Bachelor Report

Evaluation of different Handover Methods in Virtual Reality

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Abstract

Providing a natural handover of objects is a difficult task in VR. This difficulty is caused by several factors. One of them is the uncertainty of the moment when the object should be released by the agent. Another reason is the lack of realistic haptic feedback. The present thesis met these challenges. For this purpose, two VR experiments were conducted between agent and human. The pilot study tested whether the user lifts the object when taking it over. Therefore, lifting of the object was set as a condition for releasing the object, and compared with an immediate release of the object. This pilot experiment identified that in VR the object was mostly not lifted much after grasping.

A modified HCT Vive controller that is able to generate resistance was tested in the main study. As haptic feedback can increase the perceived telepresence and co-presence, we hypothesized that the resistance would achieve this effect and more naturalness of the controls during handover tasks. This resistance controller was compared to a standardized Oculus Quest 2 controller. The results showed that the resistance of pressing the button distracts the user in this task, as it occurs before the visual hand grasps an object.

Contents

List of Abbreviations

VR	Virtual Reality
VE	Virtual environment
TMC	Triggermuscle Controller
Q2C	Oculus Quest 2 Controller
OQ2	Oculus Quest 2
C/D	Control/Display
AR	Augmented reality
MR	Mixed reality
HMD	Head-mounted display
SD	Standard Deviation
n	Number
V	Variance

1 INTRODUCTION

1.1 Motivation

Virtual reality (VR) has a vast range of application areas. It is particularly popular as a testing and training environment for example in surgery, in the military, in education, in sports, or in robotics [1, 2, 3]. The reasons for this are obvious: low costs, little risk, and no damage. To explore VR environments as in the real world, we depend on our visual, auditory, and haptic senses. While visual and auditory senses can be reached well in VR, providing haptic feedback there is still a challenge. The commercially available controllers can provide vibrotactile stimuli. However, they lack kinematic input such as resistance, weight, or inertia. Haptic feedback can help to increase the user's perception of presence and improve the task performance of collaborative manipulation tasks [4, 5].

In virtual environments (VE) it is often necessary to take over objects from an agent. Accepting or handing over objects is an everyday activity for humans to which we pay little attention. Often, we do not even realize the way we pass things on to others. However, there are several different ways of handing over, depending on the object, its properties, and the mental model we have of our counterpart. The variety of factors that influence makes it difficult to implement this capability in software-controlled agents.

1.2 Goals and Hypotheses

In order to achieve a natural handover between agent and human in VR as in human-human interaction in the real world, different handover methods are evaluated in this thesis. For this purpose, two agent-human interaction experiments were performed. In these experiments, a software-controlled agent handed over items, and participants received them.

The pilot study analyzed the moment when the agent releases the object during the handover process. Two different conditions were tested for the release of the object. In the default condition, the agent releases the object immediately, while in the other case, the human recipient must lift the item before the agent releases it. The second condition was tested based on observations of human-to-human handovers in the real environment. In order to investigate whether this is a suitable condition for releasing the object in VR, the following hypothesis was tested:

> H_{Pre}: A handover is perceived more realistically if the robot releases the object after a lifting movement of the human taker.

In the main study, two different controllers were tested regarding to the haptic feedback: A standardized Oculus Quest 2 controller (Q2C) and the *Triggermuscle* controller (TMC) developed by Stellmacher et al., which can generate resistance in the index finger trigger button, were compared. Stellmacher et al. tested their Tiggermuscle controller for weight perception [6]. Even though they combined their controller with pseudo-haptics in order to increase weight perception in a previous experiment, the main study tested only the Tiggermuscle controller since the Control/Display ratio (C/D ratio) Stellmacher et al. applied would not make sense when taking over objects [7].

For the main study, it was assumed that resistance to taking over an object could increase the user’s perception of telepresence, social presence, and co-presence. It was supposed that the control mechanism might be more natural with resistance than without it. The following main hypothesis and the resulting sub hypotheses were tested:

H1. The TMC results in a more natural perception of controls during the handover process.

- H1a. The TMC increases perceived telepresence.
- H1b. The TMC increases perceived co-presence.

The influence of different properties of the objects was also observed. In the main study, four different objects were handed over twice: a mug with a handle, a mug without a handle, a full mug with a handle, and a ball. It was assumed that a full mug increases the transportation time from the agent to the target compared to an empty one. The effects of different orientations of the objects were also examined.

1.3 Structure of the Thesis

Following the introduction, the structure of the thesis is divided into three further main chapters. Chapter 2 describes the state of the art, which includes Virtual Really (2.1), Presence (2.2), Haptics (2.3), Interaction, Cooperation, and Collaboration (2.4), and Handover Tasks (2.5). Besides presence itself, the sub-chapter presence contains information about Telepresence (2.2.1), Social Presence (2.2.2), and Co-Presence (2.2.3).

In addition to the haptic perception itself, the section on haptics comprises different methods for simulating haptics in VR, starting with haptic illusions (2.3.1), followed by pseudo-haptics (2.3.2), haptic devices (2.3.3), and Visuo-haptic illusions (2.3.4).

Chapter 3 illustrates the methodology of the study. This incorporates the pilot study (3.1) and the main study (3.2), both divided into:

- Participants of the study
- Experimental Setup
- Implementation
- Results
- Discussion

The final Chapter 4 considers the conclusion of the results and potential prospective studies.

2 STATE OF THE ART

2.1 Virtual Reality

VR is nowadays a commonly used term and a frequent component of many studies. To define VR, it is necessary to understand its components themselves. Bryson specified the two components of VR: “Virtual” as an effect of being without being such, and “Reality” as a property of being real, with the addition “Real” as a property of concrete existence. Merging “Virtual” and “Reality”, we receive: The effect of possessing concrete existence without actually possessing concrete existence [8].

Sherman and Crain defined five key elements of VR: Virtual world, immersion, interaction, and people on both, the creating and receiving sides of the medium. Those features were combined into the definition: A medium consisting of interactive computer simulations that perceive the participant’s position and actions and replace or extend the feedback to one or multiple senses, creating the feeling of being mentally immersed in or present in the simulation (VE) [9].

Augmented reality (AR) and mixed reality (MR) are terms that you will encounter when dealing with VR. While AR, and VR have similar ones, several definitions are used for MR. This causes confusion. To avoid this disorder, M. Parveau and M. Addaa provided a classification called “3iVClass” between the terms VR, AR, and MR. This new method of classification is based on three criteria: Immersion, interaction, and information. Based on these criteria, AR, VR and MR were assigned the following properties:

- AR is a paradigm that combines technologies which augment the real world using virtual annotations. The interaction with physical objects is mediated. Information is not time-persistent and decorrelated from the user’s space.
- VR is a paradigm that combines technologies that generate a total VE. The interaction with virtual objects registered in 3D space is mediated via a controller. The objects are not time-persistent and are decorrelated to the user’s space.
- MR is a paradigm that combines technologies that map virtual objects spatially and in real time to the user’s real environment. Interaction with virtual and physical objects is not mediated but directly. Virtual objects are registered time-persistently and are correlated to the user’s space in the virtual 3D space [10].

2.2 Presence

The concept of presence is a fundamental feature of VR. Presence is defined as the feeling of being in an environment [11]. Some researchers equate presence with immersion; immersion, however, refers to the abilities of a medium, and presence is the subjective perception of a person. Hence, immersion can be measured by technical capabilities of the medium. In order to fully experience an environment, the user needs to feel presence [12]. To evoke the sense of presence, the focus of a person´s attention must be directed to the desired location. This is all the more successful when we experience something new for ourselves. The more novel, immediate, and unique this experience is for us, the more we focus our attention on it [13]. Presence encompasses various dimensions and subcategories, including telepresence, co-presence, and social presence.

2.2.1 Telepresence

Telepresence plays the most important role in VR. Telepresence describes the feeling of being inserted into a VE, which is physically distant from the user, via a medium. In order to evoke this feeling, the user's focus must be shifted from the physical environment to the VE. Involvement and immersion are the key factors in experiencing telepresence.

Immersion is a psychological state that includes the feeling of being enveloped by a virtual location, being involved in it, and interacting with it. When the VE produces more immersion, we perceive more presence. Isolation from the real environment, the perception of self-inclusion in a virtual place, naturalness of interaction and control, and the perception of one´s own movement are components that increase immersion. Typically, head-mounted displays (HMD) provide this isolation in VR.

Involvement is also a psychological state, but it is caused by the concentration of energy and attention on stimuli, activities, or events. The degree of involvement depends on the importance the individual attaches to these stimuli, activities, or events. As attention to the virtual experience increases, so does the level of involvement, which in turn leads to higher perceptions of telepresence. However, when attention shifts to something outside the VE the involvement and thus perceived presence decreases. Distractions such as the discomfort of the VR equipment reduce the focus on the VE.

The experience of presence in a VE is influenced by several factors, such as control factors, sensory factors, distraction factors, and realism factors (**Table 1**).

Table 1: Factors which can increase perceived telepresence.

Control Factors	
Level of Control	More control
Immediacy of Control	Control results are immediate, appropriate, and provide expected continuity
Predictability	Ability to anticipate or predict outcomes
Mode of Control	Naturalness of controls
Modification of the physical Environment	Ability to manipulate or modify objects

Sensory Factors	
Type of sensory Impressions	Visual information is perceived more strongly than other sensory information, e.g., haptic or acoustic
Richness of the Environment	More sensory information transmitted to the appropriate sensors
Multimodal Presentation	Multiple senses are reached
Consistency of multimodal Information	Different senses fit together
Degree of Motion Perception	Self-movement through the virtual world
Active Search	Ability to actively alter obtaining of visual, auditory, and haptic information
Elimination of Distractions	
Isolation	Today's HMDs are able to isolate the user to the greatest possible extent from the physical environment. This isolation eliminates visual distractions
Selective Attention	The user's ability or willingness to focus only on the VE
Interface Awareness	HMDs that are unnatural, clumsy, or full of artifacts can distract from the VE
Realism Factors	
Consistency of Information with the objective World	Experiences in the real world correspond to experiences in the virtual world
Significance of Experience	The importance of experience for the users depends on themselves and is influenced by various factors such as motivation, saliency of a task, and previous experiences
Separation anxiety or disorientation	Disorientation or being afraid of returning to the real world

The measurement of telepresence is based on questions about the perception of these factors [13].

2.2.2 Social Presence

Social presence was first described in 1976 by Short et al. They used this concept to compare face-to-face conversations across different communication media and to collate communication media with each other [14]. The key components of this subcategory are intimacy and immediacy, which are interlinked. Both components are influenced by verbal and nonverbal signals such as facial expressions, voice, gestures, and physical appearance. How well those clues can be conveyed through a medium affects perceived social presence and the way people interact with each other. Social presence describes the degree of intimacy and immediacy perceived through a medium towards another person. Social presence thus depends on the quality of the medium. Perceived intimacy and immediacy increase with positive communication outcomes. This concept is taken into account when interacting with social interaction partners, regardless of whether they are software- or human-controlled [12, 15].

2.2.3 Co-Presence

First introduced by Goffman in 1963, co-presence was defined as the perception of being together in a VE in which individuals are accessible, available, and subjected to each other. The concept of co-presence describes the sense of noticing others and the sense that others can actively perceive us. The difference to social presence is that not the quality of the medium is addressed but rather psychological interaction of the individual [15, 14]. The perceived co-presence of virtual agents depends on four factors: Reaction to virtual agents, perceived reactions of virtual agents, impression of interaction possibilities with the virtual agent, and perceived (co-)presence of virtual agents [16].

Although all three types of presence are defined differently, several studies indicated that they are correlated to each other [14, 17]. The perception of presence can be enhanced by a number of factors, one of which is haptic feedback [4]. In particular, perceived telepresence and perceived task performance can be raised through haptic feedback in collaborative or shared VEs. However, as far as social presence is concerned, the results vary. This inconsistency could be due to different experimental setups. In the experiment which included haptic feedback as well as audio communication, no significant differences in perceived social presence were observed, but in the others they were. It was assumed that the acoustic senses overlapped the haptic effect in the study which provided audio communication [18, 19, 20].

2.3 Haptics

Haptics are information that we receive through touch. By touching an object, we perceive different states of this object. The human haptic system has two different types of receptors: mechanoreceptors and thermoreceptors. These receptors separate haptic information in tactile/ cutaneous inputs sensed through the skin, and kinesthetic inputs sensed through muscles, tendons, and joints [21, 22, 23].

Haptic sensations can be divided into material properties and spatial properties. Spatial properties include shape, curvature, size, volume and orientation. These properties can be perceived kinesthetically by moving skin over the object, or cutaneously by moving the object over skin. Material properties are shown in **Table 2**.

Table 2: Material object properties [24].

Compliance / Hardness	Is perceived when objects are squeezed and depending on the material the pressure distribution changes. This sensation belongs to the cutaneous inputs. However, the deformation of an object by compression depends on the stiffness of it and is a kinematics input
Temperature	Is perceived by touching an object. This sense is a cutaneous sensation and is affected by the material thermal properties of the material, the geometry of the object and the thermal contact resistance between object and skin
Friction	A resistance to movement that can be sensed through the force felt in the limbs and through the stretching of the skin. Hence, it is a cutaneous and kinematics sensation
Viscosity	Similar to frictional resistance to motion, but the aforementioned properties apply to solid objects, while viscosity applies to liquids. Perception is kinesthetic when speed of movement and resistance are felt
Density / Weight	A kinesthetic sensation that can be estimated from weight. Heaviness is also a haptic sensation, but it is not one of the material or spatial properties. Weight is perceived as a gravitational force when an object is held statically or as an inertial force (resistance to speed or change of direction) when it is motioned. The perceived weight and the physical weight depend on various factors such as the contact area. A smaller contact area increases the perceived weight of an object

In VR, we distinguish between active and passive haptics. Both can be cutaneous, or kinematics (**Figure 1**). Active haptic feedback is not controlled by hardware, but by the active perception of haptics e.g., by moving the skin over physical surface or by applying forces. Physical props are the easiest way to provide active haptics in VR.: Virtual objects are assigned to the position of a physical replica. Passive haptics, on the other hand, are controlled by a computer and are the most common form in VR, for example, the motionless touching of an object whose tactile or kinematic properties are adapted by hardware or software [25, 26].

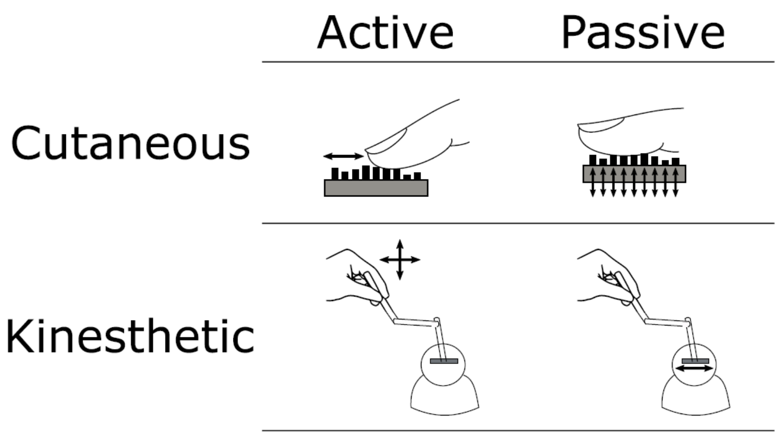

Figure 1: Classification of haptic interaction in relation to haptic devices. The four categories are cutaneous active, cutaneous passive, kinesthetic active, and kinesthetic passive [26].

2.3.1 Haptic Illusion

Commercial controller such as Oculus Touch or HTC Vive controllers provide vibrotactile stimuli. With this function haptic Illusions can be invoked. This is a method that illustrates different types of haptic sensations and has been used in various studies to investigate the compliance of rigid surfaces [27, 28, 29] different force-displacement curves of virtual buttons [30], force directions, [31, 32] and to simulate grasping and weight of virtual objects [33]. Berger and Gonzalez-Franco implemented this technique of sensing the touch of an object using two common handheld HTC Vive controllers in a VE [34]. However, the conveyance of haptics using this method is not comparable to active haptics.

2.3.2 Pseudo-Haptics

A software-based approach to address those problems is called pseudo-haptic. This method was initially developed by Lécuyer et.al. in 2000. In their experiment, they used the displacement of a virtual spring which corresponded to the forces exerted by the user. In combination with an input device that could not generate forces, the participants were able to distinguish the stiffness of a virtual from that of a real spring [35].
Since then, this technique has been studied and successfully applied to simulate various haptic sensations such as

- compliance by deforming images around a cursor input [36],
- shape by increasing and decreasing speed of movement of a cursor [37]
- friction by slowing down the speed of the background image [38]
- and weight by reducing the speed of raising a hand [39, 40, 41].

These methods rely on user inputs which differ from the displayed outputs [42]. This can also manipulate hand-eye coordination and influences the user's movements [43]. In some publications specific designations for pseudo-haptic effects can be found such as Control/Display ratio (C/D ratio), redirecting touching [44], haptic retargeting [45] or hand redirection [46]. However, the meanings varied from person to person [42].

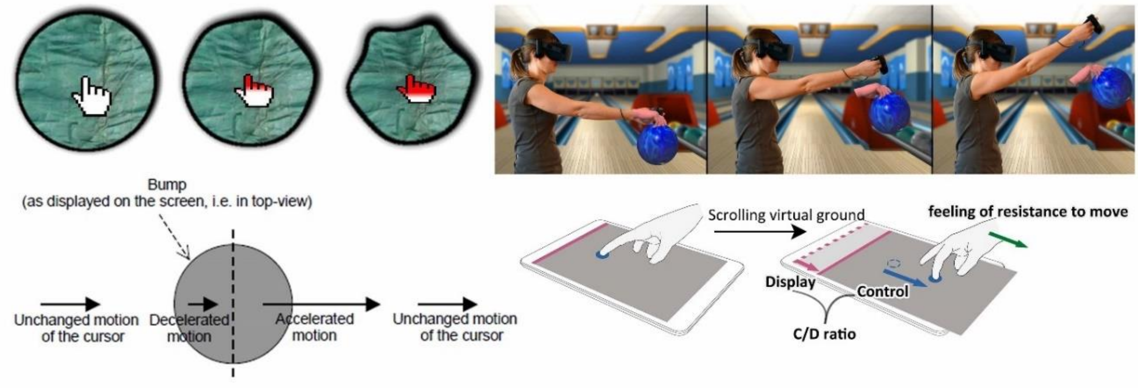

Figure 2: Pseudo haptic effects: clockwise from top left: Displayed deformation of the image around a curser input to simulate compliance from the left to the right [36]. Weight simulation by lowering the depicted hand compared to the real hand [39]. Displayed speed of the background image is in contrast to the actual finger movement to simulate resistance [38]. Motion change to simulate a bump [37].

2.3.3 Haptic Devices

Even, if pseudo haptics are a simple and inexpensive way to achieve a haptic conveying effect, they cannot replace the actual sense of touch. Other researchers have addressed the lack of haptic feedback by developing haptic devices. Numerous haptic devices have been designed such as gloves [47, 48, 49], controllers [50], haptic interfaces [51, 52, 53] or exoskeletons [54, 55, 56]. However, they are often not portable, cumbersome to wear or feel uncomfortable.

2.3.3.1 Handheld Devices

To resolve these disadvantages, handheld devices have been developed. The handheld controllers NormalTouch and TextureTouch provide the shape and texture of an object. NormalTouch renders 3D surfaces and provides force feedback via an actively tiltable and extrudable platform. Instead of the platform, TextureTouch has a pin matrix for the user’s fingertip which renders not only the shape but roughly also the structure of the surface texture [57].

CLAW, Bstick and TORC are controllers that can simulate textures and compliance. CLAW consists of a handgrip held by thump, middle, ring, and little fingers and a rotating arm. The index finger is inserted into an opening at the end of the arm, where a voice coil actuator renders textures. When grasping and touching, a servo motor in combination with a force sensor renders controllable forces to the index finger [58].

Bstick can physically change shape to render different objects. The integrated grip and vibration module can simulate the rigidity and softness of the object [59, 60]. Even though TORC is a rigid controller, it is also capable of rendering compliance [61].

Drag:on provides air resistance and weight transfer. The controller can increase and decrease its surface by opening and closing the two integrated fans to adapt air resistance and weight distribution [62, 63].

Dynamic Passive Haptic Feedback are hardware-based techniques that dynamically change their physical properties during runtime [64]. Zenner and Krüger proposed such a device called "Shifty", which provides kinematic feedback by shifting a weight along its principal axis to change rotary inertia. This generates a perception of different weights or forms [65].

Stellmacher et. al. modified a standardized HTC Vive controller with an engine that generate trigger resistance. This adjustment is the first hardware-based approach to enable actual haptic feedback with a standardized controller in VR. They simulated the weight using different trigger resistance [6].

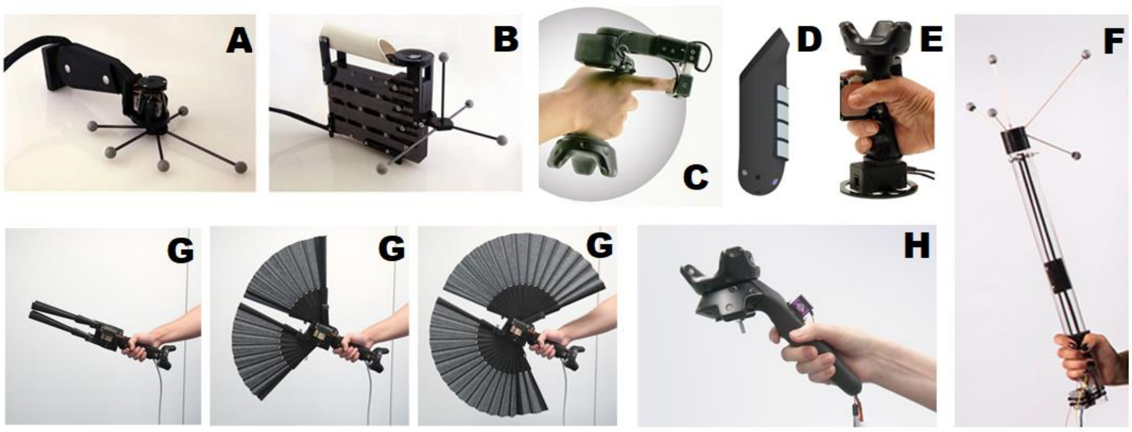

Figure 3: **(A)** NormalTouch: Renders shape and force feedback **(B)** TextureTouch: Renders shape, texture and force feedback [57] **(C)** CLAW: Renders shapes, stiffness, extent, and textures of objects [58] **(D)** Bstick: Renders compliance [59] **(E)** TORC: A rigid controller that renders compliance [61] **(F)** Shifty: Provides inertia by shifting weight along its main axis [65] **(G)** Drag:On: Provides air resistance and weight distribution by opening and closing two fan [62] **(H)** Triggermuscle: Provides trigger button resistance [6]

2.3.4 Visuo-Haptic Illusion

Visuo-Haptic Illusions combines passive haptic feedback with a pseudo-haptic effect. Thus, the perception of haptic feedback is affected by the dominance of visual perception [66]. Some haptic illusions even require visual references [34]. When touching a single physical object, Visuo-Haptics was able to successfully simulate various shapes such as curves, angles, and slopes displayed in **Figure 4** [67, 44, 68].

Figure 4: Displaying multiple shapes by touching a single one object [68].

Not only simple objects can be customized, haptic devices can also be improved by combining them with pseudo-haptics. Abtahi and Follmer applied three different pseudo-haptic illusions to shape displays, to improve their limitations of low resolution, scope, and speed. Shape displays consist of pin matrixes capable of rendering 2.5D content. Retargeting increased the perceived size of the interaction space and the speed of the pins. Redirection improved the resolution, and the speed of shape displays. The last method applied was the C/D ratio, which was used to adjust speed of the fingers to increase perceived speed of the speed [69].

FlexiFingers, an elastic exoskeleton glove for multi-finger interaction, has been combined with C/D ratio to improve the device's passive feedback. The constant level of stiffness has been adjusted with the C/D ratio to achieve different levels [70].

Yem et. al. presented a fingertip device which provides electrical feedback combined with visual feedback to simulate the elasticity and stickiness of surfaces shown in **Figure 5**. The visual deformation of the surface of objects was triggered by the application or release of forces with the index finger. The electrical feedback was through the feeling of force and pressure. The force sensation was generated by bending the fingertip backward or forward. This alone was sufficient to distinguish between two directions. Along with the visual impression, it was possible to recognize softness, hardness and stickiness of a ball. Increasing the electrical stimulation through vibration when releasing the object intensified the feeling of stickiness [71].

Figure 5: Views while pressing (left) releasing with stickiness (middle), and surface vibration after releasing (right) [71]

To improve weight perception, Shifty was combined with haptic retargeting. By combining both techniques, a significantly more intensive perception of weight was achieved than one of those individually [64].

Kim et. al. combined electrical muscle stimulation of biceps and triceps and the C/D ratio to simulate weight. The weight perception was increased in contrast to the sole pseudo haptics [72].

Virtual Mitten is a paradigm for a natural grasping experience in VR. This consist of a handheld elastic device that maps position and grip-forces onto the Virtual Mitten. By identifying grip forces, it provides elastic feedback, which additionally triggers a pseudo-haptic effect. Two different pseudo haptic effects were tested: Boolean and Progressive. Both were triggered by a grasping threshold. With the Boolean method the Virtual Mitten immediately changes color when the threshold is reached to indicate that the force applied is sufficient. Progressive feedback continuously fills Virtual Mitten with a different color by applying more and more force until the threshold is reached, and the color has completely changed. These visual effects are associated with object-specific thresholds. The higher the threshold, the slower the color changes [73].

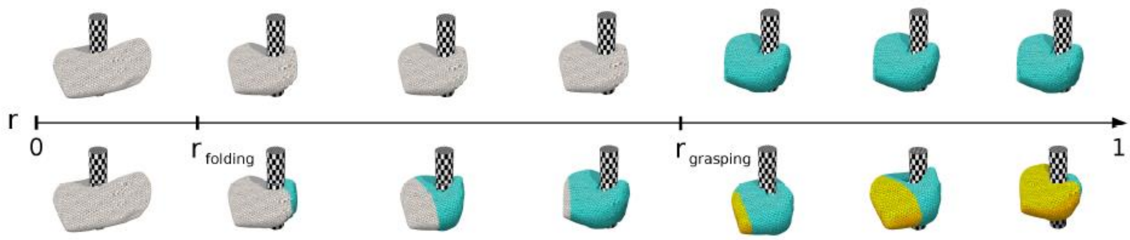

Figure 6: Visual feedback of the Virtual Mitten. Boolean method (top) progressive method (bottom) [73].

Holitouch, a wearable device that facilitates contact and activation sensations, was combined with pseudo-haptics when interacting with virtual 3D Buttons. The C/D ratio used could additionally provide stiffness [74].

TMC has also been combined with C/D ratio to increase weight perception in VR. The combined method increased weight perception to both, trigger resistance and C/D ratio [7].

2.4 Interaction, Cooperation and Collaboration

Interaction, Cooperation and Collaboration are terms that define in which way two or more actors are working together. However, cooperation and collaboration are often used interchangeably. Therefore, many researchers have not distinguished between them. Various definitions have emerged in recent years [75].

Cooperation is about achieving a mutual commitment between two or more actors. Beyond this level, however, their cooperation does not progress. Therefore, their joint agreement is not necessarily based on mutual benefit.

Collaboration, on the other hand, includes joint planning, joint implementation, and joint evaluation of the actors, in order to achieve a common objective. The shared aim, that benefits all stakeholders, is a core element of collaboration that is not required for other forms of group activities. In order to achieve this goal, all those involved have an obligation to the others to contribute their part with their individual knowledge and skills. Therefore, communication is required at all stages of the task.

In contrast, interaction consists of a master-servant-relationship. One actor issues a command and the other executes it. The disadvantage of interactive systems compared to collaborative systems is the lack of communication about the overall plan. Therefore, if the command did not work, then the masters themselves will have to find out what happened. However, collaborative systems require information e.g., knowledge of the overall plan to be aware of the consequences of problems that arise and sources of conflicts. To avoid conflicts, the system must also be able to decide which information the partner needs to know. The main characteristics of collaboration are therefore 1. communication, 2. all actors are equals, and 3. have a common goal [76, 77].

Handover tasks belong to collaboration since both actors have the common goal of handing over an object, verbal or non-verbal communication takes place throughout the entire process, and both actors have equal rights.

2.5 Handover Tasks

Handovers are defined as joint actions between a giver and a taker. Joint actions are social interactions that require spatial and temporal coordination between two or more individuals. Actions in this category are usually more difficult to perform than individual actions [78]. Handing over objects to other people is an unconscious activity for us. However, it is a big challenge to reproduce this process as it is influenced by several factors. To find suitable implementation of a partner for a handover, it is necessary to determine the process itself and the different factors that influence it. Therefore, several researchers have already observed human-to-human handovers.

The handover process is divided into two phases: A Pre-handover phase and a physical handover phase. The pre-handover phase consists of the communication between both interaction partners. The physical handover phase describes the time during which both parties have contact with the object to be transferred [78]. Human beings are thus dependent on both their physical and their social-cognitive abilities in order to manage handover tasks. This progress includes approaching, carrying, reaching, and relinquish control on physical level. In contrast, social-cognitive coordination involves agreements about *what*, *where/how,* and *when* between giver and taker. The two levels of coordination are interlinked for example, when we extend the arm, it serves both physical and social-cognitive. On the one hand, we signal our intentions, on the other hand we approach the target person. The physical states of handover process are 1. approaching, 2. reaching, and 3. transferring. Before we approach someone, we determine what we want to do and *what* to hand over. When approaching, we transmit information about the object such as its weight, its fragility, its stickiness, and its importance. This information influences all subsequent phases. Before the handover and before reaching each other, both actors exchange signals *when* they are ready for the transfer. The physical handover phase is initiated by a lifting motion of the giver and starts before the approaching person stops moving. The determination about *where* the object is to be transferred is made by movements during the reaching phase. The trajectories of the human hand often follow a minimum-jerk profile during this phase. In the transfer phase, which takes place at midpoint between both persons, the entire object force is transferred from the giver to the taker. In general, both actors are in direct contact with the object. Most inter-individual differences, such as distance between head and hand, depend on the giving person, only. The completion of the handover is signaled by a reaction of the taker, for example by moving the object after the transfer. This process is illustrated in **Figure 7** [79, 80].

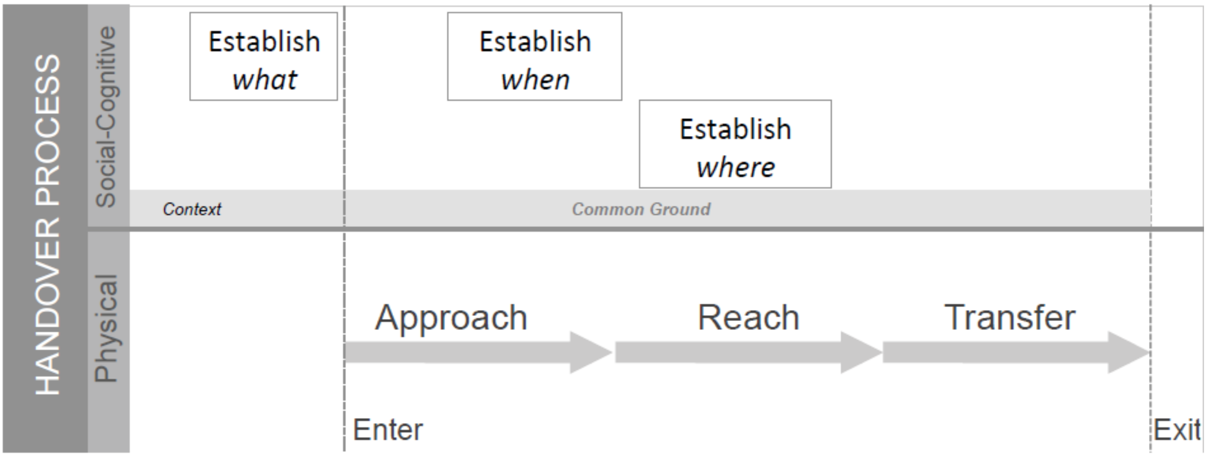

Figure 7: Time chart of the handover process divided in social-cognitive level and physical level [79].

Several factors influencing this process were investigated. Chan et al. showed that the slope of the grip-load force curve during handovers is not influenced by the weight of the object. However, it varies from person to person. Giver and taker apply a similar control strategy for the handover. However, the giver is responsible for the safety of the object, while the taker controls the handover. Handover tasks showed similarities to pick-and-place tasks. The gripping and loading forces when transferring an item correspond to the picking tasks, and the forces when receiving the object correspond to the placing task [81].

A study by Moon et al. has shown the giver's gaze affects the intended handover position and, for the taker the moment he reaches out [82]. Admoni et al. have revealed that people pay more attention to non-verbal cues provided by non-human giver´s gaze where there is a deliberate delay before releasing the object. In addition, the delay increased compliance with the hint [83].

Käppler et al. analyzed the handover of mugs with regard to the spatial direction, the filling level of the mugs, and the impairment of the recipient´s perception during the handover process. They noticed that the spatial direction has no significant impact on the duration of the handover process. However, the filling level and the perceptual impairment do taker and giver send visual signals that shorten the duration of handovers. Thus, if one person´s view is obstructed, the duration of the handover will increase [84]. After several repetitions, the duration of the handover decreases over time [85].

Kjölberg and Sallnäs tested the influence of haptic force feedback on handover tasks in a VE. In their experiment, all events could be perceived as in the physical world through simulations using a PHANTOM Desktop made by Sens-Able Technologies. The objects could be grasped, moved, and released by one or two participants. A "free" version and a "control" version of the environment were compared. In the "free" version, users could grasp and release objects freely in the VE as opposed to the "control" version, in which it was not possible for objects to be lost or released in free space. Additionally, a kind of “snap” or “click” sensation as haptic feedback occurred when an object was placed correctly. The interview following the experiment revealed that the participants did not recognize any differences between the environments, and that the free interactions were perceived as easier. They discovered that visual feedback overrides haptic feedback, especially when it comes to weight perception [86].

3 METHODOLOGY

This study evaluated different handover methods between an agent and a human in VR. For this purpose, two agent-human interaction experiments were conducted. In these experiments, a software-controlled agent handed over items, and participants received them.

3.1 Pilot Study

The pilot study analyzed the moment when the agent releases the object during the handover process. Therefore, the following hypothesis was tested:

> H_{Pre}: A handover is perceived more realistically if the robot does not immediately release the object.

In order to allow for a more natural perception of the handover between agent and user, a suitable time for the release of the object had to be found. The receiver has been observed lifting lifts the object when taking it over. To support this observation, three people were filmed handing each other a glass of water. During all six handovers, the receiver lifted the object noticeable (**Figure 8**). This lifting moment was implemented as a release condition in VR. To verify this, the pilot study was arranged.

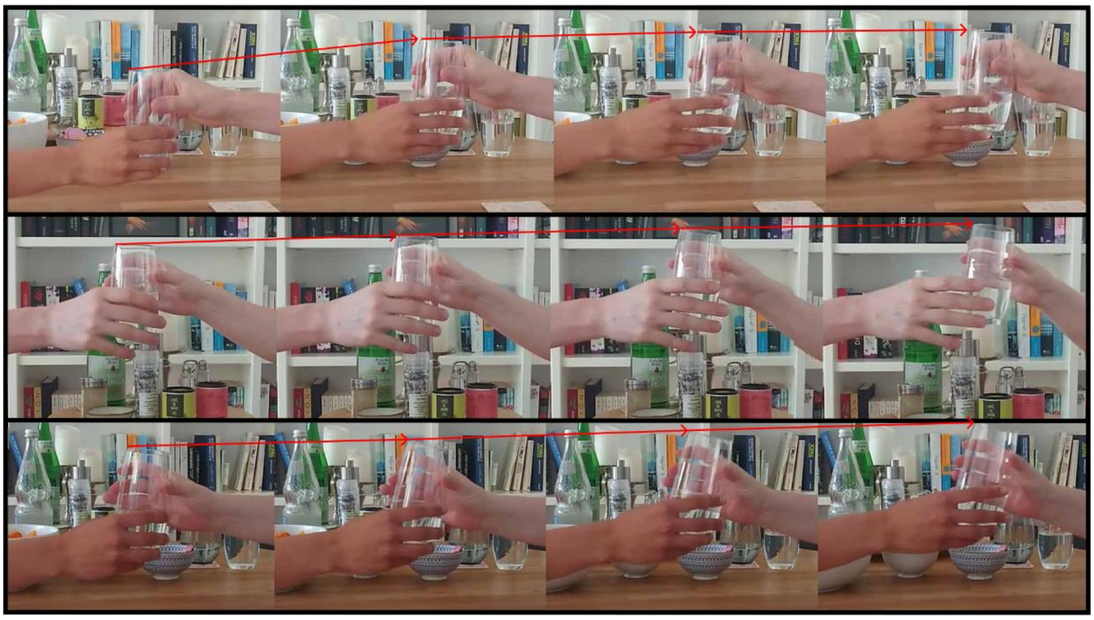

Figure 8: Three of the six handovers, represented here by four screen shots taken from the videos.

3.1.1 Participants of the Study

Four subjects participated in the pilot study, three men and one woman between the ages of 30 to 36 years. All participance had no VR experience and were right-handed.

3.1.2 Experimental Setup

The pilot study was conducted in a within-subject design. Therefore, all participants had to perform the same task. The study subjects wore a HMD Oculus Quest 2 (OQ2). They held the Q2C for right hand.

Via the HMD, users were placed into a virtual room consisting of four blue walls and a wooden textured floor. The user in front of one wall faced a gray cube with six mugs on it in front of the opposite wall. Three of the objects had a different condition. In one case, when the participant presses the index finger trigger button, the agent releases the object immediately while in the other case, the participant must lift the object 3 cm before the agent releases it. An empty green cube was positioned to the right of the participant. The agent, embodied as a robot from the Unity asset Space Robot Kyle [87], was placed in the center in front of the right wall. Since red is perceived as aggressive and green supports relaxation [88], the robot's texture was changed from red to green to appear more friendly. The task was written on a canvas located in the left corner of the room opposite the participant. The following task was set:

> Transfer all objects from the gray cube to the green one without moving from the spot. When you point to an object, a cursor appears, and you can select it by pressing the index finger button. The robot will bring you the selected object. Grab it by pressing the index finger button and place it on the green cube by releasing the button you were holding. Pay attention to the arm movements of the robot during the handover.

After the trial, the participants had to answer the following interview questions about the different conditions:

1. Do you recognize differences between the objects when they are handed over?
2. If yes, describe the differences.
3. Which handover process felt more realistic?

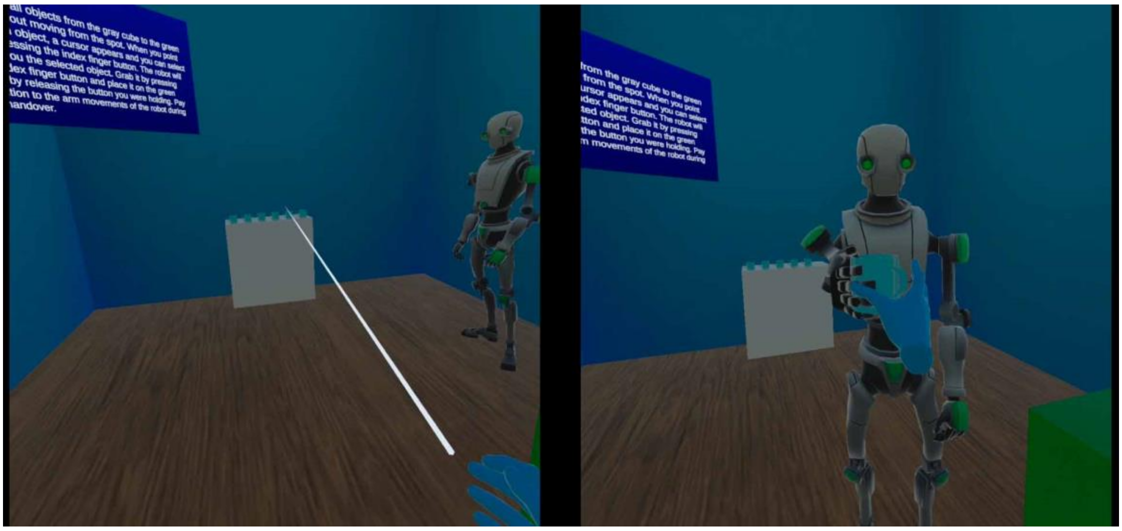

Figure 9: Participant’s view during the experiment. At the beginning on the left side, during the handover on the right side.

3.1.3 Implementation

The research environment was developed in Unity 2021.3.15f1 with a VR setup. The connection between Unity and OQ2 headset that was used in the experiment was established via XR Plug-in where Oculus was the plug-in provider. Interaction between user and VE was realized by *Oculus Interaction SDK*. A *CameraRig* from this SDK was added for the VR setup in the scene. A *CustomHand* model embodied the user’s right hand. This hand has been equipped with a *ControllerRay* from Oculus package to facilitate aiming during distance interactions. Additionally, the left hand had to be disabled as Tiggermuscle controller is only intended for the right hand. All scripts were written in C#.

Initially, the interactions between the objects and the user were enabled by the components of *Oculus Integration SDK*, however, they did not work with TMC. In order to have a uniform setup for pilot and main study, an alternative implementation that works with both controllers had to be selected. The interaction was therefore realized via *TriggerColliders* which were controlled by self-written scripts. A *TriggerCollider* was attached to the palm to enable direct object interactions. A script that detects when a grabbable object enters or leaves the *TriggerCollider* was added to the same hand. On entering this *TriggerCollider*, the grabbable object is locked at its current position, when exiting, the object is free again and can fall.

The distance interaction was realized by a Unity 3D sphere object acting as a cursor. The cursor was added to the right hand and positioned between the grabbable objects on the gray cube and the end of the *ControllerRay*. The collider of the cursor has been removed and replaced by a capsule *TriggerCollider*. The height of the collider has been adjusted to be in line that of with the *ControllerRay*. A script was added to the cursor object which detects when a grabbable object enters or exits its *TriggerCollider*. When entering, the *MeshRenderer* of the cursor is enabled, and when exiting, it is disabled. If the *MeshRenderer* is enabled, the cursor is visible, and pressing the index finger button triggers the selection of the object hit. Additionally, the cursor and *ControllerRay* are set inactive to prevent multiple objects from being selected at the same time and to avoid being distracted by their visual representation during handovers.

The package *AnimationRigging* Version 1.1.1 [89] was used for the robot's arm and head movements of the robot. A *Multi-Aim Constraint* component was added to the robot head and a *Two-Bone IK Constraint* component to its right arm. These constraints have a weight value between 0 and 1 indicating the extent to which they have an impact. Hence, when the weight is 0 the constraint has no influence, and when it is 1 the influence of the constraint is fully exploited. The default weight value was set to 0. The *Multi-Aim Constraint* rotates the head to its target, while the *Two-Bone IK Constraint* consists of a hierarchy of the wrist as hint, the forearm as middle, and the upper arm as root. The hierarchy follows the target position from the hint to the root, allowing the hint to reach the target.

An *AnimatorController* on the robot alternates between an idle animation from the asset *Idle MoCap* [90] playing by default and a walking animation from the asset *Huge FBX MoCap Library Part 1* [91].

The robot's *AnimatorController* and movements are controlled by a script on the robot. This script detects when an object is selected via the cursor script. This selection triggers the robot's gaze to turn in the direction of the item selected due to the *Multi-Aim Constraint*. Moreover, the robot turns and moves towards the selected object. While the robot is moving, the *AnimatorController* switches to the walking animation. When a predefined distance between an object and the robot is reached, the robot stops moving, and its *AnimatorController* switches back to the idle animation. Furthermore, the robot's arm rises towards the object by increasing the influence of the *Two-Bone IK Constraint*. In case the *Two-Bone IK Constraint* reaches its full impact, the gravity of the object is disabled, and the object moves to a predefined position in front of the robot. It appears as if the robot lifts the object since the robot's hand follows the position of the item. When the item has arrived at its target position, the robot turns and moves towards the user until a predefined distance between camera and robot is met. Since the fingers of the robot were too curved during the walking animation and thus reached into the item, the keyframes for the hand were removed in the walking animation. When the user takes over the object, the robot lowers its arm by reducing the influence of the *Two-Bone IK Constraint*. In addition to pressing the trigger button, this reduction is caused by two different conditions. In cases where the object's name contains an "1", "2", or "3", the y-position value of the object must be elevated by at least 3 cm to trigger the reduction of the influence of the *Two-Bone IK Constraint*. The robot's arm follows the object until this threshold of 3 cm is met, or the target cube or the floor enters the *TriggerCollider* of the object. If the name of the object does not contain the numbers "1", "2", or "3", the influence of *Two-Bone IK Constraint* decreases immediately. The robot moves back to its starting position when the *Two-Bone IK Constraint* is no longer in effect.

The grabbable objects received a *TriggerCollider* as well, which is controlled by a script on the object. The script detects when the floor or the target cube enters the *TriggerCollider* of the object. This starts a timer of 10 second which sets the object to inactive. This was implemented to avoid time differences between the placement operations caused by a target cube that has run out of space.

The TMC cannot detect to which degree the trigger button is pressed, hence the *AnimatorController* of the *CustomHand* did not work with it. Thus, this *AnimatorController* has been replaced by a new *AnimatorController* in which self-recorded animations have been added. The switching between the four self-recorded hand animations shown in **Figure 10** was controlled by a script on the hand.

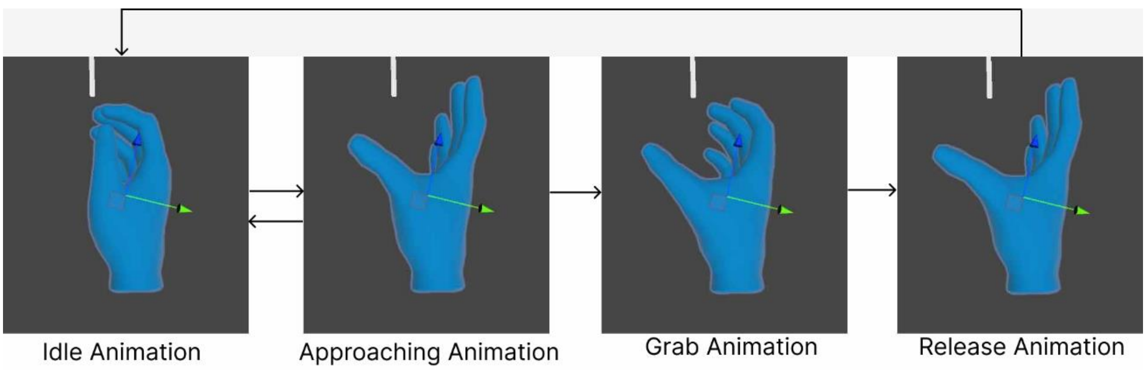

Figure 10: Hand animations in their maximum state. Transitions are interpolated between these states. Arrows indicates possible switches between the animations.

The change between idle animation and approaching animation is triggered by a distance threshold between hand and grabbable object. When the approaching animation is active, pressing the index finger button will toggle the grab animation. Releasing the button triggers the release animation.

The data were collected by saving all *Debug.Log()* lines with the respective time to the millisecond in a txt file. The following data were obtained:

- Hand position and Hand rotation of the *CustomHand* every 10 frames
- When an object is selected by the user
- When the object is grabbed by the user
- When the object is released by the robot (immediately, after reaching the 3 cm threshold or when the threshold was not reached)
- When the object is released by the user
- When the target cube enters the TriggerCollider of the object
- When the target floor enters the TriggerCollider of the object

The Unity project was afterwards built on the OQ2, so it could be run directly on it.

3.1.4 Results

Three of four participants completed the task twice because they were stunned by their first VR experience on the first trial and did not notice a difference. In all 12 handovers, one subject did not reach the threshold of 3 cm. Two of them reached it once or twice. However, they only noticed differences when the robot did not release the object. When the condition was set, one subject, who was significantly taller than the others, met the threshold. This person did not lift the object, when the robot released it immediately. In all 42 handovers 10 times the object was lifted by 1-2 cm, 7 times by more than 2 cm. The threshold was set for 6 of these seven handovers. During the other 25, the object was lifted below 1 cm. The three participants who did not reach the threshold or reached it just once or twice only recognized a difference when the robot did not let go of the object. This was perceived as weird, and the default condition where the robot immediately releases the object, was preferred. The participant who had reached the threshold answered on responded to the question “Do you recognize differences between the objects when they are handed over?” that he did not recognize anything. However, after explaining the reason of for the study, he said that sometimes he felt the need to tear even more. However, he found the condition in which the object was released immediately to be more realistic because he assumed that a robot would have the appropriate sensors for this. He also mentioned that he enjoyed it more when the lifting condition was applied because he felt like he was taking something away from the robot.

3.1.5 Discussion

The experiment showed that the 3 cm threshold was clearly too high for smaller people. Only the taller person reached that threshold every time. This result suggested that this was related to the participant´s body size rather than an intuitive action. Upon immediate release of the object movement towards the target started without an upward movement. When the lifting condition was set, some participants pulled the objects towards them, which in some cases caused a raising effect and triggered the threshold. This indicates, that lifting the object in VR is not intuitive. This could be caused by the lack of gravity. To test whether people perceive a slight deceleration as more natural, further research could test a time delay or a condition of motion in any direction. Additionally, simulating the weight of the object could make a difference, which could increase lifting during the hand over. Overall, the results indicated that the default condition is perceived to be more natural and will therefore be applied in the main study.

3.2 Main Study

The study examined whether the trigger resistance leads to a more natural perception of the controls during the handover process and whether it increases the user’s perception of telepresence, social presence, and co-presence. Additionally, the influence of the different properties and shapes of the objects is evaluated. It was assumed that the content of an object affects the transfer time from the robot to the target. Therefore, the following hypotheses were scrutinized:

- H1. The TMC results in a more natural perception of controls during the handover process.
  - H1a. The TMC increases perceived telepresence.
  - H1b. The TMC increases perceived co-presence.

Social presence was not considered since rather psychological aspects are addressed than the quality of the medium.

3.2.1 Experimental Setup

The study was conducted in a within-subject design. Therefore, all participants had to perform the same task once with a standardized Q2C and another time with the TMC [6] connected to the Q2C. The controllers were screwed together during both trials to avoid weight differences between the controllers.

Participants wore a HMD OQ2, wireless, in-ear headphones [92] that played white noise sound [93] and hearing protection, avoiding the sound of the TMC's servo motor which could cause bias.

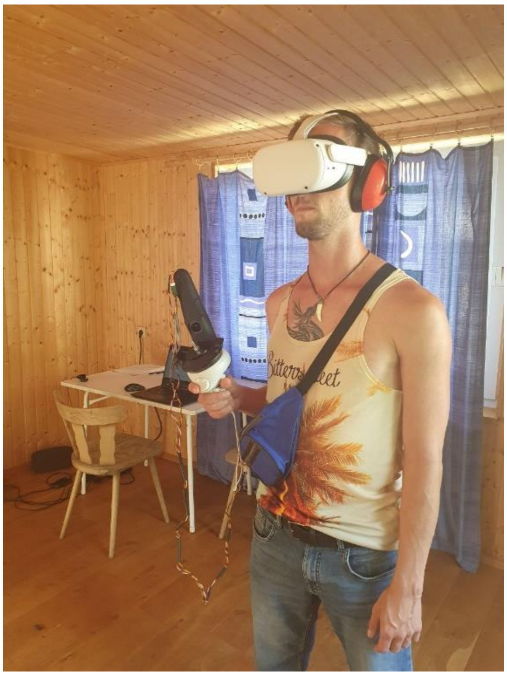

Figure 11: Participant is wearing the equipment.

The scene setup was the same as in the pilot study, except that 8 objects were placed on the gray cube. Four different objects twice each: Two empty mugs with handles, two empty mugs without handles, two full mugs with handles and two balls. For all objects, the first condition was applied. Hence, the robot releases the objects immediately. The task was slightly adapted:

> Transfer all objects from the gray cube to the green one without moving from the spot. Robot Kyle on the right side looks forward to helping you with that. When you point to an object, a cursor appears, and you can select it by pressing the index finger button once. The robot will bring you the selected object. Grab it by pressing and holding the index finger button and place it on the green cube by releasing the button you were holding. One of the objects is full. Make sure not to spill some of the liquid. Pay attention to your hand while grabbing the object.

The introduction of the robot was added to reduce the user's fear of the robot. Additionally, the height of the walls, that were 10 m high in the pilot study, was scaled down to 3 m because it was reported to be scarry.

After, the participants placed all 8 objects on the green cube or dropped them, a canvas appeared with the following text: You are done with your task. Let the conductor know that. You can take off the headset.

Afterward, they had to answer a questionnaire. Since, one participant in the pilot study had difficulties to read the task in VR it was decided to provide the questionnaire on the laptop and not as planned at the beginning in VR. After all questions were answered, the second trial began, using the other controller. After the subjects had completed the second trial and answered all the questions a second time, they had to answer a few interview questions about the entire experiment. The interview format was chosen to have the possibility to ask in more detail when uncertainties appear.

The questionnaire comprised 31 questions and is provided in the Appendix Point 6. Questions 1-17 were taken from Witmer et al. [13] and targeting telepresence. Their questionnaire contains 28 questions. Of these questions 5+6, 14-17, 18-20, 26-27 were omitted as they aim to assess vision, sound or touch, or other aspects not sought or given here such as moving around in the handover experiment. Additionally, the word “environment” was often replaced by the word “robot” to specify the question. Question 4 was limited to visual and haptic senses because audio was not part of the VR experiment. Question 5 was adapted to clarify the takeover question.

Here questions 18-25 were received from and targeting co-presence [94]. Since the questionnaire was originally designed for a presentation scenario half of the questions were not appropriate at all and left out. All appropriate questions had to be adapted to the robot interaction scenario. Some Questions, here 27-31, were obtained from [95] to evaluate the haptic feedback itself. 26 was added to identify whether a haptic sensation was perceived at all.

Interview questions:

1. Describe your experience.
2. Did you like the experiment?
3. Did you experience differences between the controllers?
4. What differences did you recognize?
5. Which controller would you prefer?

3.2.2 Implementation

The main study included two scenes: One for the Q2C and the other for the TMC. The scenes were identical, except for the hand position, which had to be adapted in the scene for the TMC, as this controller does not have a built-in motion tracker. The switches from the Quest scene to the Triggermuscle scene were controlled by pressing the index trigger button of the left controller, that was not used by the participants.

The implementation of the main study was the same as in the pilot study except that a canvas appears once all objects have been transferred, informing the participant of the completion of the task.
In the two scenes of the main study, neither object contains a number in its name that would enable the condition with the threshold of 3 cm. Hence, the robot always releases the objects immediately.

To indicate the contents of the mug a liquid shader was generated by using the packages *Shader Graph* and *Universal RP*. To illustrate liquid, a *Lit URP Shader Graph* was established. From this shader graph, a material could be generated, that was applied to a cylinder in one mug. A script on the mug controls the liquid shader. By tilting the mug too much, the content decreases, the threshold angle increases, and liquid particles are instantiated.

The connection between Unity and the TMC was established in the same way and controlled by the same script as in Carolin Stellmacher's studies [6, 7]. The TMC can render three different resistances via corresponding angles, in addition to the default setting, which generates no resistance. In the experiment conducted for this thesis, however, the TMC switched only between the default setting and the highest angle. It was determined to use only one angle because, unlike previous studies with TMC, it is not about simulating different weights. The highest angle was selected to make the difference as big as possible because in previous studies [6, 7] some participants did not recognize resistance at all. Even though it would be more natural for the handover if the resistances occurred after grabbing the object, the resistance angle is sent when the robot starts moving towards the user and is reset when the floor or the target cube enters the object's *TriggerCollider*. Therefore, the resistance is already high before grabbing the object. This was chosen because it was assumed that the resistance could be even harder to notice, especially for people with a firm grip, since when the resistance is adjusted after pressing the trigger button, it pushes the finger slightly away.
The following data were gathered additionally to those in the pilot study:

- The filling level of the mug if it was tilted too vigorously.
- When the Triggermuscle scene is loaded.

The Unity project was afterwards built on the OQ2, so it could be run directly on it.

3.2.3 Participants of the Study

A total of 21 participants, between the ages of 18 and 68, took part in the experiment, including 7 females and 14 males. The majority of 12 subjects indicated that they had used VR devices before, 6 said that they had never utilized them before, and 3 explained that they used VR devices every few months. The participants of the study were divided into two groups: Group A, consisted of 11 participants and started with the Q2C, and Group B which comprised 10 participants and started with the TMC.

3.2.4 Results

The results were derived from the data collected via the function described in Section 3.1.3 above, the questionnaire, and the interview. The answers from the questionnaire and the interview were recorded using Google Forms. Relevant data were copied from the TXT files and the questionnaire into an Excel spreadsheet. The calculations and diagrams were created with Microsoft Excel version 16 or Google Sheets. Both groups went through two cycles, which subsequently results in a subdivision of four groups: Group A Cycle 1 used Q2C (A1-R), Group B Cycle 1 used TMC (B1+R), Group A Cycle 2 used TMC (A2+R), and Group B Cycle 2 used Q2C (B2-R). Eight takeover trials were collected from each person in each cycle.

It was observed that a few of the study participants dropped some of the objects, mostly on their first attempt. In this calculation all participants were considered. Most drops occurred in the first round (Cycle 1) in Group B as displayed in **Table 3**. However, in the second cycle of Group B no objects were dropped. In Group A, two objects fell in the first cycle and three in the second. All but one of these objects were dropped on the first attempt.

Table 3: Number of dropped objects divided in takeover trials of Group B1+R.

Trial	1	2	3	4	5	6	7	8
Drops	4	3	2	1	0	0	1	0

The first parameter analyzed was the transfer time from the robot to the target. This duration was calculated between the frame when the trigger button was pressed for the takeover and the frame when the button was released.

The moment of release was once not recorded. In this case, only the remaining seven takeover trials of this individual were taken into account. If an object was dropped on the floor, the duration was excluded from the analysis. For all calculations regarding time, two persons, one from each group, were completely excluded because one did not understand the takeover mechanism and dropped most of the objects in Cycle 1, and the other examined the objects during the holding period, resulting in several outliers that were significantly longer than the other times.

In order to get an overview of the transfer time, the average duration between both groups in both cycles was compared. For this purpose, the mean value, the variance (V), the standard deviation (SD), and the number (n) of tests were calculated for all four tables. In the first cycle, the V in Group A1-R (1,75) was significantly greater than in Group B1+R (1,15). In the second cycle, it was generally smaller. However, the V was still slightly greater in Group A2+R (1,16) than in Group B2-R (0,98). To identify outliers, the SD was added three times to the determined mean value. In Group A, two outliers were identified in each cycle, whereas in Group B there was only one spike in Cycle 2. After excluding these outliers, Z-tests were performed at a significance level of 0.05% between Groups A1-R and B1+R in Cycle 1, between Groups A2+R and B2-R, as well as between Cycle 1 and Cycle 2 for Group A (A1-R and A2+R) plus between Cycle 1 and Cycle 2 for Group B (B1+R and B2-R) as shown in **Table 4.**

Table 4: Z-Test with known Variance comparing mean Duration without Outlier.

	Group A & B Cycle 1		**Group A & B Cycle 2**	
	A1-R	*B1+R*	*A2+R*	*B2-R*
mean	2,98	3,18	2,77	2,61
V	1,32	1,15	0,79	0,79
n	77	65	83	79
H	0		0	
z	-1,078		1,202	
P(Z<=z) one-sided	0,140		0,115	
Z one-sided	1,645		1,645	
P(Z<=z) two-sided	0,281		0,229	
Z two-sided	1,960		1,960	
	No Significance		No Significance	

	Group A Cycle 1 & 2		**Group B Cycle 1 & 2**	
	A1-R	*A2+R*	*B1+R*	*B2-R*
mean	2,98	2,75	3,18	2,62
V	1,32	0,80	1,15	0,81
n	77	76	65	71
H	0		0	
z	1,417		3,285	
P(Z<=z) one-sided	0,078		0,001	
Z one-sided	1,645		1,645	
P(Z<=z) two-sided	0,156		0,001	
Z two-sided	1,960		1,960	
	No Significance		Significance	

No significant differences in the average duration between the two different controllers in both cycles could be determined. Based on this result, it was assumed that the transfer time in the second cycle decreases due to a training effect, regardless of which controller was used. This assumption was confirmed in Group B. In Group A, on the other hand, no significant difference was observed between Cycle 1 and 2.

Subsequently, Groups A1-R and B2-R as well as Groups A2+R and B1+R were merged to receive two groups, one that used the Q2C and the other that used the TMC. The V, mean, and SD were calculated for both groups. The V was in Group Q2C (1,44) higher than in Group TMC (1,07). Outliers were calculated in the same way as described before and excluded for the calculation of a Z-test between both groups. In Group Q2C three outliers were eliminated, and in Group TMC only one. No significant difference between the transfer durations of both groups was observed, as displayed in **Table 5.**

Table 5: Z-test between mean transfer time of the Group Q2C and Group TMC.

	Q2C	TMC
	A1&B2 ***-R***	*B1&A2* ***+R***
mean	2,81	2,95
V	1,1	1,00
n	148	141
H	0	
z	-1,145	
P(Z<=z) one-sided	0,126	
Z one-sided	1,645	
P(Z<=z) two-sided	0,252	
Z two-sided	1,960	
	No Significance	

In the next step, the duration was compared over time. It was assumed that the transfer speed for the first objects that were passed was slower than that of the objects that were transported at the end of the experiment. To confirm this assumption, the mean duration, V, SD, and number of samples were calculated for objects 1 to 8, as shown in **Figure 13**. No outliers were excluded in this calculation. The assumption that the duration decreases over time was confirmed. This phenomenon is more prominent in the first cycle. In Group A in Cycle 1, however, the transfer of the third object took significantly longer than the transfer of the second one, which does not fit this pattern. This deviant behavior could also be observed for object 5 in the same group in Cycle 2.

It was assumed that these outliers were caused by the full mugs. To verify this theory, the mean duration of the first full mug, that was grabbed, the second filled mug that was grasps, and the object that was seized just before the first filled mug were compared. In addition to the two previously excluded persons, those participants who grabbed a full mug as the first object or dropped the object grasps immediately before the first filled mug were also excluded. This affected one further individual in Group A in the first cycle, two in Group B in the first cycle, and one in Group B in the second cycle. In Cycle 2, a Group A participant dropped the second filled mug, he had grabbed earlier. That sample was excluded from further analysis while the other two samples from this individual were included. The results are illustrated in **Figure 12.** Significant differences could be observed in the duration of grabbing the first filled mug. However, this duration for the second full mug is mostly longer or similar to the duration of the previously grabbed item. The number of full mugs in each experiment is specified in **Figure 14**.

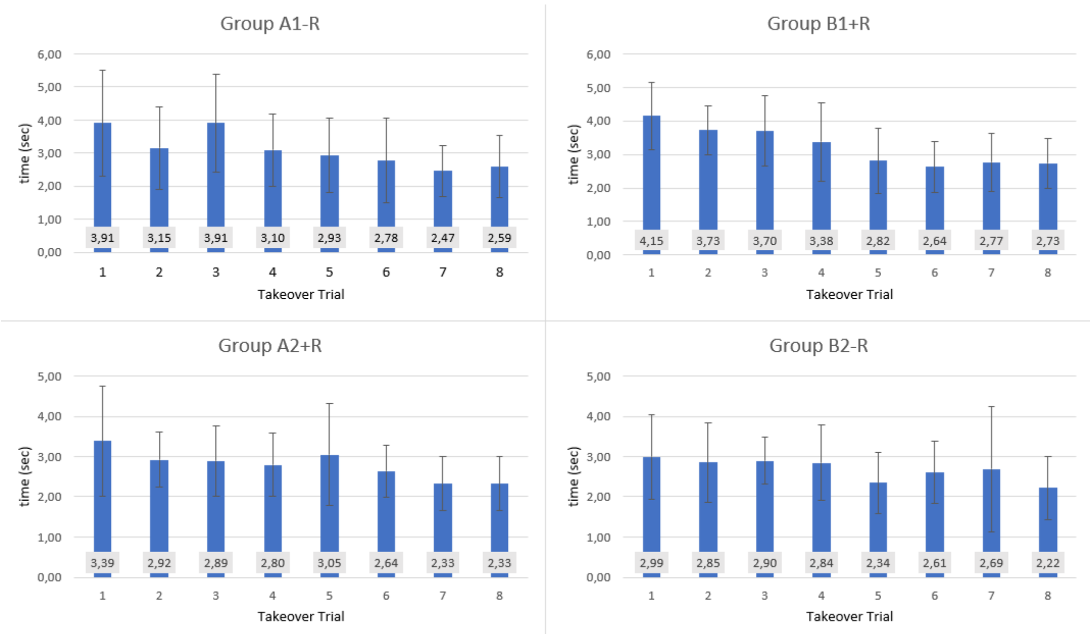

Figure 13: Transfer duration over time for Group A (left) and B (right) and Cycle 1 (top) and 2 (bottom)

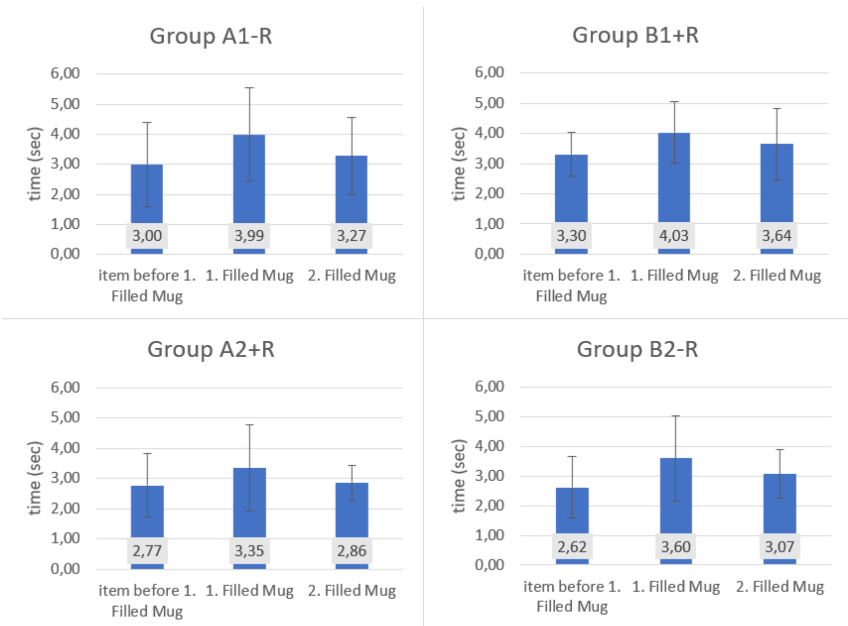

Figure 12: Mean duration in seconds of the item grabbed before the first filled mug, first grabbed filled mug, and second grabbed filled mug, divided in group A (left) and B (right) and Cycle 1 (top) and 2 (bottom).

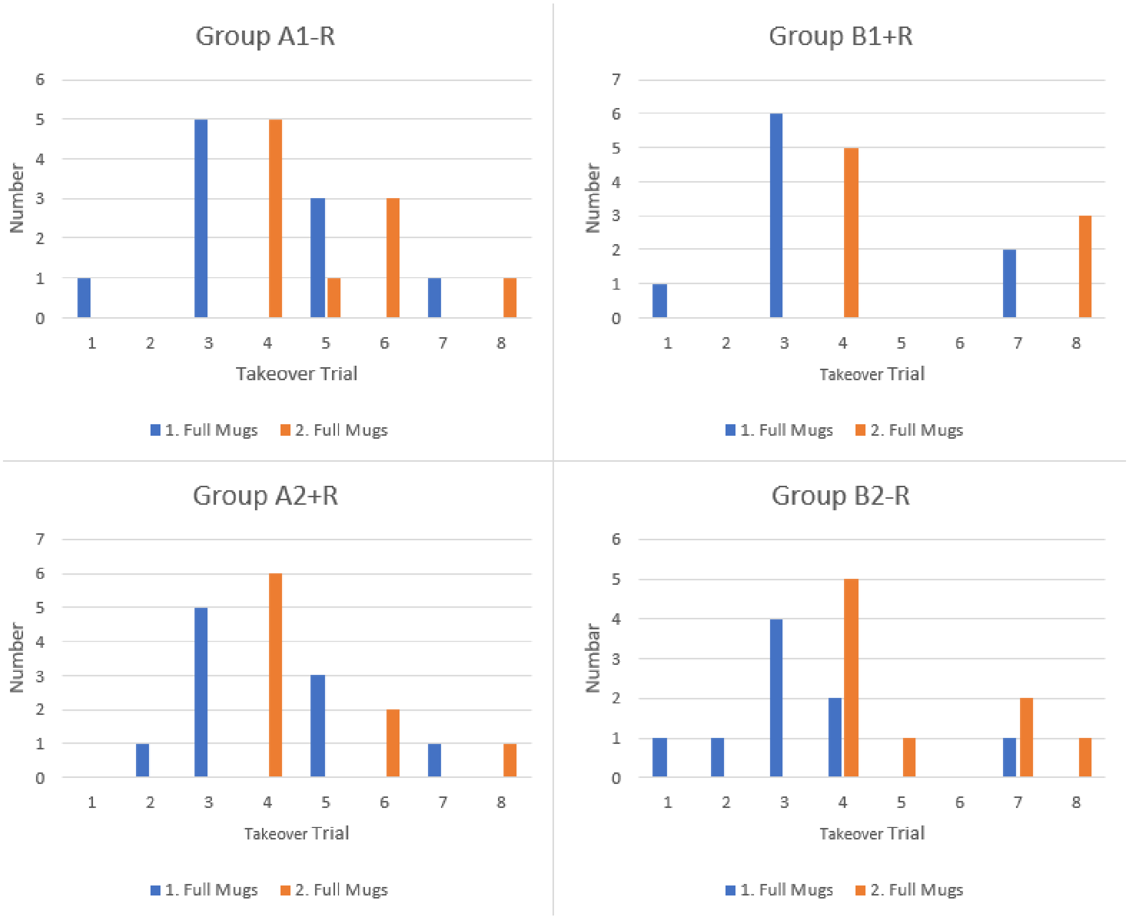

Figure 14: Number of full mugs over time broken down into first full mug grabbed and second full mug.

The next analysis examined the correlation between duration and demographics. The use of VR devices, age, skills, and the use of other controllers were taken into account. VR experience and experience with other controllers were rated on a scale of 1 to 5, with 1 representing no experience and 5 representing almost daily use. Abilities were also rated on a scale of 1 to 5 with 1 being clumsy and 5 being very skilled. For this calculation outliers were not excluded. To determine the correlation between duration of use and the demographic characteristics presented**,** Spearman's rank correlation coefficient was calculated. VR experience, the use of other controllers, and abilities were expected to be negatively correlated i.e., the more experience, the shorter the transfer duration. In contrast, expectancy about age was positively correlated, i.e., the older the age, the longer the duration. The results are illustrated in **Table 7**. The outcome shows a weak to very weak negative correlation between VR experience and duration for both groups in the first cycle, and a very weak to weak positive correlation for both groups in the second cycle. The correlation between age and duration is weakly positive in Group A in Cycle 1 and very weakly negative in Cycle 2. For group B, the correlation was moderately negative in both cycles. The abilities show a very weakly positive to weakly influence on duration in both groups for both cycles. A weak negative correlation between use of other controllers and duration was observed in Group A in both cycles, while in Group B a very weak positive correlation was observed in Cycle 1 and a moderately positive correlation was noticed in Cycle 2.

Table 6: Demographical data and time in Cycle 1 (C1) and Cycle 2 (C2) divided into Group A and B. Demographics specified are VR experience (Exp. VR), Age, Abilities, and experience with other controllers (other C.).

Group A

Exp. VR	Age	Abilities	Other C.	C1-R time	C2+R time
2	37	4	5	2,83	2,44
2	36	3	4	2,05	1,77
3	25	4	3	2,88	2,73
2	35	3	3	2,38	2,68
3	31	4	5	3,74	3,97
2	18	3	2	2,55	2,64
2	51	4	5	2,21	2,29
1	61	4	2	3,79	2,98
1	68	3	1	3,06	2,00
1	62	3	1	5,53	4,14

Group B

VR Exp.	Age	Abilities	other C.	C1+R time	C2-R time
2	51	3	2	3,69	3,25
1	50	3	1	4,11	3,06
2	53	2	2	3,22	2,90
2	22	4	2	3,37	3,30
1	57	3	1	2,71	1,70
2	57	4	2	3,87	3,27
3	54	2	2	1,89	1,83
2	45	4	2	3,29	2,82
1	60	4	1	2,22	1,98

Table 7: Calculated Spearman's Rank Correlation Coefficient between experience with VR (Exp. VR) and time, age and time, abilities and time, and experience with other controllers (Exp. Other C.) and time

	Exp. VR / time		**Age / time**		**Abillity / time**		**Exp. other C. / time**	
Group	A	B	A	B	A	B	A	B
Cycle 1	(-R) -0,36	(+R) -0,15	(-R) 0,37	(+R) -0,46	(-R) 0,17	(+R) 0,29	(-R) -0,30	(+R) 0,09
Cycle 2	(+R) 0,05	(-R) 0,20	(+R) -0,10	(-R) -0,51	(+R) 0,24	(-R) 0,38	(+R) -0,20	(-R) 0,46

The Spearman's rank correlation coefficient was then determined for all together and divided in Group TMC and Q2C were determined. As shown in **Table 8** there was no strong correlation. The only considerable difference between the controllers could be observed regarding the age.

Table 8: Spearman's rank correlation coefficient for all together (all) as well as for Group Q2C and Group TMC.

	Exp. VR	Age	Abillities	Exp. Other C.
All	-0,07	-0,12	0,27	-0,05
Q2C	-0,12	0,01	0,27	-0,01
TMC	-0,03	-0,24	0,27	-0,08

The next parameters analyzed were hand position and hand rotation when the object was grabbed. For this purpose, the rotation and position messages just before pressing the trigger button were used. In order to find out if there are significant differences due to the different shapes of the objects, the items were divided into three groups: Ball, mugs with handle, both filled and unfilled, and mugs without handle. Subsequently, the Vs, mean values, and SDs for z-, y-, and z-rotation and x-, y-, and z-position were calculated for all items together, and for the three object categories respectively (**Table 9**) All calculations for hand rotation and hand position excluded also the two previously skipped participants. All other samples, regardless of whether the object was dropped or not, were considered. With regard to the position, the z-coordinate showed the highest V between all objects, and between the mean values of the three categories, there were the greatest differences. The least contrasts were identified for the y-coordinate. Within the object categories, the largest Vs were determined for the mug with handle in x- and z-direction and for the ball in x-direction.

Table 9: V, mean, SD and n of x-position (Px) y-position (Py) z-position (Pz) and x-rotation (Rx), y-rotation (Ry), and z-rotation (Rz) for all objects (All), mug with handle (Mug +), ball, and mug without handle (mug -)

	grab Position			grab Rotation		
	P x	P y	P z	R x	R y	R z
All V	0,0028	0,0005	0,0058	111	253	180
All mean	-1,26	1,35	0,26	339	91	283
All SD	0,05	0,02	0,08	11	16	13
All n	304	304	304	304	304	304
Mug + V	0,0027	0,0005	0,0028	92	250	103
Mug + mean	-1,25	1,36	0,26	340	91	282
Mug + SD	0,05	0,02	0,05	10	16	10
Mug + n	152	152	152	152	152	152
Ball V	0,0025	0,0006	0,0015	146	192	359
Ball mean	-1,29	1,34	0,34	336	81	287
Ball SD	0,05	0,02	0,04	12	14	19
Ball n	76	76	76	76	76	76
Mug - V	0,0018	0,0004	0,0007	102	123	136
Mug - mean	-1,24	1,34	0,16	341	101	282
Mug - SD	0,04	0,02	0,03	10	11	12
Mug - n	76	76	76	76	76	76

For the rotation, the y-coordinate showed the highest V and the largest differences in the mean values between the object categories, and the z-coordinate had the lowest V. However, the differences between the mean values were similar for the x- and z-directions. Within the item groups, the highest V for x- and z-directions was received in Group “Ball”, and for the y-direction in Group “Mug with handle”.

Z-tests with a significance level 0.05% between the three object categories were conducted for all three position coordinates and rotation coordinates. The z-value and identified significant differences are displayed in **Table 10.** Significant discrepancies for the position were identified between all objects in all directions except between “Mug with handle” and “Ball” with respect to the y-coordinate. The rotation showed substantial differences in y-direction between all object categories, and in x- and z-direction just between the “Mug with handle” and the “Mug without handle” none.

Table 10: Results of the two sided Z-tests with significance level 0,05% and a critical value of 1,96. Displayed are the Z-Value and the resulting significance of x-position (Px), y-position (Py), and z-position (Pz) as well as x-rotation (Rx), y-rotation (Ry), and z-rotation (Rz) between the three object categories.

	Px		Py		Pz	
	Z-Value	Significance	Z-Value	Significance	Z-Value	Significance
Mug with Handle vs. Ball	4,70	Yes	4,11	Yes	13,07	Yes
Mug with Handle vs. Mug without	2,78	Yes	4,61	Yes	17,93	Yes
Ball vs. Mug without Handle	6,82	Yes	0,07	No	32,53	Yes

	Rx		Ry		Rz	
	Z-Value	Significance	Z-Value	Significance	Z-Value	Significance
Mug with Handle vs. Ball	2,75	Yes	4,91	Yes	2,5	Yes
Mug with Handle vs. Mug without	0,4	No	5,61	Yes	0,48	No
Ball vs. Mug without Handle	2,73	Yes	9,90	Yes	1,98	Yes

The questionnaire and the interview were intended to provide information that supports the hypotheses. The answers to the questionnaire were sorted according to the use of the controllers. Hence, the answers for the Q2C were provided by Group A Cycle 1 and Group B Cycle 2, and the answers for the Tiggermuscle controller were provided by Group B Cycle 1 and Group A Cycle 2. All participants and all responses were taken into account for the calculations. First, the mean values for the replies after using the Q2C and after using the TMC were calculated (**Table 11**). Thereafter, one-sided t-tests with an assumed different Vs and a significance level of 0.05% were effected for questions with a difference greater than 0.20 in the mean value. Significant differences were obtained for question 2 “How responsive was the robot to actions that you performed?”, statement 18 “The robot’s behavior influenced my actions.”, and statement 26 “I felt a haptic sensation in my hand when I took over the object.” as shown in **Table 11**. In addition, the Pearson correlation coefficient was calculated between the answers and, respectively, VR experience, age, and experience with other controllers was evaluated for each question. The correlation was mostly very weak. A correlation above 0.30 was identified regarding VR experience for question 2 (-0.35), regarding age for question 16 (-0.34), and regarding experience with other controllers for question 2 (-0.36) and question 13 (-0.45). The interview was conducted in German since the native language of all participants was German. At the beginning of the interview, participants were asked to describe their experience. Six subjects directly addressed the controller differences, while the others described the task, the room, their feelings, or the immersion. Eighteen stated they liked the experiment, mostly adding “funny”, “interesting”, or “totally” and the other three answered “boring”, “trivial”, or “there is worse”. The majority of eighteen participants recognized differences between the controllers, and just three did not. However, the differences described by the subjects varied (**Figure 15**). Only six subjects, all belonging to Group A, indicated that they had recognized the resistance of the TMC. Another five of the same group stated that gabbing with the second controller was more difficult. In Group B, the most frequently mentioned differences were the different weights (or weight distribution) of the controllers and the different reaction times of the controllers. Most of the subjects in Group A reported difficulties with the second (TMC) controller caused by resistance or a perceived delay between input and output. In the group that started with the TMC, none of the subjects noticed these difficulties. However, some of the members of Group B mentioned that the second (Q2C) controller would have a faster reaction time. One of them indicated that the reaction time of the Q2C would be even too fast. Most participants mentioned the vibration of the TMC. The vibration was not considered in the experiment as it is just a side effect of the servo motor and was not intended. One subject in Group A stated that after grabbing with the resistance controller, he felt as if he actually had an object in his hands and also had more control over it. Another person indicated that the resistance occurred too early since it was there before the object was grabbed and the hand closed only after overcoming the resistance.

The majority of Group A participants indicated that they would prefer the Q2C, they had used initially, and most of the other group stated that they would favor the TMC they used in the first cycle (**Figure 16**).

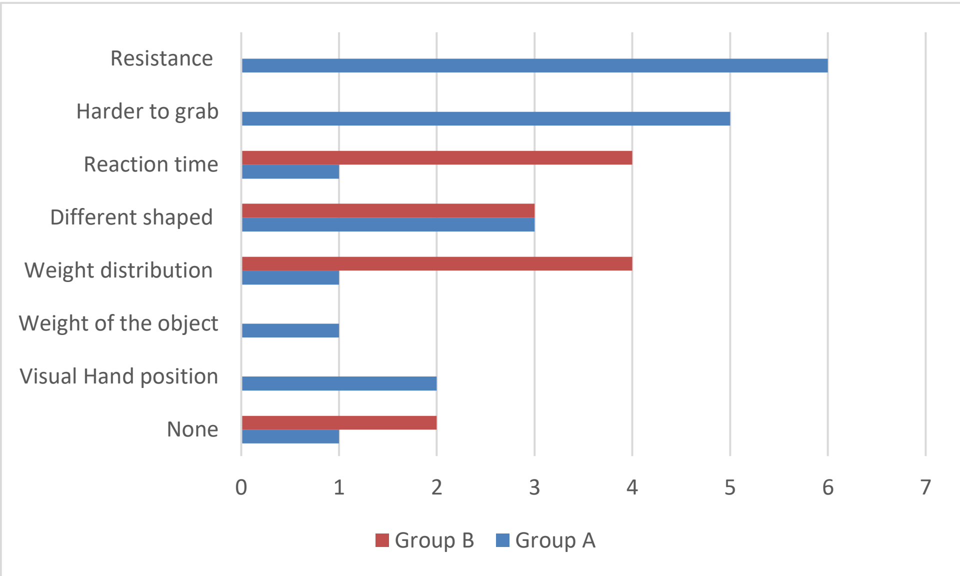

Figure 15: Difference between the controllers mentioned by the participants divided in Group A and Group B.

Table 11: Mean values of responses regarding TMC (Resistance) and Q2C (Quest) and the identified significance between them.

	Question	Quest	Resistance	Significance
1.	How much were you able to control events?	4,33	3,95	no
2.	How responsive was the robot to actions that you performed?	4,57	4,19	yes
3.	How natural did your interactions with the robot seem?	3,62	3,67	no
4.	How completely were your visual and haptic senses engaged?	3,48	3,67	no
5.	How natural was the mechanism which controlled the takeover?	3,57	3,19	no
6.	How aware were you of events occurring in the real world around you?	2,14	2,05	no
7.	How aware were you of your display and control devices?	3,52	3,24	no
8.	How compelling was your sense of objects moving through space?	3,76	3,86	no
9.	How inconsistent or disconnected was the information coming from your various senses?	2,38	2,29	no
10.	How much did your experiences in the virtual environment seem consistent with your real-world experiences?	3,14	2,95	no
11.	Were you able to anticipate what would happen next in response to the actions that you performed?	4,57	4,29	no
12.	How well could you move or manipulate objects in the virtual environment?	4,24	3,76	no
13.	To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?	1,62	1,90	no
14.	How involved were you in the virtual environment experience?	4,00	4,00	no
15.	How distracting was the control mechanism?	2,14	2,24	no
16.	How much delay did you experience between your actions and expected outcomes?	1,67	1,90	no
17.	How much did the visual display quality interfere or distract you from performing assigned tasks?	1,86	1,67	no
18.	The robot's behavior influenced my actions.	4,05	3,19	yes
19.	The robot's behavior had an influence on my mood.	1,62	1,62	no
20.	I reacted to the robot's behavior.	3,90	4,05	no
21.	The robot reacted to my actions.	4,38	4,14	no
22.	I had the feeling to interact with a physical robot.	2,62	2,48	no
23.	I had the impression that the robot noticed me in the virtual room.	3,33	2,95	no
24.	I had the feeling of being with the robot.	2,95	3,10	no
25.	I felt alone in the virtual environment.	2,14	1,95	no
26.	I felt a haptic sensation in my hand when I took over the object.	2,24	3,19	yes
27.	The haptic feedback helped me identify what was going on.	2,67	3,00	no
28.	The haptic feedback was realistic.	2,19	2,38	no
29.	The haptic feedback felt disconnected from the rest of the experience.	2,10	2,05	no
30.	The haptic feedback distracted me from the task.	1,38	1,57	no
31.	The haptic feedback felt appropriate.	2,57	3,10	no

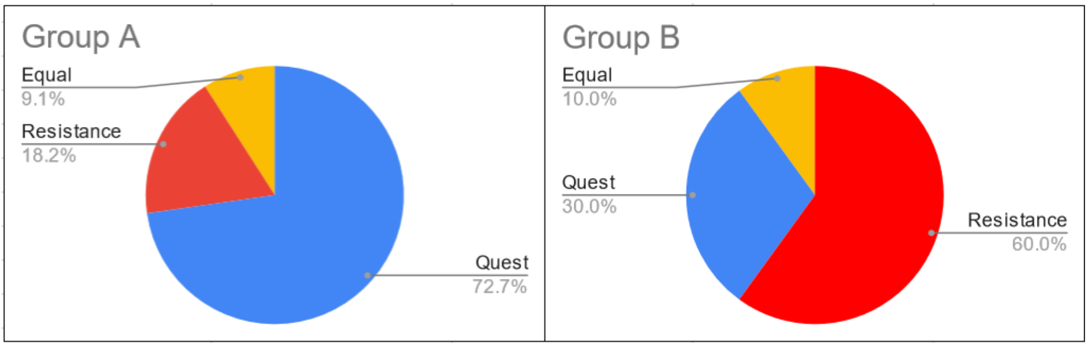

Figure 16: Indicated controller preferences divided in Group A and Group B

3.2.5 Discussion

The aim of the main study was to identify whether the TMC can improve the control mechanism in terms of naturalness and increase the perception of telepresence and co-presence. The questionnaire was intended to provide evidence that supports these assumptions. Only three aspects in the questionnaire showed significant differences between the controllers. When participants used the TMC:

- The robot was perceived as less responsive.
- The user was less influenced by the robot's actions.
- A haptic sensation during the takeover was rather perceived.

These results disproved the hypotheses H1a "The TMC increases perceived telepresence.", and H1b "The TMC increases perceived co-presence.". Hypothesis H1 "The TMC results in a more natural perception of controls during the handover process." could not be confirmed. Even though, a haptic sensation was perceived significantly more frequently, this question does not provide any information about its naturalness.

The correlation coefficient between the questionnaire replies and the demographics showed no strong connection, suggesting that the responses are independent of demographics. However, the results indicate that people who play video games more often have a slightly higher expectation of the robot's reaction time and are less confused when removing the headset than people who are not experienced in video games. A possible explanation for this is that they are accustomed to higher standards and to immersion in VEs. Furthermore, older people seem to notice delays a little less than younger people.

In the interview, the majority of Group A members stated difficulties with the resistance of the second controller. These statements may be due to their practice with the Q2C which has a very easy to press button. In addition, they did not anticipate any resistance, especially as it occurred independently of the visual impressions. The group that started with the TMC perceived rather the opposite. They were familiarized with a harder to press button and if they recognized any differences regarding the controls at all, they were surprised by the fast input. However, a significant number of Group B preferred the TMC because the Q2C had a very head-loaded weight distribution. This occurred because the heavier and longer TMC was screwed on it, which is normally not the case. For the TMC, the additional weight from Q2C was not so noticeable since it is smaller and lighter.

The subjective impression of most members in Group A is reflected in their performance in terms of time. This group could not significantly improve their performance in the second cycle, in contrast to the other group.

Despite the fact that the results could not support the hypotheses, the analysis with respect to duration between the number of transferred objects showed expected outcomes that coincide with the results from Huber et al. [85], who tested handover tasks between humans and robots in the real world. Even though there were outliers within the decreasing durations over time, this could be attributed to the filled objects, which increased the transfer duration significantly. This finding corresponds to that provided by Käppler et al. [84]. They investigated handovers in a human-human interaction scenario. The correlation between transportation duration and demographics was not strong. With respect to the experience with VR, the results provide evidence that familiarity with the medium improves performance. However, people who have much experience do not improve their transfer time as much as people who do not have much experience.

Concerning the age, the outcomes were different between Group A and B. The negative correlation in Group B could be related to the non-representative age distribution. Most members of this group were between 50 and 60 years of age, only two were younger. By far the youngest participant had no experience with VR or other controllers. In the other Group (A) which exhibits a more spreading age distribution, the correlation was positive in the first cycle, as expected. However, the correlation changed to negative in the second cycle. This finding could be due to results from the questionnaire which show that older people sensed fewer delays, which in turn may have distracted younger participants. This assumption also corresponds with statements from the interview.

Looking at the relation between self-assessed abilities and time, it seems that people who perceive themselves as skilled in daily life are slightly slower in VR than people who consider themselves to be clumsy. This could be explained by the fact that mishaps tend to happen to careless persons, who are often faster.

With regard to the use of other controllers, the results for Group A indicate that those persons with more experience perform better. However, the outcomes for Group B suggest the opposite. Since there was generally very little experience with other controllers in this group, this could be a reason.

The findings with respect to position showed significant differences between the objects. Especially in the z-direction, large differences were observed, which were probably caused by the implementation. The robot brought the objects from the left side closer to the user than the right-positioned items, which resulted in position differences up to 0.21 in z-direction between the balls on the left side (0.37-0.38) and mugs without handle on the right side (0.17-0.22). These deviations in the simulation also occurred in the x-direction, resulting in differences of up to 0.04 between balls (-1,26--1,27) and mugs without handle (-1,23--1,25). The y-position of the objects was constant at 1,35.

Consequently, the y-coordinate is the only one that is actually comparable. Concerning this coordinate, clear differences between the “Mugs with handle” and the other two objects were determined. A possible explanation for this finding could be that the handle, that covers the center of the object, leads people to grab the object more often from above in comparison with objects that have no orientation.

The hand rotation results showed that the greatest differences for all object categories are around the y-axis. This finding may be attributable to the fact that for this axis none of the objects have a predetermined orientation. However, this could also be caused by the position differences in the x-direction, which are particularly noticeable with the high z-value between “Ball” and “Mugs without handle” which have the largest differences for the x-position. For the x- and z-rotation, there were considerable differences between the “Ball” and the other two object categories, but not between the x-rotation and the y-rotation. A possible reason could be the same cylindrical shape that defines these orientations, and which is not specified for the ball.

4 CONCLUSION AND FUTURE WORK

Programming an agent that enables a natural handover is a challenging task in VR. There are several factors that influence a handover. Some of these factors have already been examined in human-human interaction or human-robot interaction scenarios. However, an uncertain factor remains the moment of releasing an object. Humans rely on their physical and social-cognitive abilities to “feel” the right moment. These abilities are difficult to reproduce. People have been observed lifting objects at the end of a handover. However, the results of the pilot study showed that this is not intuitive in VR, which could be due to the lack of gravity. The lack of haptic feedback is another issue in VR, because it is important for handovers. Various hardware- and software-based approaches have been proposed that could simulate haptic feedback in VR. One of these is the TMC which has been tested for weight perception. The TMC can provide resistance to the trigger button. Researchers were able to demonstrate that the perception of telepresence and co-presence in virtual environments is enhanced by haptic feedback. It was hypothesized that the resistance of the TMC could lead to a more natural perception during handovers and thus increase telepresence and co-presence. The outcome indicated that the resistance of the TMC was perceived as distracting rather than natural. This could be attributable to the implementation. The resistance occurred before the displayed hand grabbed the object rather than when the object was actually grasped. It was deliberately implemented in this way suspecting that the difference would be less noticeable if the resistance angle changed when the button is already pressed.

The following key conclusions can be drawn from the findings in the main study:

- Humans associate more effort on their part with less responsiveness on the part of their counterpart.
- Younger people seem to be more sensitive for haptic resistance.
- Even without a different weight the displayed full mugs increase the transfer duration.
- Even without collision between object and hand different displayed shapes of objects have influence on hand rotation and hand position in VR.

4.1 Future Work

The handover of objects between agents and humans is a field of study that still requires much research. Possible factors that could improve the aspects evaluated in this thesis would first be to eliminate the perceived gap between visual and haptic feedback. To banish the perceived delay of the trigger mechanisms and generate the desired effect of increasing telepresence and co-presence during the handover process in VR, an implementation could be tested in future work that provides haptic feedback at the very moment the button is pressed and thus the visual hand actually grasps the object or immediately after pressing the button. This can also be realized with the TMC. Even if the users do not have to overcome the resistance because the button is already pressed, a change in the button could nevertheless be noticed since this effect is immediate and unexpected. A pseudo-haptic effect that moves the displayed hand down to simulate it´s gravity when the agent releases the object could also be explored.

Potential future work could examine the moment of releasing the object more closely. Since the lifting condition was not appropriate for releasing the object in VR, another condition could be evaluated, such as a time delay or a condition of motion in any direction, to find out if it is perceived as more natural when a slight deceleration occurs before the agent releases the object. A condition of motion in any direction could be enriched by a pseudo-haptic effect that slows down the speed of the displayed hand to produce resistance on a psychological level. In addition, when an effect that generates a feeling of gravity is used, it could be tested if people lift the object higher than they do without gravity. Overall, these aspects need to be further explored in order to approach the implementation of a realistic handover agent.

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Appendix

1. The Unity Project and a digital version of this bachelor report you can find here:

➔ https://github.com/moan7/BachelorAndrzejewski

2. Pilot Study: Consent Agreement

Pilot Study: Evaluation of Hand-over methods in Virtual Reality
Conductor: Monika Andrzejewski

Consent Agreement

Description: You are being invited to take part in this research project that evaluates hand-over tasks in Virtual Reality (VR). You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide it is important for you to understand why the research is being done and what participation will involve. Please take time to read the following information carefully. Ask the conductor if there is anything that is not clear or if you would like more information.

Duration: Your participation will take about approximately 15 minutes.

Procedure: If you agree to participate in this study, you will be asked to:
- Answer questions in written form on a laptop
- Perform a task in VR
- Wear the VR equipment.
- Answer interview questions

Purpose: The pilot study evaluates different hand-over conditions and is part of the conductor's Bachelor thesis.

Risks: There exists minimal risk for this experiment. However, some individuals may experience discomforts such as headache, nausea or dizziness. In such case, the experiment will be stopped. Any participant that admits to a history of epilepsy will be disqualified from the process in order to prevent and mishaps from use of the VR headset.

Benefits: This study is part of the conductors Bachelor thesis. Your participation helps to gather information for future development and benefits public research about hand-over tasks which could result in the improvement of interaction in VR.

Confidentiality: No data gathered during the experiment is tied to personal information and thus cannot be paired with your identity.

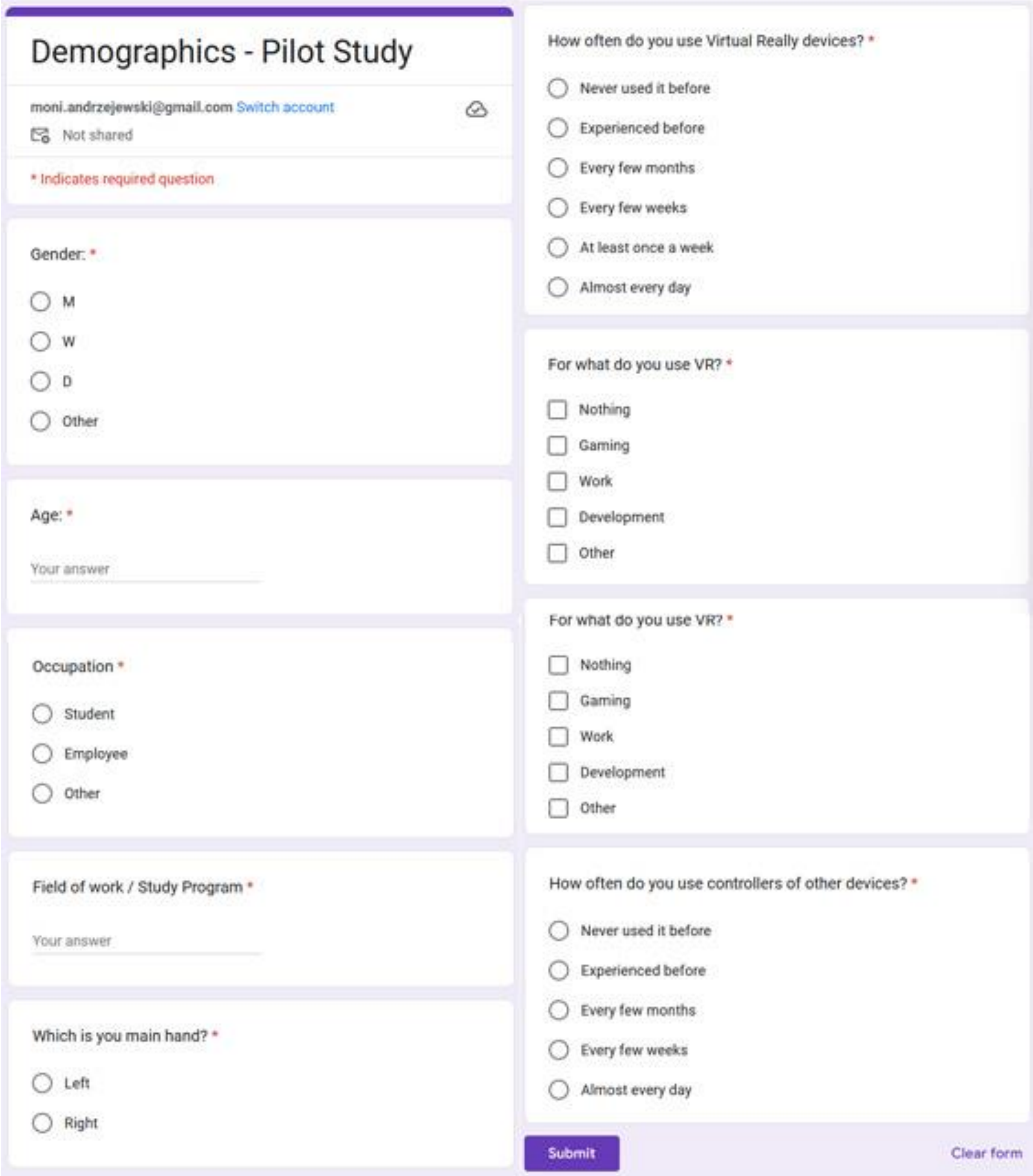
Rights: This experiment is entirely voluntary in that it is your choice to participate. If at any point during the process you wish to withdraw, you are free to do so and your performance data will be disregarded. This cannot be done after the process is finished because all data is anonymous.

Consent: With your signature below, you will confirm that you have read this document carefully and agree to:

☐ Participate in this research experiment under the conditions described above.

Date, Signature ____

3. Pilot Study: Demographic Questions



Demographics - Pilot Study

moni.andrzejewski@gmail.com Switch account

Not shared

* Indicates required question

Gender: *

- M
- W
- D
- Other

Age: *

Your answer

Occupation *

- Student
- Employee
- Other

Field of work / Study Program *

Your answer

Which is you main hand? *

- Left
- Right

How often do you use Virtual Really devices? *

- Never used it before
- Experienced before
- Every few months
- Every few weeks
- At least once a week
- Almost every day

For what do you use VR? *

- Nothing
- Gaming
- Work
- Development
- Other

For what do you use VR? *

- Nothing
- Gaming
- Work
- Development
- Other

How often do you use controllers of other devices? *

- Never used it before
- Experienced before
- Every few months
- Every few weeks
- Almost every day

Submit

Clear form

4. Main Study: Consent Agreement

Study: Evaluation of Hand-over methods in Virtual Reality
Conductor: Monika Andrzejewski

Consent Agreement

Description: You are being invited to take part in this research project that evaluates controller for hand-over tasks in Virtual Reality (VR). You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide it is important for you to understand why the research is being done and what participation will involve. Please take time to read the following information carefully. Ask the conductor if there is anything that is not clear or if you would like more information.

Duration: Your participation will take about approximately 20-30 minutes.

Procedure: If you agree to participate in this study, you will be asked to:
- Answer questions in written form on a laptop
- Perform tasks in VR
- Wear headphones, hearing protectors and the VR equipment
- Answer interview questions.

Purpose: The study evaluates different controller regarding hand-over tasks and is part of the conductor's Bachelor thesis.

Risks: There exists minimal risk for this experiment. However, some individuals may experience discomforts such as headache, nausea or dizziness. In such case, the experiment will be stopped. Any participant that admits to a history of epilepsy will be disqualified from the process in order to prevent and mishaps from use of the VR headset.

Benefits: This study is part of the conductors Bachelor thesis. Your participation helps to gather information for future development and benefits public research about hand-over tasks which could result in the improvement of interaction in VR.

Confidentiality: No data gathered during the experiment is tied to personal information and thus cannot be paired with your identity.

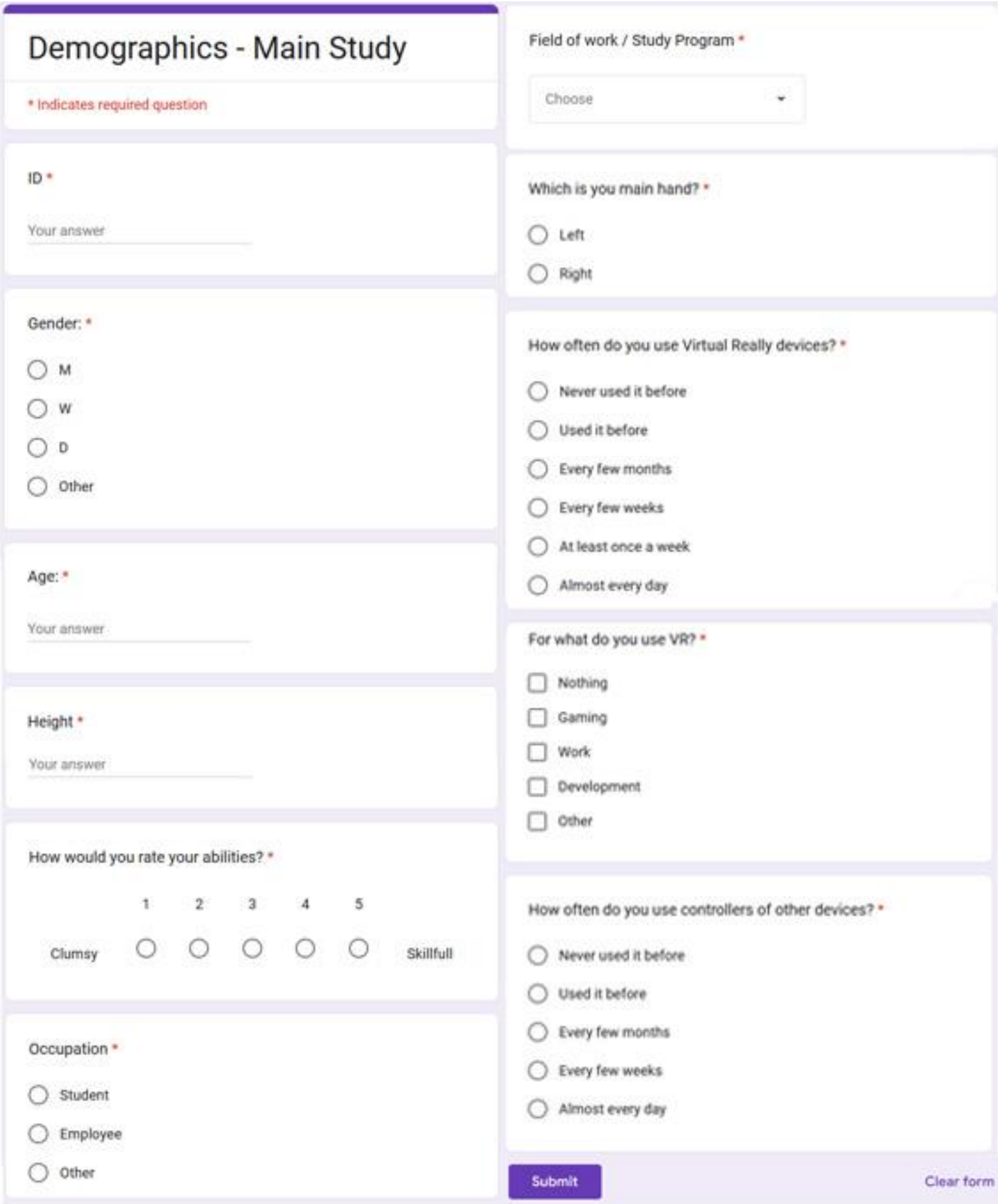
Rights: This experiment is entirely voluntary in that it is your choice to participate. If at any point during the process you wish to withdraw, you are free to do so, and your performance data will be disregarded. This cannot be done after the process is finished because all data is anonymous.

Consent: With your signature below, you will confirm that you have read this document carefully and agree to:

☐ Participate in this research experiment under the conditions described above.

Date, Signature ____

5. Main Study: Demographic Questions



Demographics - Main Study

* Indicates required question

ID *

Your answer

Gender: *

- M
- W
- D
- Other

Age: *

Your answer

Height *

Your answer

How would you rate your abilities? *

	1	2	3	4	5	
Clumsy	○	○	○	○	○	Skillfull

Occupation *

- Student
- Employee
- Other

Field of work / Study Program *

Choose

Which is you main hand? *

- Left
- Right

How often do you use Virtual Really devices? *

- Never used it before
- Used it before
- Every few months
- Every few weeks
- At least once a week
- Almost every day

For what do you use VR? *

- Nothing
- Gaming
- Work
- Development
- Other

How often do you use controllers of other devices? *

- Never used it before
- Used it before
- Every few months
- Every few weeks
- Almost every day

Submit

Clear form

6. Main Study: Questionnaire

1. Questionnaire - Main Study

* Indicates required question

ID *

Your answer

1. How much were you able to control events? *

not at all 1 2 3 4 5 very

2. How responsive was the robot to actions that you performed? *

not at all 1 2 3 4 5 very

3. How natural did your interactions with the robot seem? *

not at all 1 2 3 4 5 very

4. How completely were your visual and haptic senses engaged? *

not at all 1 2 3 4 5 very

5. How natural was the mechanism which controlled the takeover. *

not at all 1 2 3 4 5 very

6. How aware were you of events occurring in the real world around you? *

not at all 1 2 3 4 5 very

7. How aware were you of your display and control devices? *

not at all 1 2 3 4 5 very

8. How compelling was your sense of objects moving through space? *

not at all 1 2 3 4 5 very

9. How inconsistent or disconnected was the information coming from your various senses? *

not at all 1 2 3 4 5 very

10. How much did your experiences in the virtual environment seem consistent with your real-world experiences? *

not at all 1 2 3 4 5 very

11. Were you able to anticipate what would happen next in response to the actions that you performed? *

not at all 1 2 3 4 5 very

12. How well could you move or manipulate objects in the virtual environment? *

not at all 1 2 3 4 5 very

13. To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session? *

not at all 1 2 3 4 5 very

14. How involved were you in the virtual environment experience? *

not at all 1 2 3 4 5 very

15. How distracting was the control mechanism? *

not at all 1 2 3 4 5 very

16. How much delay did you experience between your actions and expected outcomes? *

	1	2	3	4	5	
not at all	○	○	○	○	○	very

17. How much did the visual display quality interfere or distract you from performing assigned tasks? *

	1	2	3	4	5	
not at all	○	○	○	○	○	very

Rate how much you agree with the statements.

18. The robot's behavior influenced my actions. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

19. The robot's behavior had an influence on my mood. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

20. I reacted to the robot's behavior. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

21. The robot reacted to my actions. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

22. I had the feeling to interact with a physical robot. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

23. I had the impression that the robot noticed me in the virtual room. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

24. I had the feeling of being with the robot. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

25. I felt alone in the virtual environment. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

26. I felt a haptic sensation in my hand when I took over the object. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

27. The haptic feedback helped me identify what was going on. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

28. The haptic feedback was realistic. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

29. The haptic feedback felt disconnected from the rest of the experience. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

30. The haptic feedback distracted me from the task. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

31. The haptic feedback felt appropriate. *

	1	2	3	4	5	
not at all	○	○	○	○	○	totally agree

Submit

Clear form