a little time, however when I got used to the way it feels and objects moves/rotates it became much easier

Playing with physics, throwing objects around just feels cool and fun. Using my own body felt natural.

movement is really good, rotation with the auxiliary hand was cumbersome

It quickly felt natural to use, sometimes a little more difficult when you had to rotate etc.

I felt the interaction was very natural, and it was quite cool have the possibility of moving/behaving this way

The system was very innovative yet very easy to use!

having the ability to interact with the system in the way it is made it very fun, being able to take objects and control their movement in space with simple hand gestures makes it extremely fun.

I thought that the interaction was really cool, and I enjoyed having superhuman stretching and strength like luffy in one piece.

manipulating objects is fun. Learning is fun too.

it was an interesting type of interaction but required to be reset after a while because in became a bit inaccurate

I liked the way of interacting a lot. It was new. A more interesting or fun task would have made me rate it higher.

I think it was a very nice interaction form. In the first test the challenge lied in the coorodination of both hands. However, it was really easy to learn.

It seemed intuitive and lived up to a lot of the childhood dreams of being an x-man i had

It felt very intuitive to interact with it. When it was natural it felt more smooth to operate

The delay in the objects moving to wherever was pointed really gave them a sense of weight, which made the entire experience quite fun.

I found it very entertaining to move the shapes around and figure out how to place them correctly. It was challenging but not too much.

Did you feel any similarity between the system you just interacted with and something you have seen before (This could be a game, movie, TV show, comic book etc.)	This interaction	Test 1 time	Test 2 time
Yeah, I felt like a Jedi grandmaster controlling objects with my mind.	B	60	61
It reminded me of the game 'Boom Blox' (Nintendo Wii).	A	62	245
superhero movies	B	61	270
one peace, incredible, fantastik 4	A	38	306
I think an solar system VR app ability to take planets and throw them around. Nowhere near as much control at this though.	B	26	154
Games that have motions controls and let's you throw stuff around	A	30	336
Spiderman	B	22	87
Hmmm it felt super power ish, but I don't know. Maybe spider man web	A	29	410
I do see a similarity to some superhero/comic thing, not sure were I have seen it - Xmen maybe?	B	31	113
I felt like elastic girl and very powerful!	A	50	140
It made me feel like Spiderman while moving objects fast and swinging, and a bit like magneto from Xmen while rotating and moving objects slowly.	B	21	59
Ye, for example one piece (luffy) and the incredibles (elastagirl) and mr. fantastic	A	56	214
possibly some minority report - Though I don't remember that as much 3d manipulation - more just surfaces	B	64	124
without knowing too much about it, i was thinking something like the Green Lantern superhero or some other telekinesis power. Maybe also similar to the powers in The Chronicle	A	27	95
Reminded me of telekineses done in various movies/games, but I've never seen anything like it in VR.	B	46	108
not really. havent played any games or interaction that had these kind of interactions	A	34	150
I felt like a character from X-men or Chronicle	B	16	65
not really, maybe a little like elastigirl	A	46	250
Similar to a lot of other VR games. The objects still being part of the physics was reminiscent of Half-Life: Alyx, and moving them at a distance is similar to many other VR applications	B	19	53
It felt a bit like using the Force from Star Wars!	A	52	115

I think that I would like to use this system frequently	I found the system unnecessarily complex.	I thought the system was easy to use.	the support of a technical person to be able to use	functions in this system were well integrated.	much inconsistency in this system.
5	1	5	1	5	1
2	4	2	2	3	4
5	2	4	2	5	1
3	3	3	2	5	2
4	4	4	2	4	5
3	4	2	2	2	4
2	2	2	2	3	3
2	4	2	4	2	2
3	2	3	2	3	1
5	2	4	1	5	2
4	1	5	1	5	1
4	4	2	1	5	4
4	4	4	4	4	4
4	3	3	1	4	2
4	2	4	5	5	2
5	2	3	3	4	2
5	1	5	1	5	1
4	3	3	2	4	3
4	2	4	2	4	1
5	2	5	2	5	1

people would learn to use this system very quickly.	I found the system very cumbersome to use.	I felt very confident using the system.	things before I could get going with this system.	I felt like i had a supernatural power	1 to 10 how fun you thought the system was to
4	1	4	3	5	10
3	4	2	2	3	4
4	2	4	2	4	8
3	4	4	2	5	8
5	2	4	1	4	8
2	4	2	2	4	5
3	4	4	2	2	4
2	4	3	4	4	7
4	2	4	2	2	6
5	1	4	1	5	10
5	1	5	1	1	7
1	4	1	1	5	7
4	2	4	2	5	9
3	2	3	4	4	7
5	1	5	3	5	8
3	2	4	3	1	10
5	1	5	1	5	7
3	3	3	2	5	9
3	2	4	3	5	7
3	2	5	1	5	9

Please explain in a few words why you answered in the way you did to the question above.	Did you feel any similarity between the system you just interacted with and something you have seen before
disengage from my hand and let it far away, but it was much more intuitive after getting used to that feeling.	I felt more like Mr. Fantastic this time, being able to stretch my arm really looooooong.
I felt like I wasn't very adept at using the control system; perhaps with more practice it would feel more enjoyable.	Perhaps the interactive display in the film 'Minority Report'.
i think the system, was easier to use but maybe a little less like you have super powers	movies
The other system was better	x-Men
Really nice you can rotate objects like you would normally yourself.	Not really no.
It was harder to move things around and rotate. It did not feel as natural as the other method.	There is a sort of tractor beam in Ratchet and Clank which it felt similar to, as well as a sort of magnetic superpower reminiscent of Magneto from X-men
Scaled movement worked fine, but there was no scaled rotation	Half life, maybe?
It seemed more difficult than the other method	Again I got some spider man vibes
It was quite exhausting for the arms, and the thing about rescaling and resetting made it a bit unnatural (though it was intuitive)	Again some kind of superhero, comic books thing
to control the distance of the object, but with a bit of training, I think it will become a natural way of interacting.	It felt a bit like the interaction in Half Life Alex, but with more freedom to play and explore.
I think this system was like clicking and dragging an object in any software that has a 3d environment. Does the job but it isn't fun	I didn't like it had any similarities with anything from what I can recall.
the way it worked but often I couldnt make it rotate, maybe it was me being bad, but it made the system less fun to interact with. But still overall a good experience.	Yes, I felt like luffy from one piece with the stretchy arms, and a little like naruto with the rasengan when doing the rotations with the hands.
do before - Compared to the previous interaction, which was like using a fishing rod. This interaction felt less like using a tool, but rather augmenting my physical capabilities.	Inspector Gadget
i felt like i had more control over the rotations but it took a bit longer to get used to it. Also it was a bit harder to control the distance of the object while rotating	Again it reminded me of The Chronicle
More fun than the other as it was easer to pick up and use along the way. Once again, a more interesting task would make me rank it higher. Could see myself use this in a game.	Elastic girl. The new Dungeons and Dragons movie (two sorcerers have a fight with big hands made of stone/fire that they control with their own hand.)
It was more of a challange to get akin to the interaction. The intearction made my not dominan hand more usefull as i felt i could use both hands equally good	Tom Cruise movie(cant remmeber the name. Enders Game
The interaction is extremely intuitive and comes so naturally, but it doesnt feel as entertaining as the previous version	This felter closer to a Fister Fantastic or Luffy.
like more of a challenge to overcome. I felt that this was more of an experience than the previous one, felt more like a game.	not really again, maybe the force from star wars
It felt a bit less fun as the objects felt too weightless. Felt less like I was interacting with a world, and more like I was interacting with a simulation	Reminds me of Rayman (Game Series), with his detached hands being able to fly away from his body
This interaction was really cool and I loved that you didn't have to "grab" things in order to move them around.	Still the Force, but better than before - with a little Dr. Strange too.

E Participants grouped for previous participation in GES

	GoGo		Telekinesis	
	Did participate	Did not participate	Did participate	Did not participate
	52.5	90	72.5	85
	70	72.5	72.5	90
	97.5	82.5	90	62.5
	75	67.5	57.5	67.5
	100	60	87.5	37.5
	77.5	97.5	40	62.5
	75	82.5	32.5	37.5
	85	100	47.5	90
	87.5	80	87.5	62.5
		90		67.5
		80		60
Median	77.5	82.5	72.5	62.5
Mean	80	82.04545	65.27778	65.68182

Table 7: SUS answers grouped in participants who did and did not participate in GES

	GoGo		Telekinesis	
	Did participate	Did not participate	Did participate	Did not participate
	4	10	6	10
	6	7	8	9
	7	8	10	6
	8	8	7	7
	7	9	9	7
	7	8	4	8
	8	8	7	5
	10	10	7	10
	8	7	9	7
		9		10
		8		9
Median	7	8	7	8
Mean	7.222222	8.363636	7.444444	8

Table 8: Fun answers grouped in participants who did and did not participate in GES

	GoGo		Telekinesis	
	Did participate	Did not participate	Did participate	Did not participate
	2	5	2	5
	2	5	3	4
	1	4	5	4
	5	4	5	5
	5	5	5	4
	4	4	3	5
	5	5	4	4
	5	5	5	5
	4	3	5	4
		3		1
		2		5
Median	4	4	5	4
Mean	3.666667	4.090909	4.111111	4.181818

Table 9: "I felt like i had a superpower" answers grouped in participants who did and did not participate in GES