SHARE
YOUR REALITY

TU Delft CWI

Master Thesis

Karthikeya Puttur Venkatraj

Share Your Reality: The effects of haptic feedback on virtual avatar co-embodiment

Master Thesis

Karthikeya Puttur Venkatraj

Msc. Integrated Product Design

Faculty of Industrial Design Engineering

TU Delft

Chair

Dr. Gijs Huisman

Industrial Design Engineering

Delft University of Technology (TU Delft)

Mentor

Wo Meijer

Industrial Design Engineering

Delft University of Technology (TU Delft)

Organisation Mentor

Dr. Abdallah El Ali

Centrum Wiskunde & Informatica (CWI)

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PREFACE

This thesis signifies the culmination of a two-year-long journey towards obtaining a master's degree in industrial design engineering at TU delft. I embarked on this thesis with a desire to delve into research on virtual reality technology, aiming to learn the methodologies and disciplines involved in conducting research using this technology. This report documents a six-month exploration of a virtual paradigm that feels almost like a creation of fiction.

Undoubtedly, this experience has been filled with challenges, encompassing both highs and lows throughout the process. Nevertheless, I'm deeply gratified to have successfully completed this project on a positive note. The obstacles that I encountered and overcame has given me the confidence to adeptly solve problems in future projects.

I invite you to read this report to get insight into the process that was adopted and the outcomes that was achieved. My aspiration is that it offers inspiration and contributes towards the advancement of the world of virtual reality.

ACKNOWLEDGEMENTS

I dedicate this section to express my gratitude to all those who supported me throughout this journey. This project's accomplishment wouldn't have been possible without their contributions.

First and foremost, my sincere gratitude goes to my supervisory team, Gijs for introducing me to this topic and offering me the opportunity to work on it. Your advice and assistance throughout the project have been invaluable. Wo, thank you for your continuous support and guidance throughout the process. Your encouragement has been the driving force that has kept my motivation high from start to finish. I valued all our conversations and your feedback on a personal level. I am able to deliver this work at the level it is in thanks to your assistance.

Abdo, I am grateful to you for giving me the opportunity to conduct this research at CWI. Your consistent supervision and support have been instrumental in my progress. All the valuable connections facilitated by your guidance have truly enriched this whole experience for me. I also want to extend my appreciation for the entire team at CWI for making me a part of the team and sharing their knowledge with me. The expertise level in the team is inspirational and has motivated me to pursue a career in research.

A Special mention goes to Laveena, thank you for standing by me through the highs and lows and offering unwavering motivation to me throughout. I extend my thanks to my friends for making this journey memorable and being the support system I need to be happy in this home away from home. Lastly my heartfelt gratitude goes to my family for their unconditional love and support that they have always provided. I cannot even dream of reaching this stage in life without them by my side.

नासतो विद्यते भावो नाभावो विद्यते सतः ।
उभयोरपि दृष्टोऽन्तस्त्वनयोस्तत्त्वदर्शिभिः ॥ 16॥

nāsato vidyate bhāvo nābhāvo vidyate sataḥ
ubhayorapi dṛiṣhṭo 'nta stvanayos tattva-darśhibhiḥ

The unreal has never existed. The real always exists.
The mysterious truth about both existence and non-existence is directly perceived by those with the eyes to see.
(Bhagavad Gita Chapter 2, Verse 16)

ABSTRACT

The advent of Virtual Reality (VR) technologies has begun a shift in communication between people and their interaction with 3D virtual environments. VR has great potential to provide high immersion to users, allowing designers to create vivid and impossible interactions. However, while software and technology play a crucial role in creating a VR experience, as designers we must understand how humans perceive these elements of sensory illusions in order to create experiences that are appropriately received and interpreted.

Recent efforts in "Social Virtual Reality" explore shared experiences and collaboration between users through remote interactions in virtual environments. One emerging concept is "Virtual Co-embodiment", enabling two users to share a virtual character. This interaction fosters a unique multiplayer experience, promoting social co-ordination and collaborative user experiences. Co-embodiment achieves heightened levels of co-presence while still preserving a strong sense of agency and body ownership for both the users. The influence of feedback mechanisms on these factors is an important point of interest.

This project expands on this idea of co-embodiment by investigating how haptic feedback affects these factors between dyads performing shared perceptual activities. To examine these effects, an experiment was designed wherein pairs of participants in co-embodiment, performed reaching tasks with varying levels of control over the shared hand avatar, both with and without haptic feedback conditions. This was facilitated using a VR system that was tailor-made to meet these requirements. Objective measurements of their motion were collected during the interaction and subjective responses were recorded post-interaction.

The results showed that participants sense of agency was significantly lower in conditions where they received haptic feedback when their hand positions overlapped, compared to conditions where there was no haptic feedback. Participants made negative associations of the haptic feedback during the experiment as expressed in the post-experiment interviews, which could have affected their perceptions of agency. They also show significantly greater sense of agency during tasks where they shared a common target with their partner, while co-presence and embodiment levels were significantly higher in tasks where there were multiple targets. Participants also spontaneously adopted leader and follower roles during the interactions with different motion strategies to gain control over the shared avatar. These, along with other findings of the qualitative and quantitative analysis are compiled to extract insights to inform future research of this concept. Additionally, limitations of the study are discussed along with recommendations for further improvements to enhance this paradigm.

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Chapter 1 Introduction

An introduction to this research is given in Section 1.1, followed by an overview of the project scope and approach in Section 1.2 In Section 1.3 key concepts are highlighted that provide a basis for the rest of the work discussed in the project

The topics discussed in Section 1.3 are :

1.3.1 Avatar embodiment

1.3.2 Avatar co-embodiment

1.3.3 Perceptual crossing

1.1 INTRODUCTION

Virtual reality

In this current era of virtual reality (VR), the accessibility of the technology has reached users from diverse backgrounds. Primarily linked to the entertainment industry, this technology has also found application in sectors including medicine (Li et al., 2017), manufacturing (Gonzalez-Franco et al., 2017), and military (Harris et al., 2023), where it serves as a training tool. Its potential in training fields is notably high due to the exceptional level of immersion it can deliver. Immersion as defined by Slater et al., (2022) is the '*technological capacity of a medium to generate experiences that can remove people from their physical reality*'.

Through VR, people can immerse themselves in a world through the first person perspective that produces a sense of body ownership and agency towards their virtual avatars, while allowing precise control and variation of stimuli. These variations can significantly impact the user's perception (Gibbs et al., 2022) of presence in the virtual environment. Researchers have studied these changes in perception by varying virtual representations of the user themselves with different avatar embodiment techniques (Debarba et al., 2022; Ogawa et al., 2020), as well as feedback stimuli (Günther et al., 2020; Wagener et al., 2022).

Virtual Co-embodiment

Recently, researchers have introduced, the concept of "Virtual Co-embodiment"; two users embodying one shared avatar. This type of interaction offers a unique multiplayer experience characterized by shared control and embodiment, fostering collaborative user experiences that induce social coordination. Experiments evaluating the impact of different control schema on the users' perception of agency and embodiment (Hapuarachchi et al., 2023; Kodama et al., 2022) have shown enhanced levels of embodiment with low levels of control over the shared avatar. This makes it promising tool to be used for VR based rehabilitation and training applications. Since it is valuable for the learner (with low control), to feel a strong sense of agency while performing the activity with a teacher (with high control).

While researchers have explored this method in relation to users' perception of embodiment, the role of social presence and its influence on social coordination within this context is not yet been fully characterized. Moreover, there is currently no feedback channel available to the user that provides information about the partner's presence during co-embodiment. Enabling such feedback could potentially impact the dynamics between the users and their subsequent co-ordination. This approach can contribute to a deeper understanding of the emergent social co-ordination between the users and its manipulations. Haptic feedback is preferred in this case over auditory and visual feedback, as it does not lead to any scalability issues during implementation.

PROJECT OUTLINE

This project extends the co-embodiment research by examining how haptic feedback affects users' perception of control and co-presence when sharing an avatar in a collaborative VR environment. We developed a VR system where pairs of participants shared a virtual hand. This setup facilitated a mixed methods experiment to evaluate how the provision of haptic feedback when the users' hand position overlapped in virtual space impacts their perception of control and co-presence. The goal of this research is to determine whether the introduction of a non-verbal communication channel during co-embodied experience results in heightened levels of control and presence.

1.2 PROJECT OVERVIEW

1.2.1 SCOPE

The project aims to generate insights for the future development of 'Virtual Co-embodiment'. The focus will be on precisely defining the paradigm that combines co-embodiment with a haptic feedback mechanism as an indicator of social presence during co-embodiment.

To investigate the influence of this feedback mechanism a custom VR system was developed. Using this system a mixed methods study is modeled to isolate potential effects on the users' perceived sense of agency, co-presence and body-ownership. However, evaluating body ownership is limited in relation to virtual hands. This choice of avatar representation was made to reduce the level of complexity during the systems' development.

The project's outcomes include insights gained from the experimental study and the design and development of the haptic co-embodiment system. The project was realized through a collaboration between TU Delft and Distributed & Interactive Systems (DIS) research group at Centrum Wiskunde & Informatica in Amsterdam. It was conceptualized and executed for obtaining the Master's in Integrated product design from the faculty of Industrial design engineering Faculty (IDE) at TU Delft.

1.2.2 PROJECT APPROACH

The structure of this project consists of three phases (Figure 1). In the first phase, literature on the different aspects of VR, social cognition and haptics was extensively studied. During this phase, previous experiments exploring these topics are studied in detail, and the findings from these experiments are used as a guideline to frame the research questions and the experiment protocol.

In the second phase, the VR system used to evaluate the impact of haptics on co-embodiment is developed. This system allows two users to share an avatar, and collects the objective motion data and subjective data on their perceived sense of agency, co-presence and body ownership during the interactions. Additionally, a set different feedback patterns and intensities of vibrations are tested in a pre-study to make informed choices on the type of haptic feedback to be used in the main experiment. This phase ends with a pilot test to check the flow of the experiment and debug any errors. After the pilot tests, the data collection process is reviewed and the setup to be used in the experiment is finalized.

The last phase is the evaluation of the designed system through an experiment. A total of 20 sessions (40 participants in pairs) are conducted for the final evaluation. The data collected from these sessions are then processed and analyzed to generate qualitative and quantitative insights and evaluate the research.

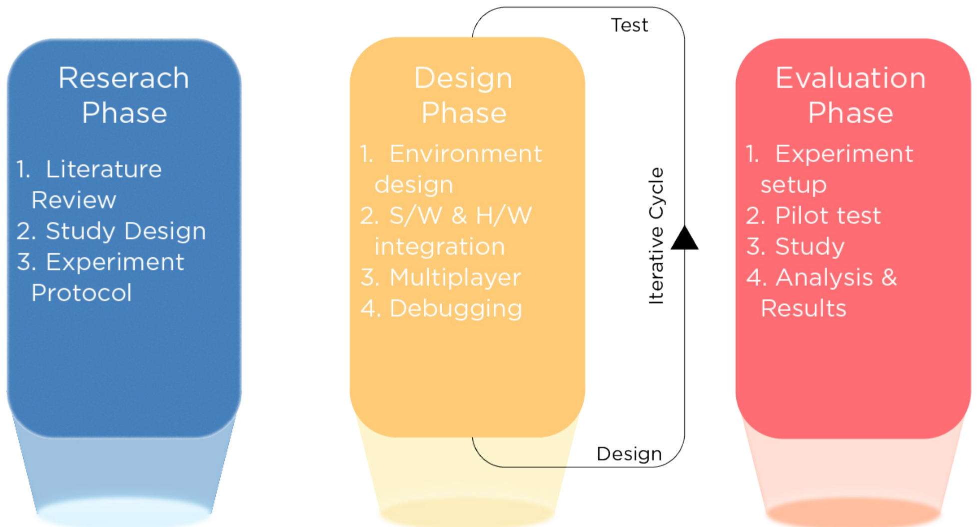


Figure 1. Three phases of the project

1.2 KEY CONCEPTS

The context for this work is derived from the topics of 'Avatar embodiment', 'Avatar Co-embodiment' and 'Perceptual crossing', that were explored during the initial phase of the project. These topics helped shape the paradigm in which this work is situated and provided crucial insights for making informed considerations. Understanding these concepts is essential for grasping the context and motivation behind the subsequent exploration and findings.

1.3.1 AVATAR EMBODIMENT

The illusion of the body is considered one of the main illusions produced in VR along with Place (PI) and Plausibility (Psi) illusions. PI refers to the illusion of being present within the virtual environment while Psi refers to the illusion that, interactions within the virtual environment are perceived to be real. These three illusions are components of an overall response that can be broadly placed under the concept of 'Presence'. Body illusions occur when a person wears a wide field-of-view, stereo Head Mounted Display (HMD) and they observe a life size avatar substituting their own (Figure 2). This avatar moves synchronously with respect to their own movement using real time motion tracking of the hands and head, a phenomenon known as visuomotor synchrony. (Slater et al., 2022).

Such sensory illusions of the body are not limited to experiences only using HMD's, for example Rubber hand illusions (when tactile sensations of an artificial limb are perceived as sensations on a person's real limbs) are very well known in the field of psychology . The phenomenon observed in this illusion is referred to as visuotactile synchrony.

Avatar embodiment refers to the integration of visuomotor or visuotactile synchrony into the first person view of the body, typically creating an illusion that the virtual body is the users' actual body. The study of this experience reveals the extent to which a person identifies themselves with the body they perceive, and examines the interplay of visual, touch and proprioception (Botvinick & Cohen, 1998).

Figure 2. Person wearing HMD experiencing avatar embodiment

1.3.2 AVATAR CO-EMBODIMENT

Social interactions play a key factor in VR to prevent isolation of individuals in the virtual environment (Rizvic et al., 2022). Therefore, researchers are trying to understand how different shared interactions can be designed for VR (Rasch et al., 2023; Theodoropoulos et al., 2023). The recent advancements of this technology has seen its use in a variety of social platforms such as VRChat, Rec room etc., (Oh et al., 2018). There are different ways in which these social platforms implement multiplayer functionality, but the most commonly used method is giving each user their own individual avatar to navigate the virtual environment.

Alternatively, it is possible for multiple users to embody a single avatar, known as 'Virtual Co-embodiment' (Figure 3). This is inherently different from a shared visual experience where multiple users would only share the same viewing perspective, as the motion of the shared avatar is generated by taking the weighted average of both the user's hand position and orientation (Fribourg et al., 2021). Through co-embodiment, pairs of users can simultaneously interact with the virtual environment.

However, this is just one of the ways co-embodiment can been achieved. Since then Researchers have also developed methods where multiple people control separate limbs of a shared avatar (Hapuarachchi et al., 2023). However, the focus of this research is on the first method where shared interactions can be manipulated by both the users and their influence is determined by the percentage of control they possess.

Figure 3. "Vitual Co-Embodiment" of two users in a single avatar (Fribourg et al., 2021)

1.3.3 PERCEPTUAL CROSSING

The Individualistic approach of social cognition suggests that, social cognition is limited only to individual reasoning and simulation capacity. The criticism to this approach is that interpersonal engagement is not taken into account (Jaegher & Froese, 2009). If movements play an important role in the sense making activity during an interaction, and interpersonal coordination of movement is possible between the people, then the activity may get coordinated during interaction. This coordination of sense making activities is called participatory sense-making (Auvray et al., 2009).

Auvray, Lenay, and Stewart (2009) introduced the paradigm of perceptual crossing, where remote interactions between two participants can lead to coordinated movement and this shared sense-making. The paradigm of this interaction was designed such that the task can only be solved through the interaction between people and cannot be solved by individuals alone. Interestingly when this design was tested with dyads (pair of participants) in a 1D environment (Figure 4) the results showed that participants were able to spontaneously interactionally solve the task. The extensions of this paradigm also revealed similar results when it was tested in a 2D environment (Lenay et al., 2011).

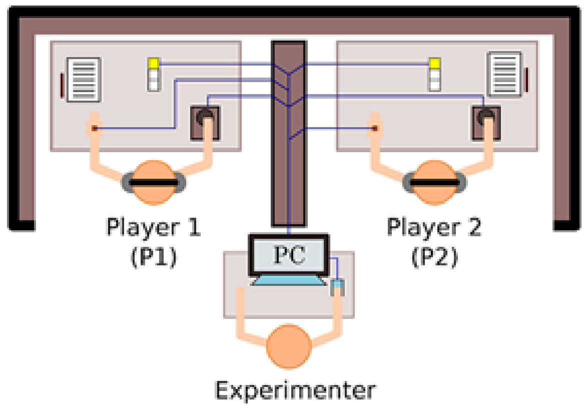


Figure 4. Setup of perceptual crossing experiment (Auvray et al., 2009)

The way the interaction was established in the original experiment was through "all-none" tactile feedback given to participants as they explored a 1D environment and interacted with a fixed object, the other participants' avatar and a shadow object rigidly linked to the other participants avatar (Figure 5).

The objective was to identify which of the interactions is with the partner's avatar. This was the only condition in the experiment when both participants would simultaneously receive haptic feedback. Further interpretations of the results from this paradigm reveal that coordination and synchronization is possible even in a simple environment through an embodied interaction. It also demonstrated that social coordination is an autonomous interaction process (Auvray & Rohde, 2012). This aspect of the perceptual crossing paradigm presents an interesting opportunity to integrate a haptic communication channel within online interactions that corresponds to the presence of another intentional subject.

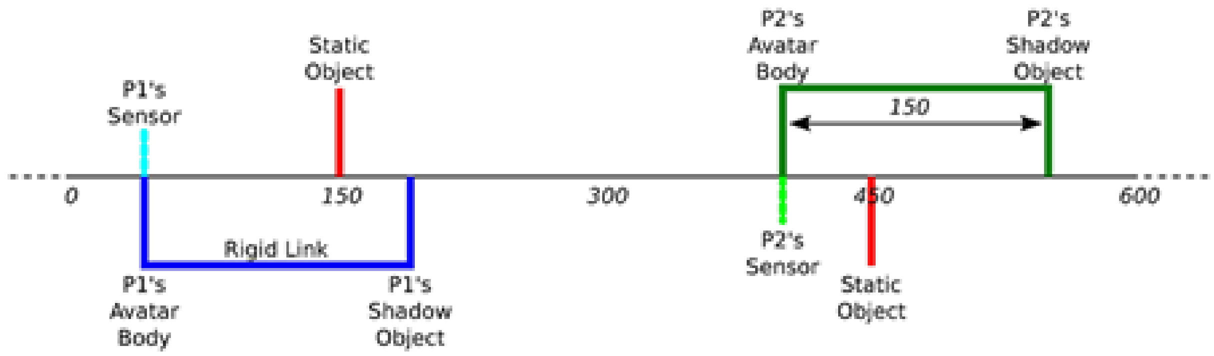


Figure 5. 1D environment that pairs of participants explored (Auvray et al., 2009)

Chapter 2 Research

This chapter provides an in-depth review of the literature that was studied during the research phase of the project. Section 2.1 highlights the key insights derived from this phase. The relevant information that was collected in this context is presented in a coherent manner in Section 2.2.

Within Section 2.2, the following subjects are covered:

2.2.1 Sense of embodiment

2.2.2 Social Presence

2.2.3 Weighted average co-embodiment method

2.2.4 Joint action task

2.2.5 Collaborative training in VR

2.2.6 Emerging directions of co-embodiment

2.2.7 Haptics

2.1 KEY INSIGHTS

1. Co-embodiment leads to a situation where there is intermingling of self-presence with social presence. Here the identity of the self is intrinsically linked to the avatar along with the presence of another intentional subject. This intentionality is translated through the amount of control available for each person over the shared avatar.

2. Experiments of co-embodiment have shown that participants are able to autonomously coordinate their movement if the task is directed towards a shared goal. There is a need to understand how this coordination of movement emerges and if it can be manipulated through variation in the stimuli that the participants receive.

3. There is evidence that shows that haptic feedback can enhance the perception of presence in VR. However, there is a gap in the understanding of haptics in combination with co-embodiment. Possible directions to implement haptics is by linking the feedback mechanism to the presence of the other user and influence their perceived sense of agency. This requires a stable nonverbal communication channel between the users.

4. The interaction condition from the perceptual crossing paradigm can be implemented during co-embodiment as a haptic nonverbal communication channel, providing an indication of the presence of the other user. The challenge here would be to design it in a way that does not cause discomfort or annoyance to the user while also differentiating it from other types of feedback.

2.2 RELATED WORK

2.2.1 SENSE OF EMBODIMENT

The understanding with respect to how we perceive (something) through our body has been a very important question in cognitive sciences. In the context of avatar embodiment (Section 1.3.1) this feeling is broadly classified under the term 'Sense Of Embodiment' (SOE) which can be manifested through three main components: Sense of Self-Location, Sense of Body Ownership, and the Sense of Agency (Kilteni et al., 2012). Sense of Self-Location refers to the feeling of 'being inside' a virtual body, while sense of body ownership and agency refers to the feeling of 'having' and 'controlling' the virtual body. Studies have explored various factors and their influence on these components, which show that manipulations of the overall SOE is possible through changes in avatar representations, degree of control and perspective of the users (Fribourg et al., 2020; Ogawa et al., 2017, 2019). Similarly the influence of sharing the virtual body with another user and its effect on SOE was studied in experiments of virtual co-embodiment. Here the sense of agency and body ownership play key role that determines the engagement level during the shared perceptual activity.

2.2.2 SOCIAL PRESENCE

Research has shown that individuals are capable of adapting to different media to achieve their communication goals (Papacharissi, 2005). When there is another entity which is sentient or appears to be sentient is present in the same environment, another dimension called 'Social presence' comes into play. This depends on the perceived ability of the person to access the intentions, intelligence and sensory impressions of another individual. The context and characteristics of this individual can influence the perceptions of social presence. Therefore, this is a crucial aspect for VR that requires mediation between people, without social presence, the other entity is perceived to be artificial and not as an intentional social being (Oh et al., 2018). However the impact of co-embodiment on social presence in VR has not been studied in detail.

2.2.3 WEIGHTED AVERAGE CO-EMBODIMENT METHOD

This method involves assigning each user a weight between 0 and 100 percent, and the shared avatars movement is calculated by interpolating the weighted average of the real time position and orientation of the controllers of both the users (Figure 6). The earliest implementation of the co-embodiment concept is in the experiment by Hagiwara et al., (2019). Here the motion of the two participants' movements and captured using a motion tracking system. In the study by Fribourg et al., (2021) that introduces the term "Virtual Co-embodiment", the same method of distribution of control has also been implemented. An important consideration that was made while designing both these systems was to let the users have the virtual view of their perspective as shared head motion will lead to motion sickness.

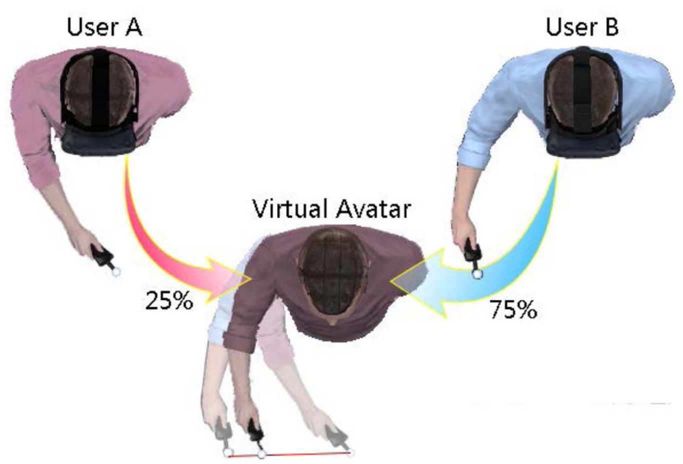


Figure 6. Weights of User A & User B averaged over the virtual avatar (Fribourg et al., (2021)

2.2.4 JOINT ACTION TASK

A common way to evaluate co-embodiment is with a "reaching task", where participants touch an object such as a cube (Hagiwara et al., 2019) using a shared avatar (Figure 7). This type of reaching task creates a situation where the shared perceptual activity is focused only on the motion of both the participants, since adding any other interactions such as button presses will create a more complex sequence of actions that needs to be performed by the participants making it undesirable.

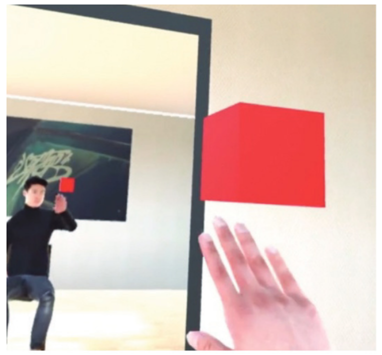


Figure 7. Reaching task using cube (Hagiwara et al., 2019)

In the main experiment of Fribourg et al., (2021), the motion task was performed for three different situations: free, target, and trajectory (Figure 8). During the free task each participant was free to choose any sphere to touch, while in the target task the sphere to be touched was highlighted for both the participants. Trajectory task involved following a particular path before touching a highlighted sphere and focused more on precision. The motivation behind the design of the experiments was to understand the influence of movement freedom and intention, on the level of embodiment and the feeling of control over the shared avatar.

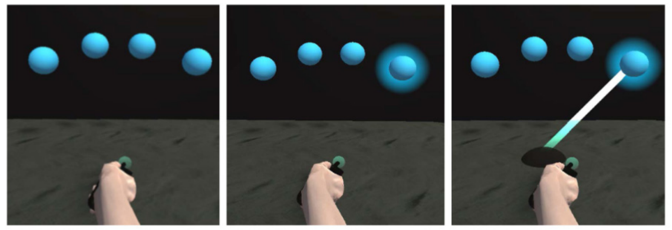


Figure 8. Free (left), Target (center) and tragectory task (right) in experiment by Fribourgh et al., (2021)

2.2.5 COLLABORATIVE TRAINING IN VR

Follow up studies by Kodama et al.,(2022, 2023) have further investigated the use of the weighted average co-embodiment method for use in the context of collaborative training for motion skill learning. The first study of Kodama et al.,(2022), compared this method with the perspective sharing method and evaluated the task performance and motor skill learning ability of participants. Perspective sharing is a method in which a translucent avatar was superimposed on the learner's first person perspective view (Figure 9). The second study of Kodama et al.,(2023), was more focused on transitional control weights for the users and its effects on the user's sense of agency. The task setup in this case was an irritating maze task which involved moving the aim of the controller through a maze (see Figure 10).

Figure 9. Perspective sharing method where participant learns by following translucent (red) avatar (Kodama et al,. (2022)

The results from (Fribourg et al., 2021; Hagiwara et al., 2019; Kodama et al., 2022) all showed that sense of agency increased with the increase in the control weight for the participant. However Kodama et al., (2023) did not observe a difference between the different control weight conditions. In all the studies participants were able to coordinate their movements in joint action in a novel way of interacting leading to sharing of motor intention and synchronization.

2.2.6 EMERGING DIRECTIONS OF CO-EMBODIMENT

This concept is now expanding into several directions, more recently Hapuarachchi et al., (2023) and Hapuarachchi & Kitazaki, (2022) developed co-embodiment systems where dyads controlled separate limbs of the shared avatar. Like the previous experiments on co-embodiment these were also tested with reaching tasks. While the study by Hapuarachchi & Kitazaki, (2022) explored the manipulation of sense of agency by providing visual feedback of the partners target (Figure 10). The study by Hapuarachchi et al., (2023) implemented passive haptics by attaching a brace to the back of the users which allowed them to maintain consistent shoulder posture while controlling the separate arms independently as they performed the task (Figure 11).

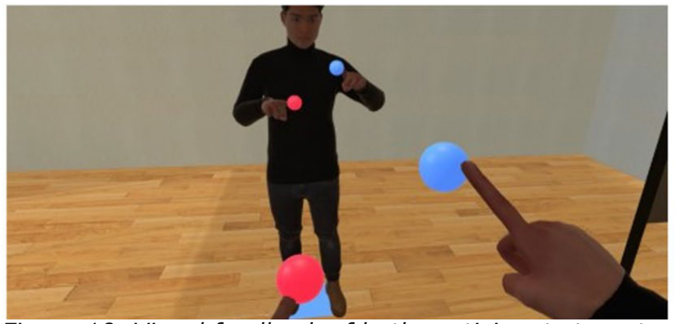


Figure 10. Visual feedback of both participants targets (Hapuarachchi et al., (2022)

Identifying what type of feedback modalities can be integrated into the co-embodiment method could provide advanced perceptual capabilities for the user. In a comparison of haptic and visual feedback on presence, a study by Gibbs et al., (2022) clearly showed greater sense of presence for conditions where participants received feedback and interestingly, sense of presence was higher when there was haptic only feedback compared to visual only feedback.

Figure 11. Back brace designed to maintain shoulder posture (Hapuarachchi et al., (2023)

2.2.7 HAPTICS

Sense of touch plays an important role to enhance user experiences in human technology interaction, there has been significant work done to simulate touch under an umbrella term known as "haptics", which refers to a number of different types of tactile stimuli which can be integrated into digital experiences (Wee et al., 2021). The most common haptic feedback in computer applications are vibrations and force feedback (Salminen et al., 2008). Researchers have explored how tactile stimuli can be programmed to elicit emotional and behavioral responses in humans (Ju et al., 2021) and work is also being done to understand how different types of haptic feedback can be implemented in VR (Günther et al., 2020; Marchal et al., 2013). These studies often implement haptics through interfaces such as wearables or physical props. While most commercial VR systems implement feedback in the form of vibrations of the motion controller and are commonly used when users interact with elements in the virtual scene.

Studies that have explored the use of haptics to provide this communication medium in the context of shared virtual spaces report enhanced user experience (Jung et al., 2021; Zhang et al., 2023). One of the limitations of VR is the lack of nonverbal communication channels that indicates the presence of another person. In the case of shared embodiment it is desirable to have indications of presence to benefit coordination. Generally, visual feedback offers more information to the user; however, it may lead to cluttered, chaotic experiences. Therefore the use of haptic feedback could provide a way to non-verbally communicate presence without overwhelming the view of the user during co-embodied interactions. The challenge here is to design the feedback mechanism in a way that does not increase the cognitive load required to differentiate between the interaction with the environment and the presence of the other user.

Chapter 3 Design

This chapter provides the detailed description of the development of the VR system that was used to conduct the experiment that is discussed in Chapter 4. Section 3.1 provides information regarding the choices that were made for the system components.

The design of the different components of the system are highlighted in the following sections

3.2 Immersive environment design

3.3 Virtual Character deign

3.4 Core logic

3.5 Data collection

Section 3.6 provides an explaination of the the haptic feedback design through a pre-study.

3.1 TECHNOLOGY

3.1.1 SOFTWARE & HARDWARE ANALYSIS

In order to study the effects of haptic on The project requires a VR system that enables two users to co-embody a shared avatar. Unreal engine 5.1 (Figure 12) was selected as the basis for the application due to past experience using the software. Unreal along with the VR expansion plugin (VR Expansion Plugin – A Virtual Reality Tool Kit, n.d.) template, was used as a base on which required features for the experiment such as multiplayer sessions, shared character animations, and task interactions were added.

For the VR headset Oculus Quest 2's (Figure 13) were used, since they provided the required functionality of motion tracking and vibration feedback. An important consideration that had to be made was to either develop the software as an application on the headset itself or as a computer application, as this would determine how the networking system is implemented and how the data is measured and stored during each session. Since the headsets processing capabilities are limited, it was decided to develop the application for a computer using the Oculus Quest 2 through a linked connection to provide better stability than connecting via Wi-Fi.

Figure 12. Unreal Engine by Epic games


Figure 13. Oculus Quest 2 by Meta

3.1.2 PLATFORM SPECIFICATIONS

The local multiplayer system is developed using the native unreal engine client server model (Networking Overview, n.d.). The schematic of the experimental setup is shown in Figure 14. Two computers are connected to each other through ethernet, using a router. One computer will be the host and Player 1, and the other computer will be a client and Player 2. Each computer is connected via Cable link to the Oculus Quest 2 HMD and motion controllers. The data collection for Player 1 and Player 2 is done separately and stored in the hard drive of the associated computer.

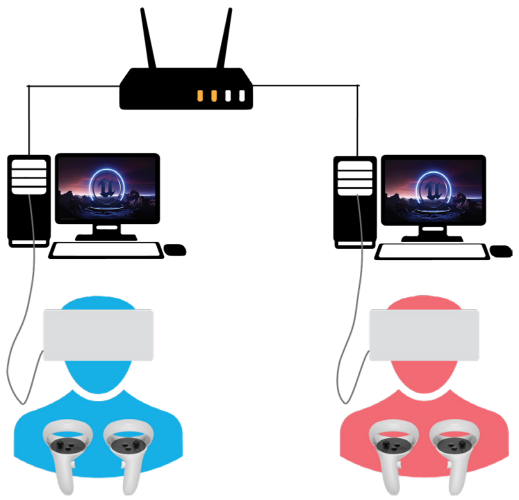


Figure 14. Schematic of experiment setup

3.2 Immersive Environment Design

3.2.1 GAME WORLD AND LEVELS

The game world is the virtual environment where the gameplay takes place, where *Levels* represent distinct areas in this world containing different assets and gameplay mechanics. A simple background and lighting setup using the sky sphere component in the engine, which consists of a sky background and a single directional light, is used consistently in all the levels. This type of minimalist environment is designed to avoid any distracting elements in the scene ensuring participants focus on performing the task during the experiment (Figure 15).


Figure 15. Level design can range from simple (left) to complex environments depending on context (Sandro Kornely, 2021)

The flow of the application is divided into multiple levels, corresponding to the different phases of the experiment described in Section 4.2. The training phase consisted of 5 levels whereas Task 1 and Task 2 consisted of 28 levels each.

3.2.2 TRAINING LEVELS

In the first level of the training phase, participants are given instructions on how to use the motion controller to answer the questionnaires (see Figure 16) and how to perform the task during the experiment (Figure 17).

Figure 16. Instructions on how to use the selection controls on the controller

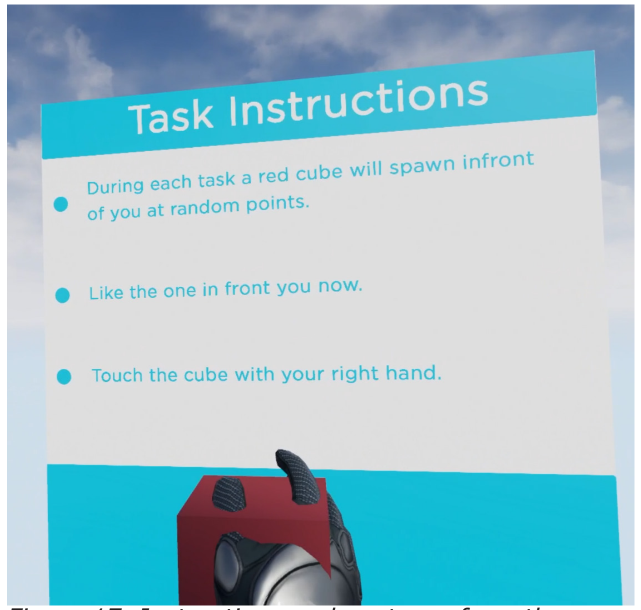


Figure 17. Instructions on how to perform the interaction in the task

Next, participants perform the training trial individually, as shown in Figure 18.

Figure 18. Training task where participants learn to use right hand to touch cubes

After the training trial is finished, they are placed in the server level (Figure 19). In this level, Player 1 first hosts a server and joins the lobby level. Then, player 2 searches for this server and joins the lobby level as a client (Figure 20). When both players press ready, the main experiment, which includes Task 1 and Task 2, begins.

Figure 19. Server level where Player 1 starts the server and Player 2 to joins

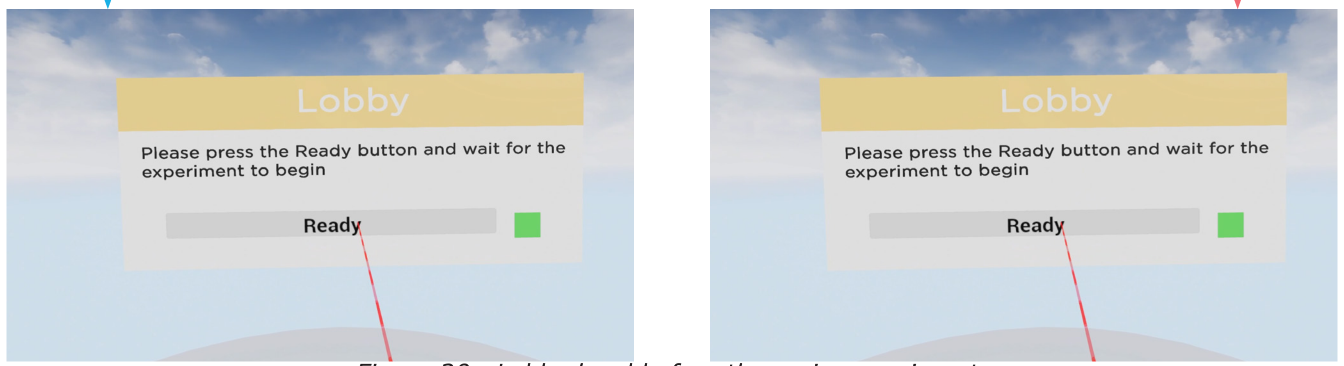


Figure 20 . Lobby level before the main experiment begins

3.2.3 MAIN EXPERIMENT LEVELS

There are 2 different types of levels in the main experiment: trial levels and questionnaire levels.

Trial Level

The trial levels consist of a platform on which the motion task takes place (Figure 21), here both players are spawned in the same location. Both Task 1 and Task 2 have the same environment setup. The current trial and task number is displayed to the participant in front of their view along with the instructions (Figure 22) on how to perform the task in both the tasks.

Figure 21. Layout in Trial levels

Figure 22. Intructions displayed to participants during Task 1 (left) and (Task 2)

Questionnaire Level

The questionnaire type of level consists of two platforms (Figure 23), these platforms have a separate spawn point with Player 1 always spawning on the left platform while Player 2 spawning on the right platform. In these levels each player has their own separate avatar in order to answer the questionnaire, the two platforms are separated by a wall so that players do not see each other. A widget is used to display the questions and record the answers from both the players in these levels.

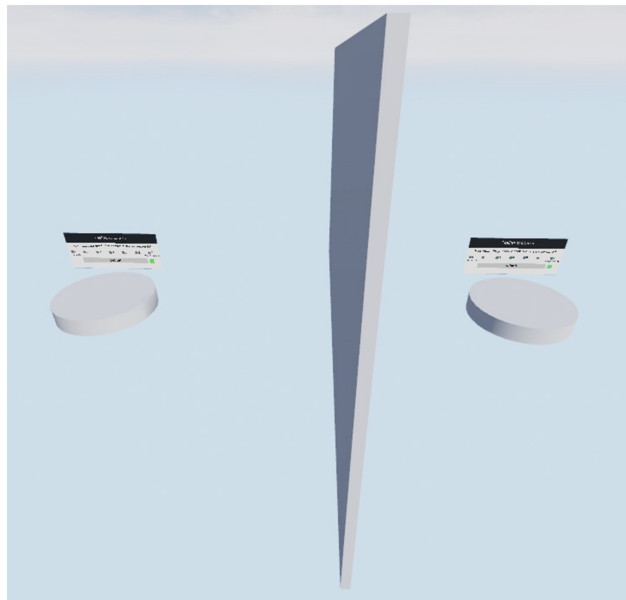


Figure 23. Layout in Questionnaire levels

3.3 VIRTUAL CHRACTER DESIGN

There are two types of characters that players use during the experiment: Multiplayer character and Questionnaire character. These are spawned corresponding to the two types of levels in the main experiment and are designed to have specific functionality required for interacting in these levels.

Multiplayer Character

Since players will co-embody an avatar in the trial levels; this character has no meshes attached to it (Figure 24). This character has a spherical collision component attached to right and left controller components. When the corresponding (P1,right – P2,right ; P1,left – P2,left) controller spheres of the players overlap, haptic feedback is given to the respective controller of both players. This haptic feedback is sustained in the controller as long as there is overlap between the collision spheres.

This character is also responsible for recording the position and orientation of the controllers and respective players to CSV files.

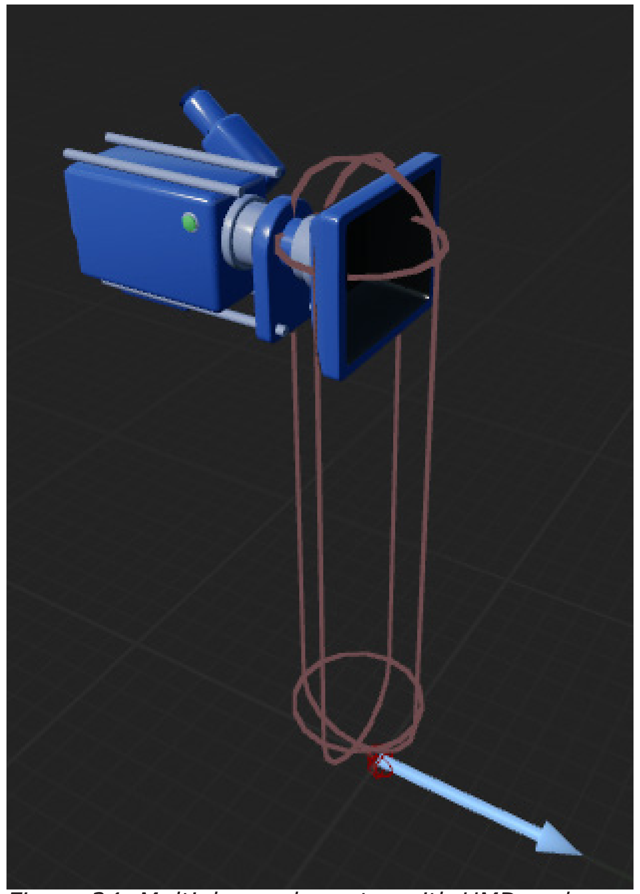


Figure 24. Multiplayer character with HMD and collision component

Questionnaire character

Since the participants have to separately answer questions in the questionnaire level, this character has hand meshes attached to the motion controllers (Figure 25). The controller is also programmed with the point and select functionality.

Figure 25. First person view of questionnaire character with hand meshes

3.4 CORE LOGIC

3.4.1 GAME MODE

The game mode is the backbone of Unreal, that is responsible for initializing the game world and spawning the players. The default game mode can be overridden to provide specific functionality for each level using custom game modes. There are two main game modes that are created with respect to the trial levels and questionnaire levels. Both game modes are used for level transitions at the end of each level (Figure 26). Since the game mode is a class that exists on the server, it has the authority to move all players from the current level to the next level.

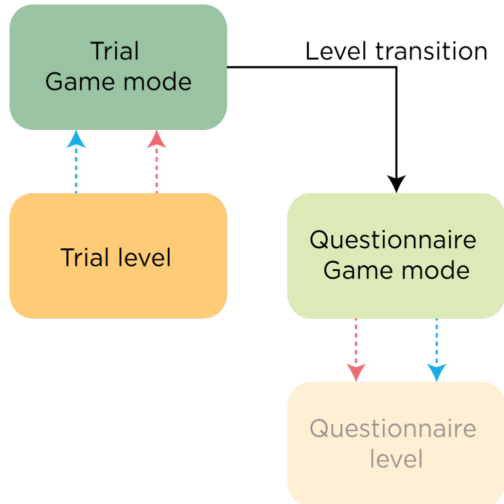


Figure 26. Level transition using game modes

3.4.2 CO-EMBODIMENT SYSTEM

In order to create a co-embodied avatar, the level spawns a "shared hands" avatar in the middle of the trial level (Figure 27). To determine the position of each of the shared hands, the avatar linearly interpolates between the position between Player 1 and Player 2 based on an Alpha value that ranges from 0 to 1. This weight (Alpha) controls the interpolation such that the resulting position is 100% of Player 1 when alpha is 0 and 100% of Player 2's position when alpha is 1. This value can be set to vary the control over the shared hands in every level, in order to create the necessary conditions outlined in the study design (Section 4.1.2). Therefore, three values are set for this variable in this application: 0.25, 0.5 and 0.75. If it is set to 0.25, Player 1 has 25% control and Player 2 has 75% control. If it is set to 0.5, both players have equal (50%) control and when it is set to 0.75, Player 1 has 75% control and Player 2 has 25% control over the motion of the shared hands.

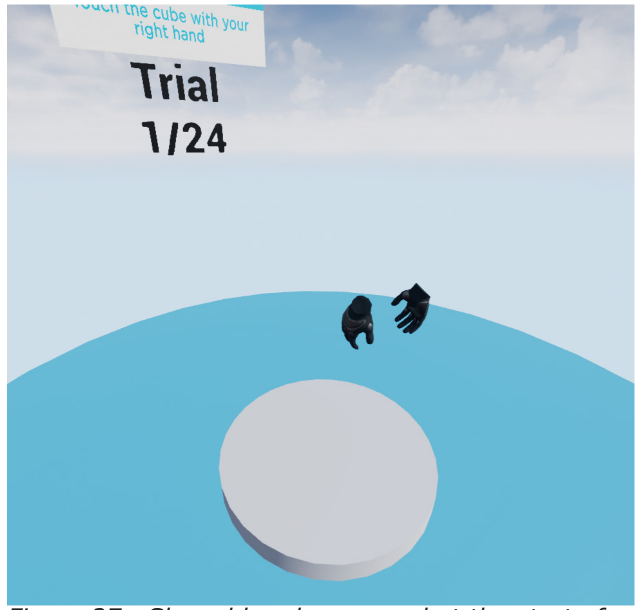


Figure 27 . Shared hands spawned at the start of the trial level

3.5.3 CUBE INTERACTION

Players perform Task 1 (Figure 28) in the first 12 trial levels and Task 2 (Figure 29) in the next 12 trial levels during the main experiment. After the shared hands are spawned into the level after a 1 second delay, a cube (Task 1) or set of cubes (Task2) is spawned in front of the spawn point.

Figure 28. Task 1 cube spawn position

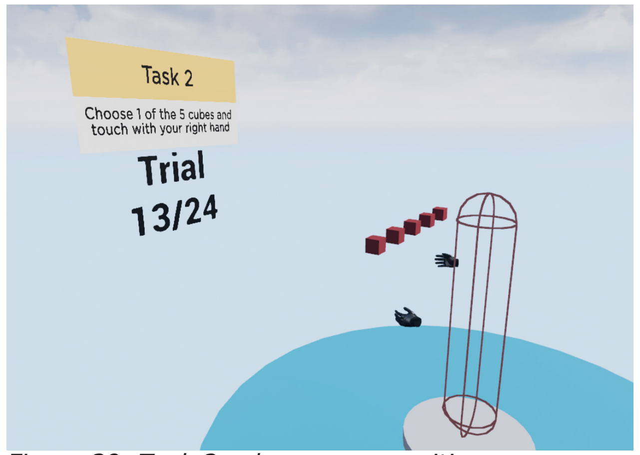


Figure 29. Task 2 cubes spawn positions

The players have to co-ordinate their movement to move the shared right hand to touch these cubes. The cube consists of a basic mesh with collision component attached to it. When the shared right hand collides with the cube, it triggers the cube to destroy itself and communicates to the game mode to spawn the next cube or set of cubes. This interaction repeats till the end of the trial.

3.4.4 QUESTIONNAIRE INTERACTION

Throughout the experiment participants should provide ratings between 1 and 7 for different questions during the questionnaire levels. Participants must choose only one option and submit their answer. This interaction is designed in the application using a widget. The different questions that need to be used are first created using Photoshop and saved as images. These are then added as textures that will be displayed on the widget in the level, the multiple (1 – 7) options are added to this layout using interactable check boxes. When a player points and selects one of these check boxes, a check mark appears which indicates the selection of that object. In order to confirm their choice players must then select the submit button. Successful submission is indicated by a green light (see Figure 30). The answer is submitted only when a single option is selected, the submit button is disabled in case zero or multiple options are selected . Both players should answer all the questions simultaneously. Therefore the level transition is linked to a condition that checks if both the players have answered the questions. All the images that were used for widgets are provided in appendix A.

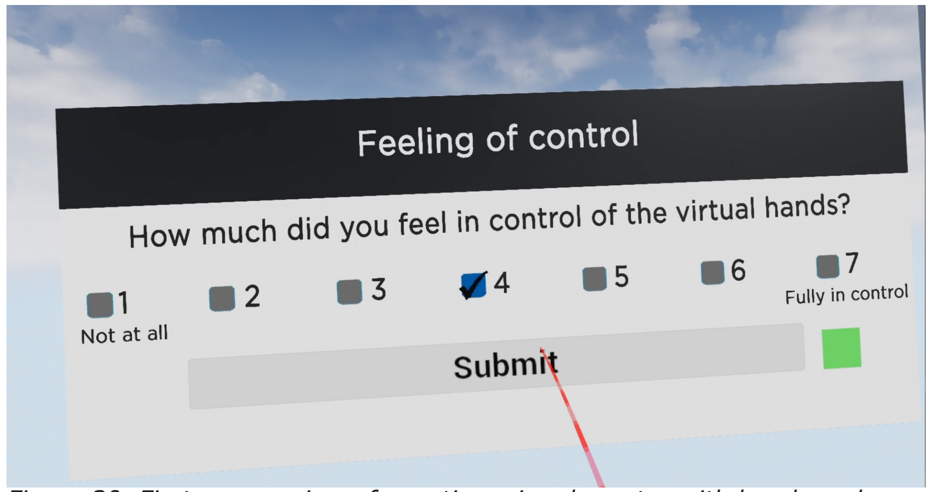


Figure 30. First person view of questionnaire character with hand meshes

3.4 DATA COLLECTION

The data collection process is an important part of the application that works behind the scenes during the experiment and was carefully designed to avoid extra processing and loss of data. Different types of data are collected at different levels of the experiment and stored as CSV files. When the application is launched, it creates the files described below:

SESSION DETAILS

The start and end timestamps of each level are recorded along with the task number as well as the trial number. This way the timestamps of all the levels during the entire session is stored in a single file.

PLAYER TRANSFORMS

The players' transform (Figure 31) data separated in columns with respect to the sub-components of position (X, Y and Z co-ordinates) and orientation (Roll, Pitch and Yaw) are recorded in separate files for each players' head and hands. This file contains the transform data of all the levels with timestamps as a reference, allowing the data to be traced to the respective task and trial in which they were recorded.

OVERLAP DURATION

The duration of overlap between the player hands were recorded using timestamps with along with task and trial numbers.

QUESTIONNAIRE ANSWERS

The answers from the questionnaire levels are stored separately for feeling of control, copresence and embodiment questions along with the player number, trial number and task number.

VIEWPOINT RECORDING

The first person view of both the players are also recorded using OBS video capture software on both the computers.

Figure 31. Player hand postion co-ordinates (Top) and orientation data

3.5 HAPTIC FEEDBACK DESIGN

Unreal provides a haptic feedback component that provides the capability to create vibrations with specific frequency, amplitude and intensity level. Previous experiments by Wentzel et al., (2020) tested techniques to modulate amplification levels of vibrations, and found that it impacted user's comfort. Therefore, the haptic feedback used during the experiment should be designed such that its intensity is high enough for the participants to notice it without causing discomfort. In order to make an informed decision on the intensity and pattern of the vibration, a pre-study was conducted.

SETUP

Participants tested 4 vibration patterns: Intermittent, Sinusoidal, Heartbeat and Constant (Figure 32). These patterns in combination with 4 intensity levels: 10, 20, 30, 40 were tested in VR using the same motion controllers that would be used in the main experiment.

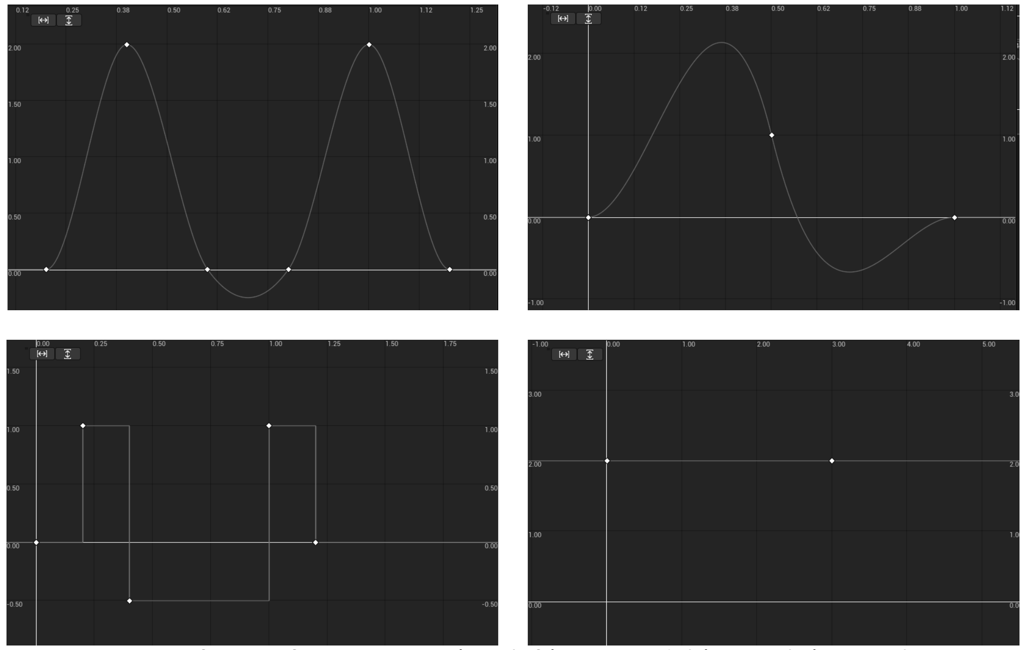


Figure 32. Waveforms of Intermittent (top left), Sinusoidal (top right), Heartbeat (Bottom left) and Constant (Bottom right) haptic feedback patterns

In this pre-study participants were asked to place their virtual hands into a red orb which would activate the vibrations (Figure 33).

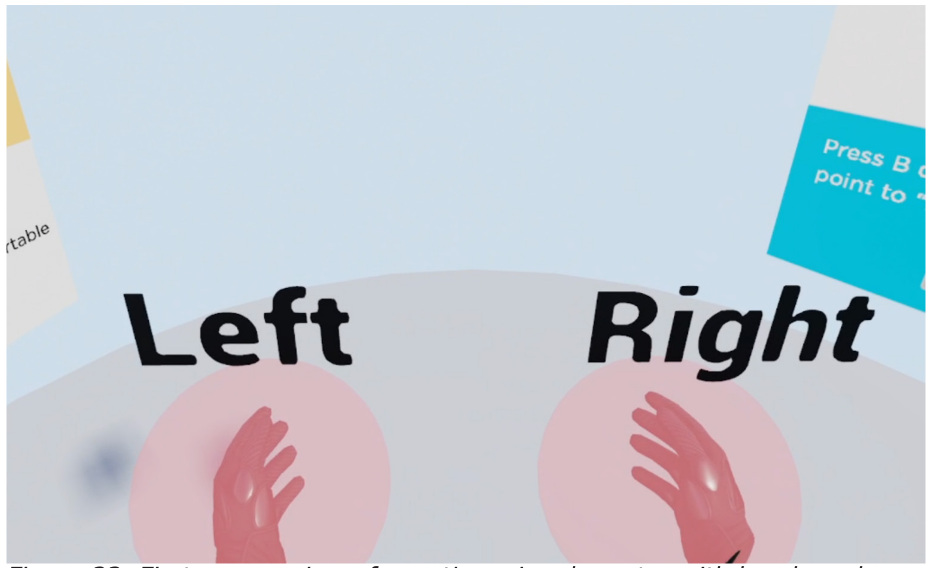


Figure 33. First person view of questionnaire character with hand meshes

Two charts displayed the questions on the perceived comfort and intensity level that participants had to answer (Figure 34). These factors were rated using a 7 point Likert scale and the answers were recorded.

Figure 34. Intructions displayed to participants during Task 1 (left) and (Task 2)

RESULTS OF PRE-STUDY

Variation		Results	
Type	Intensity	Perceived Intensity	Perceived Comfort
Intermittent	10	3.2	4.4
Intermittent	20	3.6	4.4
Intermittent	30	4.533	3.866
Intermittent	40	5.266	3.466
Heartbeat	10	1.8	5.2
Heartbeat	20	3.33	4.266
Heartbeat	30	3.466	3.933
Heartbeat	40	4	3.8
Sinusoidal	10	3.466	5.133
Sinusoidal	20	4.266	4.4
Sinusoidal	30	5.4	3.866
Sinusoidal	40	4.266	3.6
Constant	10	3.866	4.2
Constant	20	5.33	3.2
Constant	30	6.6	2.4
Constant	40	6.73	2.266

Table 1. Results of pre-study conducted for selection of haptic feedback

In this pre-study a total of 15 participants tested 16 variations. Session lasted for an average of 10 minutes per participant. The preference of pattern was very subjective to each participant whereas high intensity vibrations (30,40) had very low comfort rating. The highest comfort rating was given to the heartbeat and sinusoidal patterns at intensity 10. However, the intensity level was very low to be noticed by some participants. From Table 1, for the variation (Sinusoidal, 20) that had sinusoidal pattern at intensity 20, provided a balanced level of intensity while still being comfortable. Participants (P10 and P13) also expressed that the sensations were pleasant even when the pattern was not synchronized between the two hands. Therefore, the combination of sinusoidal vibration pattern at the intensity level of 20 was chosen to be implemented for the main experiment. The full datasheet of this study is provided in appendix B.

Chapter 4 Experiment

This chapter introduces the research approach that was adopted for the study in Section 4.1. The research questions, study design and main hypothesis are highlighted in this section. Section 4.2 describes the protocol and flow of the experiment. The measures that are taken during the experiment are listed in Section 4.3. The chapter ends with a summary of participants recruited, setup and procedure the experiment.

4.1 RESEARCH APPROACH

The approach that was adopted to conduct this research was built on the insights that was gathered from the related work that was described in Section 2.1. These insights were used to frame the research questions and study design that will guide the protocol of the experimental study. The measures and constraints have been defined with respect to the considerations made in previous experiments that studied the co-embodiment method.

4.1.1 RESEARCH QUESTION (RQ)

"What is the effect of haptic feedback on sense of agency, co-presence and ownership between users sharing a virtual hand using weighted average based virtual co-embodiment method?"

SUB QUESTIONS

1. What is the weight distribution required for control of a shared avatar (between leader and follower) to perform a successful motion task?
2. What is the correlation between sense of agency and haptic feedback for follower and leader (W25,W75)?
3. What is the impact of co-embodiment on time to complete the task without haptic feedback versus with haptic feedback?
4. Does the knowledge of sharing the avatar with another person have an impact on the perception of the avatar?

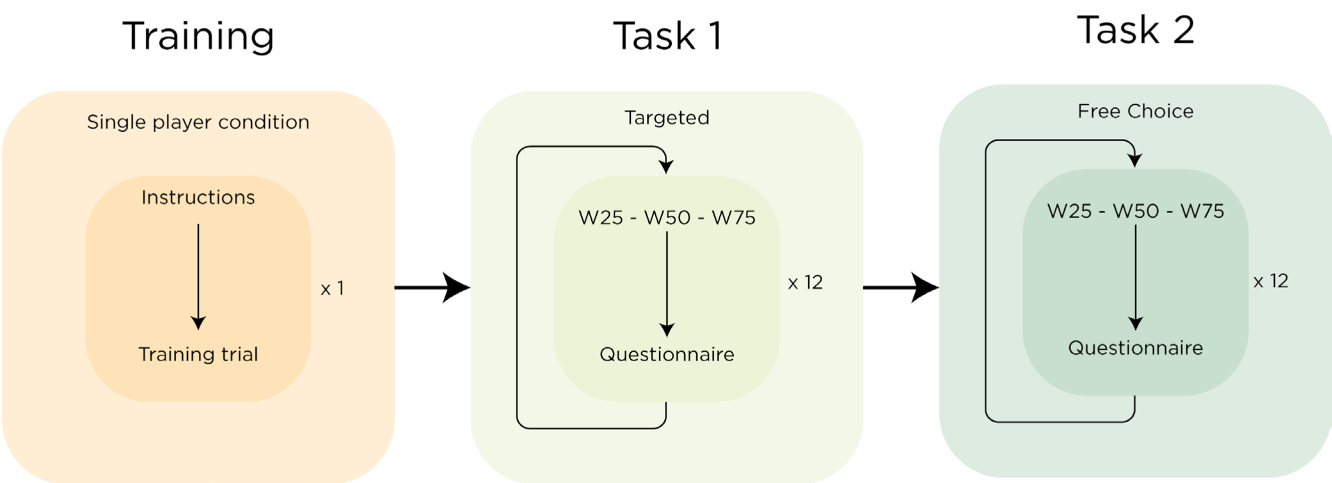


Figure 35. The overall organization of the study

4.1.2 STUDY DESIGN

The experiment was divided into three phases: Training, Task 1 and Task 2 (Figure 35). A within-subject design with repeated measures was adopted for the experiment. There were two independent variables considered: *control* and *haptic* feedback (Figure 36). The *control* variable consisted of three levels: 25, 50, 75% (W25,W50,W75) and *haptic feedback* consisted of two levels: with or without haptic feedback (on overlap conditions). *Control* is allocated to each participant in a pair such that their sum always adds to 100% in each trial (See Figure 37). This variable determined the percentage of participants movement that was reflected in the shared avatar. This design results in overall 6 conditions (*3 control x 2 haptic feedback*) to be tested for each participant. Each condition is repeated twice by the participants for each task, bringing the total to 24 trials for the entire study. This was done to lower participant fatigue and potential motion sickness from long VR sessions. Order of the trials are counterbalanced for all combinations of *control* and *haptic feedback* as starting conditions only for Task 1, subsequent trials are randomized to reduce ordering effects. Task 2 was not accounted for counterbalancing since the training was only designed with respect to the Task 1 interaction.

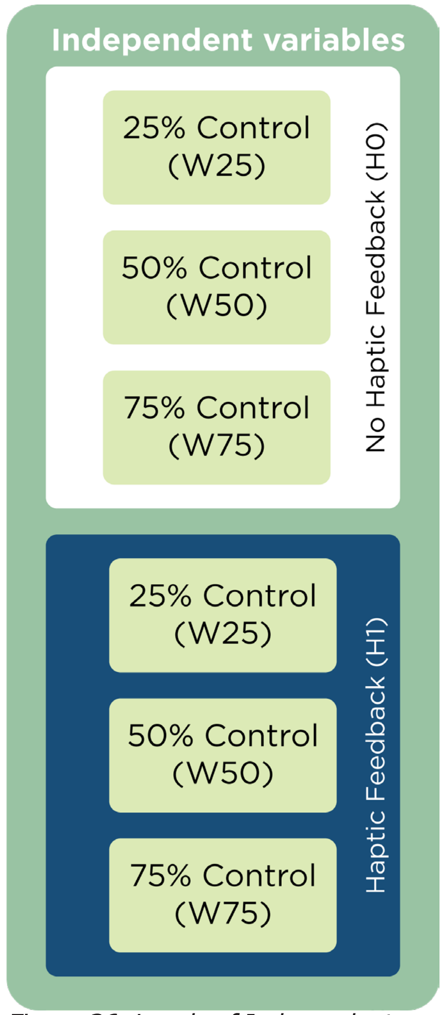


Figure 36. Levels of Independent variables; Control & Haptic feedback

HYPOTHESIS

Based on the study design along with the results from Fribourg et al., (2021); Hagiwara et al., (2019) and Kodama et al., (2022), which showed that sense of agency was stronger when participants had higher control over the shared avatar. The first hypothesis was formulated that;

H1 – *The control weight positively correlates with sense of agency*

In addition, the evidence from the study by Gibbs et al., (2022) clearly indicated that haptic feedback enhanced the users' perception of presence in VR. Therefore, the second hypothesis was formulated that;

H2 – *Sense of agency is greater with haptic feedback conditions compared to conditions without haptic feedback.*

When H2 is supported, the enhanced sense of agency through haptic feedback might lead to better task performance. To test the validity of this, the third hypothesis is formulated that;

H3 – *The task completion time will be lower with haptic feedback conditions compared to conditions without haptic feedback.*

EXPERIMENT FLOW

This flowchart visualizes one full session of the study that is described in Section 4.1.2, the control distribution shows the three combinations that can set between the participant. Each trial level is followed by a feeling of control questionnaire level, and each condition of haptic feedback ends with co-presence and embodiment questionnaire level. This flowchart is meant to complement the description of the sequence of levels of the experiment.

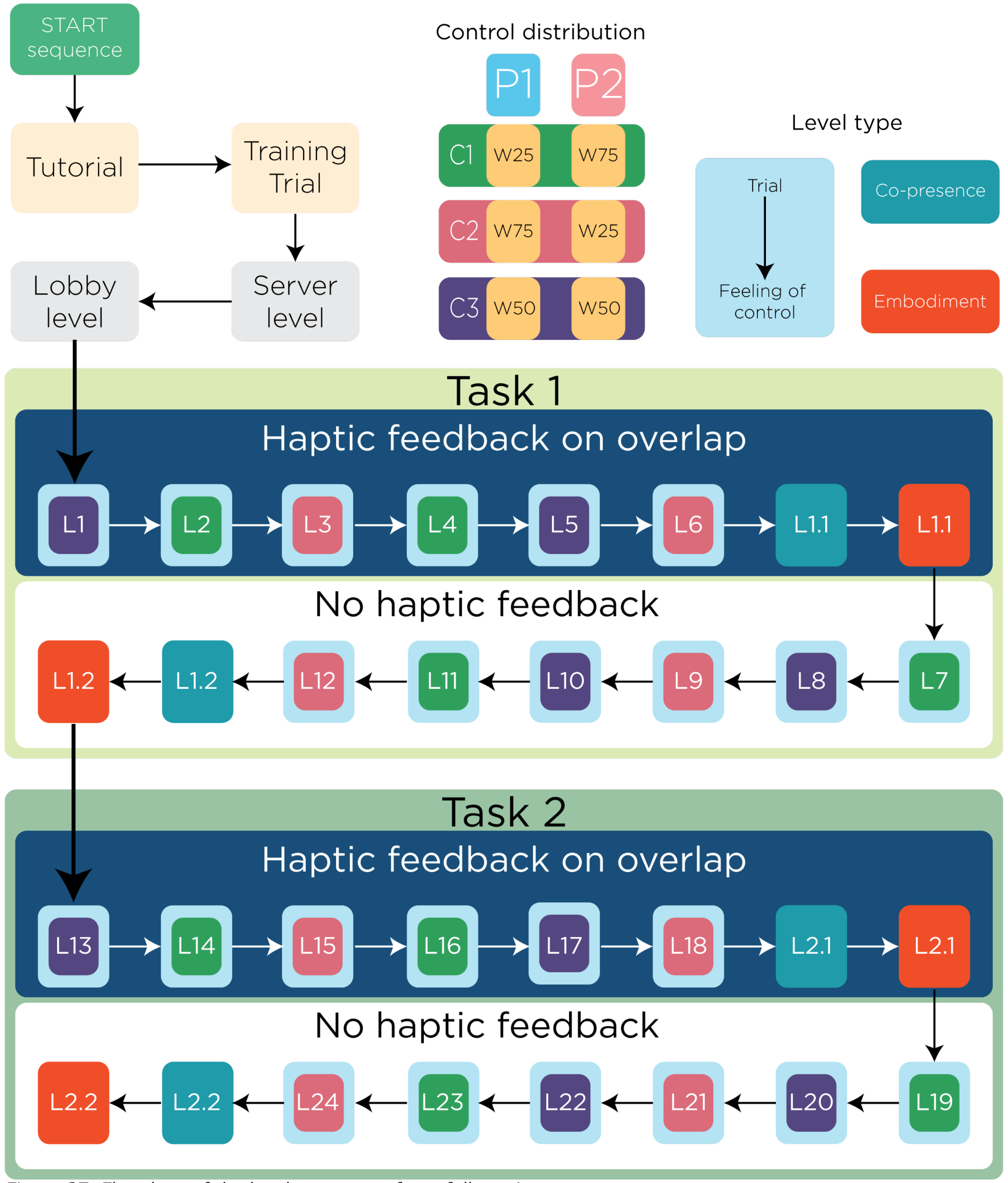


Figure 37. Flowchart of the level sequence of one full session

4.2 EXPERIMENT PROTOCOL

The three main factors that are considered in the RQ is sense of agency, co-presence and ownership (towards virtual hand). To evaluate the impact of haptics on these factors, the experiment involved pairs of participants conducting a simple motion task similar to the previous experiments (Fribourg et al., 2021; Hagiwara et al., 2019). Participants performed these tasks with varying levels of shared control, as well as with and without haptic feedback when the hand positions of the participant pairs overlap. During the experiment participants provide subjective ratings on feelings of control, co-presence and body ownership after each set of trials using questionnaires.

During the interaction participants only used their right hand in a standing position, to avoid making the interaction more complex (Figure 38). Similar to Fribourg et al., (2021), participants were briefed that they would be sharing the avatar during all trials and instructed not to verbally communicate with each other during the session. In order to study the effect of the vibrations with respect to the autonomous interaction process and not as a means of establishing synchronization similar to the approach in the perceptual crossing experiments, participants are not briefed about the functionality of the vibrations.

Figure 38. Pairs of participants performing the motion task using right hand in standing position.

PHASE 0: TRAINING

In the training phase, the basics of using the VR system was explained to each participant, which included how to use the controller buttons to interact with widgets in the scene. After this each participant performed a training trial. This trial only took place once at the start of the session and the participants performed it individually. This trial was the reference (of full control) that can be compared to the control they possessed during the shared interactions.

4.2.1 TASK DESIGN

Intention towards performing the action has an impact on participants' sense of agency (Fribourg et al., 2021). Therefore, to assess this impact through choices in actions, two types of reaching tasks were implemented in the experiment: Targeted and Free. The contrast between the two tasks will also provide insights into the different strategies that participants adopted during the co-embodied interaction.

TASK 1 (TARGETED)

In task 1, the participants had to move the shared right hand to touch a cube that spawned in front of the participants field of view (Figure 39) . Once the shared hand collides with the cube, the cube would get destroyed and after a second delay another cube is spawned at a (partially) randomized location. The spawn location of the cube was constrained with defined limits within the space in front of the participants position. The delay provided a small reset time for the participants, this was intended to avoid continuous movement that can lead to arm fatigue. A sound also originated from the spawn location of the cube, to indicate to the participant of the location of the new cube. The cube is spawned for a total of 17 times for each trial, making the average interaction time for each trail to last around one minute.

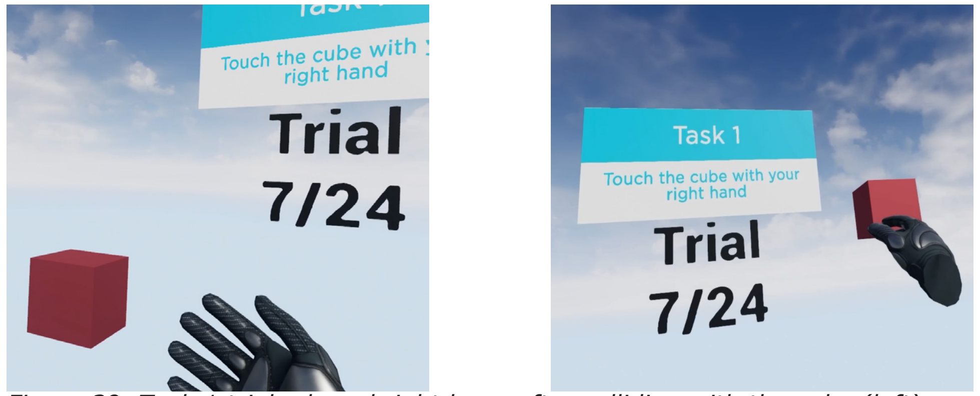


Figure 39. Task 1 trial; shared right hang after colliding with the cube (left) respawns at a another location

TASK 2 (FREE)

In task 2, five cubes are spawned in front of the participants, who have to move the shared hand to touch any one of them (Figure 40) . In this case, when the shared hand collided with any one of the cubes, all the cubes would get destroyed and after a second delay all the cubes would respawn back in the same positions. Since the participants are free to select any cube, there is a possibility that both the participants will not choose the same target. In this way, this task simulated a more realistic scenario where participants will have different targets during shared embodiment.

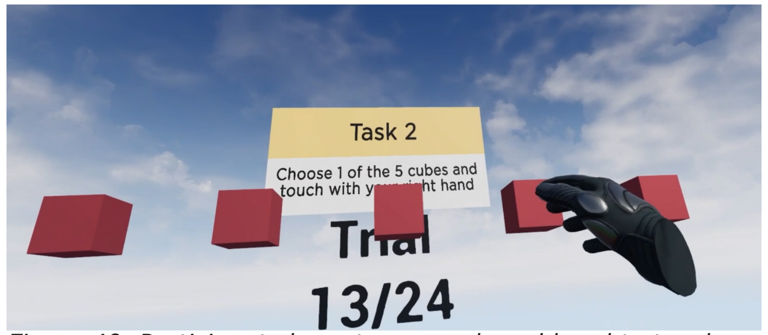


Figure 40. Participants have to move shared hand to touch one of the five cubes in Task 2

4.3 MEASURES

OBJECTIVE MEASURES

The rotation (Roll, Pitch, and Yaw) and position (X, Y, Z co-ordinates) of the HMD and motion controllers of both participants are recorded at a sample rate 70 Hz during the entire session. Additionally the system records the start and end time of each trial as well as duration of overlap of the participants' right hands.

SUBJECTIVE MEASURES

Participants filled in the Simulator Sickness Questionnaire(SSQ) (Kennedy et al., 1993) before and after the experiment. Participants also fill in the Igroup presence questionnaire (IPQ) after the experiment is finished. Both SSQ and IPQ are filled on paper by the participants.

Participants wear an Oculus Quest 2 VR headset during all the main phases of the experiment (Training, Task 1, Task 2). To understand the participants' feeling of control over the shared avatar, participants provided a rating between 1 and 7 for the question "*How much do you feel in control*" at the end of each trial. This will be the subjective measure of their perceived feeling of control over the shared avatar during that trial. After each block of haptic feedback condition participants would answer three questions about their "Sense of co-presence" and three questions about their "Sense of embodiment" taken from standard questionnaires of co-presence (Pimentel & Vinkers, 2021) and avatar embodiment (Peck & Gonzalez-Franco, 2021). Using all the questions from these questionnaires would be the ideal method of measurement. However, only three questions were selected based on the relevance to the study design to reduce workload of the participants and the total time of the session.

CO-PRESENCE QUESTIONNAIRE

Q1- *"I felt that I was in the presence of the other person"*

Q2- *"I felt that the other person and I were together in the same space"*

Q3- *"I felt that the other person responded to shifts in my movement (e.g posture, position)"*

EMBODIMENT QUESTIONNAIRE

Q1 - *"I felt as if my (real) hands were drifting toward the virtual hands or as if the virtual hands were drifting toward my (real) hands"*

Q2 - *"I felt as if the movements of the virtual hands were influencing my own movements"*

Q3 - *"At some point it felt as if my real hands was starting to take on the posture or shape of the virtual hands that I saw"*

SEMI STRUCTURED INTERVIEW

After the VR experiment was finished and participants filled out a post experiment SSQ, a semi structured interview was conducted to record insights and feedback about the experience from both participants together. The full interview guide is provided in the appendix C.

4.4 EXPERIMENT SUMMARY

4.4.1 PARTICIPANTS

Power analysis showed that, for 24 measurements taken during each session the required sample size is 20. Therefore 20 pairs (40 individuals) were recruited to conduct the experiment. As there were no specific requirements for participants, recruitment was carried out through multiple social media platforms (Whatsapp groups, Instagram), and posters (Figure 41) were placed around the TU Delft campus. Two people could sign up for a single session and were invited to the experiment location. The first 10 of the experiments were conducted in the VR Zone located in the TU Delft library, and the second 10 were conducted in a studio at the Faculty of Industrial Design Engineering.

Figure 41. Posters shared for participant reqruitment

DEMOGRAPHICS

Participants' age ranged from 20 to 35 years (mean age: 25.95) (Figure 42), 23 were female, and 19 were male. 15 participants reported no prior experience; 17 participants reported being novice users (having used VR at least once), and 8 participants reported occasional use of VR. From the 20 pairs, 3 pairs were couples, 12 pairs were friends and 5 pairs did not know each other.

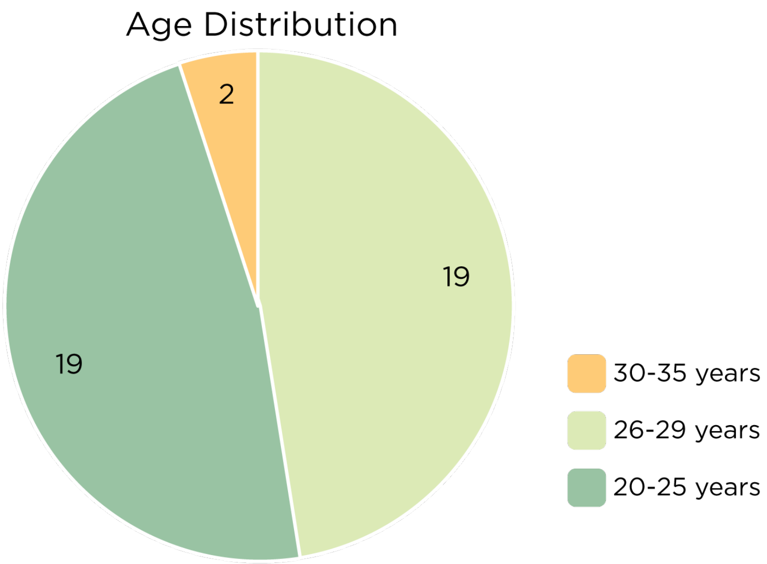


Figure 42. Age distribution of participants in the experiment

4.4.2 SETUP

At the experiment location, a table was placed where both the participants would fill the informed consent, SSQ, and IPQ. Two computers were placed side by side on a separate table and were connected to HMDs. One participant was randomly assigned to the computer acting as Player 1, and the other to the computer acting as Player 2. A video camera was also placed in a location to record both participants' motion while they performed the experiment. The position in which both participants would stand was marked on the floor. The setup at both locations are shown in Figure 43.

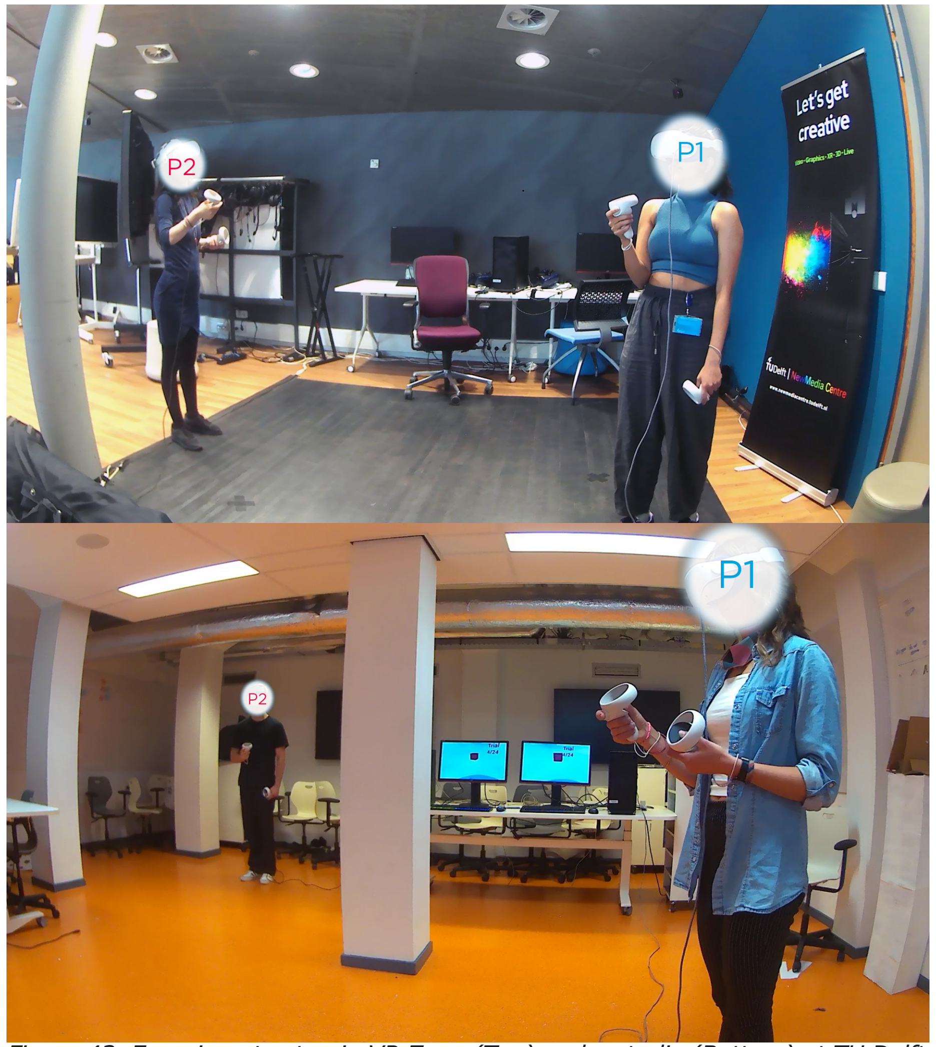


Figure 43. Experiment setup in VR Zone (Top) and a studio (Bottom) at TU Delft

4.4.3 PROCEDURE

Upon Arrival, participants were asked to read and sign the informed consent form and fill in a pre-experiment SSQ. They were informed about the relationship of the shared avatar movement with respect to their own movements and were instructed to not talk to each other during the experiment. Each participant performs 25 trials (including repetitions), and answers questions 32 times (24 Feeling of control + 4 Co-presence + 4 Embodiment) in total during the experiment. At the end of the experiment, participants are again asked to fill in the SSQ along with IPQ as well. Finally, a semi-structured interview was conducted with both the participants together, which lasted around 15 minutes. The sessions lasted for an average of 60 minutes, while the VR experiment itself took approximately 25 minutes. Each participant was also compensated with a 10 Euro gift voucher for taking part in the experiment. After each session the data recorded on both the computers were then saved on an external hard disk.

Chapter 5 Results

In order to comprehensively analyze the collected data a mixed method approach was employed. The results of this analysis is provided in this chapter. Section 5.1 provides detailed quantitative results of the statistical analysis tests that was conducted on participants' responses on the feelings of control, co-presence and embodiment. Subsequently, Section 5.2 delves into the qualitiative analysis of the post-experiment interviews, along with images that capture specific aspects of the experiment.

ANALYSIS

A mixed methods approach was adopted for analysis, which means the results of the quantitative analysis is interpreted along with the qualitative analysis to explain the phenomena observed. The qualitative data was processed and statistical analysis (Section 5.1) was conducted using the software "R". Qualitative insights were extracted from the recorded transcripts of the semi structured interviews followed by thematic analysis to identify relevant recurring themes in all 20 sessions. Pairs are labeled as P1 – P20 (Player – '1' or Player – '2'; indicating the two participants), for example, [P4-2] means Pair number 4; Player 2.

5.1 QUANTITATIVE RESULTS

The combined effects of task, control and haptic feedback on participants subjective ratings of perceived feeling of control, co-presence and embodiment was analyzed by fitting a full mixed-effects model for each dataset. First the normality of the data was tested using the Shapiro-Wilk test. Results (Table 2) showed that the data distribution significantly deviated from normality ($p < 0.05$). Therefore aligned rank transforms were applied to the data before fitting it to the model (Wobbrock et al., 2011). Holm-Bonferroni correction was applied to the datasets and contrast tests are conducted using ART-C (Elkin et al., 2021). Analysis of variance table for all response variables are provided in Table 3.

Response Variable	Task	W	*p*
Feeling of control	1	0.94	<0.000
	2	0.94	<0.000
Co-presence 1	1	0.91	<0.000
	2	0.85	<0.000
Co-presence 2	1	0.92	<0.000
	2	0.91	<0.000
Co-presence 3	1	0.93	<0.000
	2	0.90	<0.000
Embodiment 1	1	0.91	<0.000
	2	0.88	<0.000
Embodiment 2	1	0.90	<0.000
	2	0.83	<0.000
Embodiment 3	1	0.94	<0.002
	2	0.94	<0.002

Table 2. Results of Shaprio-Wilk normality tests

Response Variable	Factor	*F*	*df*	*p*	η_p^2
Feeling of control	**Task**	172.02	1	<.000***	0.16
	Haptics	12.93	1	<.000***	0.01
	Control	0.24	2	0.78	0.00
	Task x Haptics	13.61	1	<.000***	0.01
	Task x Control	0.30	2	0.74	0.00
	Haptics x Control	0.52	2	0.59	0.00
	Task x Haptics x Control	0.05	2	0.95	0.00
Co-presence 1	**Task**	26.35	1	<.000***	0.18
	Haptics	0.24	1	0.62	0.00
	Task x Haptics	0.80	1	0.37	0.01
Co-presence 2	**Task**	34.38	1	<.000***	0.23
	Haptics	0.03	1	0.86	0.00
	Task x Haptics	2.31	1	0.13	0.02
Co-presence 3	**Task**	28.28	1	<.000***	0.19
	Haptics	1.24	1	0.27	0.01
	Task x Haptics	0.51	1	0.48	0.00
Embodiment 1	**Task**	1.72	1	0.19	0.01
	Haptics	1.42	1	0.24	0.01
	Task x Haptics	0.22	1	0.64	0.00
Embodiment 2	**Task**	10.38	1	<.001**	0.08
	Haptics	1.00	1	0.32	0.01
	Task x Haptics	1.31	1	0.26	0.01
Embodiment 3	**Task**	0.99	1	0.32	0.01
	Haptics	0.01	1	0.94	0.00
	Task x Haptics	0.09	1	0.77	0.00

Table 3. Analysis of variance on the full mixed-effects model for feeling of control, co-presence, and embodiment using Aligned Rank Transformed data

5.1.1 FEELING OF CONTROL

The analysis of the feeling of control ratings has been visualized in the box plots in Figure 44, where lines with asterisks indicate pairwise (Bonferroni corrected) significance. From Table 3 (Feeling of control) a full mixed-effects model showed significance for Task ($p < 0.000$) and Haptics ($p < 0.000$). Significant interaction effects were also found between Task and Haptics ($p < 0.000$). Contrast test for the main effect of Task revealed that responses were significantly higher in Task 1 compared to Task 2. Moreover, contrast test for Haptics revealed that participants' feeling of control were significantly greater in conditions without haptic feedback when compared to conditions with haptic feedback. Contrast test on the interaction effects between Task and Haptics showed significant difference to all levels ($p < 0.000$) except Task 1, without haptics condition and Task 1, with haptics condition ($p = 0.219$) significant interactions effects between Task and Haptics. Full contrasts tests table is provided in appendix D.

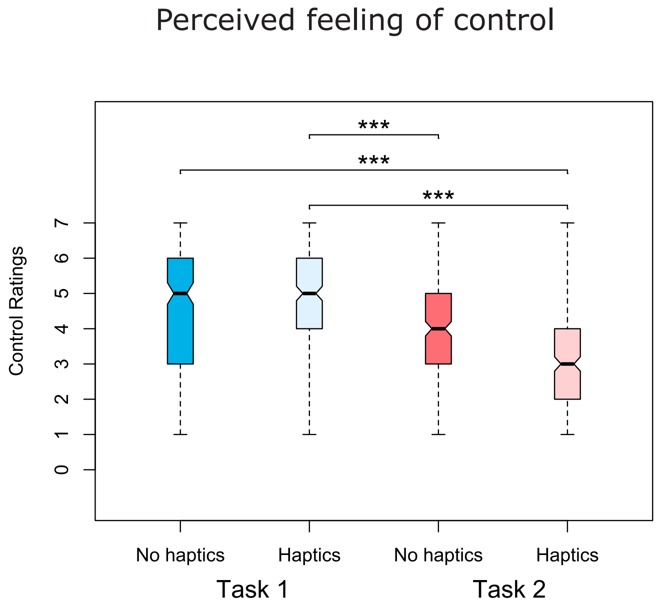


Figure 44. Perceived feelings of control corresponding to haptic feedback in Task 1 and Task 2

The comparison of the reported feeling of control with respect to the actual control that participants had over the shared avatar is shown as box plots in Figure 45. Participants tended to overestimate and rate higher feelings of control when they had only 25% control (median = 5, mean rating = 4.468, SD = 1.400) and 50% control (median = 5, mean rating = 4.487, SD = 1.453) in Task 1. However, in the case of 75% control (median = 4, mean rating = 4.481, SD = 1.466), participants felt lower than actual level of control over the shared avatar.

Contrasting results are observed for Task 2, where ratings were for conditions of 25% control (median = 3, mean rating = 3.393, SD = 1.419) and 50% (median = 4, mean rating = 3.45, SD = 1.444) control was most accurate compared to the actual percentage of control. Notably, in the case of 75% control (median = 3.5, mean rating = 3.425, SD = 1.502), participants rated very low feelings of control in Task 2.

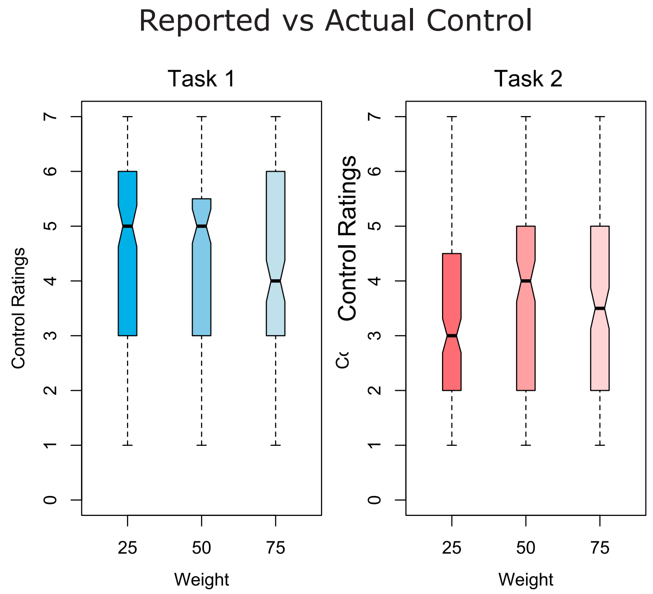


Figure 45 . Reported feelings of control corresponding to control weight

5.1.2 CO-PRESENCE

The analysis of the participant ratings of the co-presence questionnaire is visualized using box plots in Figure 46, where lines with asterisks indicating pairwise (Bonferroni corrected) significance. From Table 3 (Co-presence 1; Co-presence 2; Co-presence 3) a full mixed-effects model showed significance only for Task ($p < 0.000$) for all three responses. No significant interaction effects was found. Contrasts test showed that co-presence ratings were significantly higher in Task 2 compared to Task 1 for Co-presence 1, Co-presence 2, and Co-presence 3.

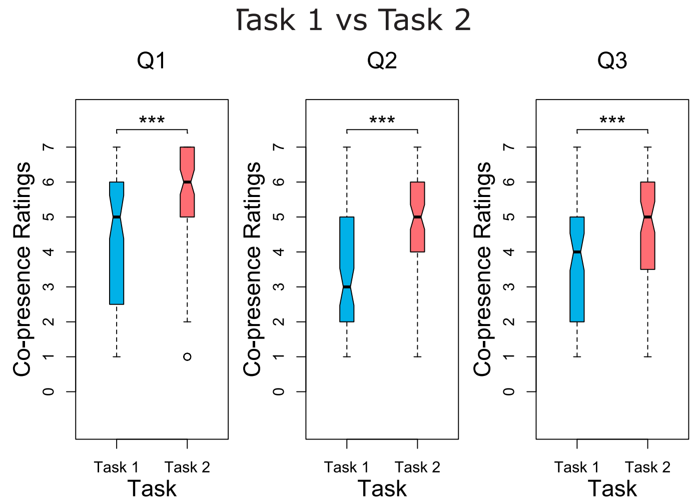


Figure 46. Perceived co-presence ratings in Task 1 and Task 2

There is no difference observed between medians of haptic conditions (median = 5, mean rating = 4.837, SD = 1.878) and non-haptic conditions (median = 5, mean rating = 4.812, SD = 1.929) for question 1. The median ratings for question 2, haptic conditions (median = 4, mean rating = 4.15, SD = 1.949) and non-haptic conditions (median = 4, mean rating = 4.1, SD = 1.959) also show no significant difference. However, for question 3, haptic conditions (median = 4, mean rating = 4.087, SD = 1.863) were rated lower than non-haptic conditions (median = 5, mean rating = 4.387, SD = 1.858). These results reveal that participants experienced a lower sense of co-presence in the haptic conditions during the experiment. Nevertheless, these effects are not significant.

The internal consistency of the dataset, consisting of three items of Co-presence, was assessed using Cronbach's alpha. The analysis was conducted on a sample of 160 units. The resulting Cronbach's alpha value was found to be 0.869, indicating high level of internal consistency.

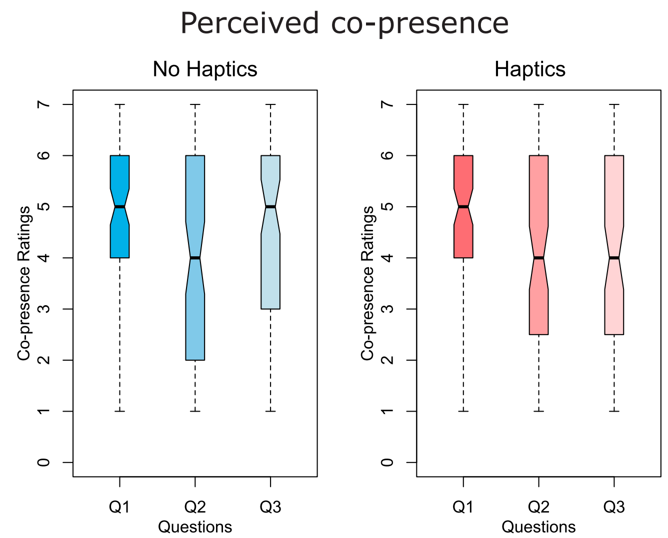


Figure 47. Perceived co-presence corresponding to haptic feedback conditions

5.1.3 EMBODIMENT (OWNERSHIP)

The analysis of the participant ratings of the embodiment questionnaire is visualized using box plots in Figure 48, where lines with asterisks indicating pairwise (Bonferroni corrected) significance. From Table 3 (Embodiment 1; Embodiment 2; Embodiment 3) a full mixed-effects model showed significance only for Task ($p < 0.001$) for Embodiment 2 responses. No significant interaction effects was found. Contrasts test showed that Embodiment 2 ratings were significantly higher in Task 2 compared to Task 1.

For Question 1, no difference is observed between ratings in haptic conditions (median = 5, mean rating = 5, SD = 1.272) and non-haptic conditions (median = 5, mean rating = 5.212, SD = 1.299) . Similarly, for question 2, no difference is observed between haptic conditions (median = 6, mean rating = 5.3, SD = 1.296) and non-haptic conditions (median = 6, mean rating = 5.4, SD = 1.506). A small difference was observed for Question 3 ratings, where haptic conditions (median = 4, mean rating = 4.312, SD = 1.454) were lower than non-haptic conditions (median = 4.5, mean rating = 4.337, SD = 1.542). Similar to the co-presence effect, participants experienced diminished sense of ownership with respect to the virtual hand in haptic conditions during the experiment, but this effect is not significant.

The internal consistency of the dataset, consisting of three items of Embodiment, was assessed using Cronbach's alpha. The analysis was conducted on a sample of 160 units. The resulting Cronbach's alpha value was found to be 0.58, indicating moderate level of internal consistency.

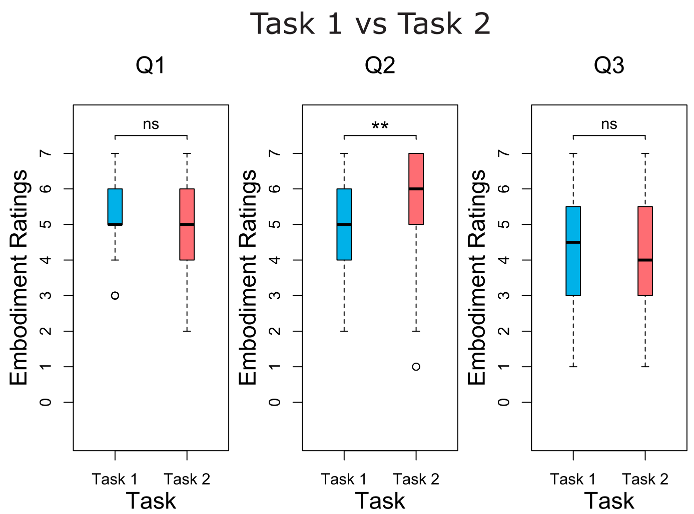


Figure 48. Perceived embodiment ratings in Task 1 and Task 2

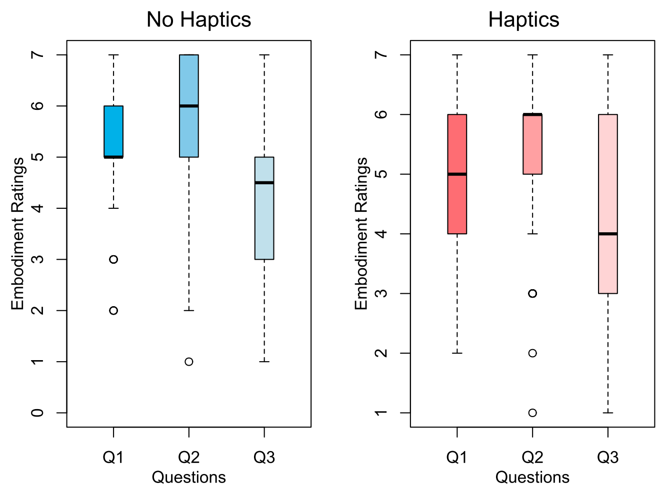


Figure 49. Perceived embodiment corresponding to haptic feedback conditions

5.1.4 COMPLETION TIME

The analysis of the duration of each condition is shown in table 4. The mean time taken during Task 1 is less than the time taken by participants when they performed the training trial individually. The results also show that completion time was lower when participants performed the task with haptic feedback compared to conditions without haptic feedback during Task 1. However, in Task 2, the completion time was lower in conditions without haptic feedback compared to conditions with haptic feedback during Task 2. The standard deviation observed in these values is high; this is due to the fact that participants were not told that completion time was important. Therefore, these results have to be interpreted carefully with respect to the impact of haptics on the task performance of the participants.

Experimental Condition	Mean completion time (in sec)	Standard Deviation
Training Trail	36.07	6.78
Overall Task 1	34.98	5.75
Task 1, 50% control without haptics	35.62	5.82
Task 1, 50% control with haptics	35.30	6.01
Task 1, 25%-75% control without haptics	34.81	5.58
Task 1, 25%-75% control with haptics	34.67	4.68
Task 2, 50% control without haptics	17.57	9.15
Task 2, 50% control with haptics	20.52	9.68
Task 2, 25%-75% control without haptics	17.21	7.56
Task 2, 25%-75% control with haptics	18.32	9.15

Table 4. Task completion time during for combinations of control and haptics

5.1.5 IPQ PRESENCE RATINGS

Table 5 shows the results with respect to each presence factor within IPQ. The IPQ had a 7-point Likert scale, ranging from -3 to 3, however this was transformed to a scale of 1 to 7 during analysis. This reveals that participants experienced high level of involvement (mean = 5.075) and spatial presence (4.29), but felt only average levels of general presence and realism.

Sub-components	Mean	SD
G = Sense of being there	3.52	1.78
SP = Spatial Presence	4.29	1.74
INV = Involvement	5.07	1.49
REAL = Experience realism	3.52	1.92

Table 5. IPQ results

5.1.6 MOTION SICKNESS IN VR

Participants' reported motion sickness was measured before and after the experiment. A Wilcoxon signed-rank test was conducted since the data did not have normal distribution. The result showed significant difference between the pre-study (Median = 1.125, IQR = 0.31) and post-study (Median = 1.281, IQR = 0.39) scores ($Z = -4.03$, $p < 0.01$, $r = -0.63$) indicating that participants did experience motion sickness during the experiment.

5.2 QUALITATIVE RESULTS

5.2.1 PERCEPTION OF SHARED MOTION

Although clear instructions were provided to both the participants at the start of the experiment, only half of the participants (21) were consciously aware that the motion of the avatar was shared between them and their partner during Task 1. The rest expressed that it only became evident to them during Task 2, when differences in choices emerged between them and their partners. Participants noted that even though they were briefed about the shared motion of the avatar, the level immersion during task performance was such that they did not realize that the interaction was being performed simultaneously by both participants. They attributed the restrictions in movement to 'glitches' or 'delays', which they believed could have been caused by the VR application. For instance, [P8-1] mentioned, 'In the beginning It felt like the hand was not working well', and [P16-2] remarked 'I saw this (movement), and I thought it was an algorithm'.

Figure 50. Participants (right) assessing their control through opposite movements during Task 1

Participants who were aware of the motion sharing employed various strategies to try and gauge the extent of control they had during each trial. For instance, [P3-2] mentioned, 'From the start I was aware that someone else was moving the hands,. I was trying to check control by doing the opposite movement'. Similar behavior was also observed during task 2. [P11-1] expressed, 'I experimented a lot in the second task to understand what the other person is thinking and choosing'.

5.2.2 TRADE-OFFS IN CO-EMBODIMENT

Participants also associated their experience while performing Task 1 to be more comfortable than during Task 2. For instance, [P10-2] stated 'I didnt feel much in the beginning but in the second task with the choice it felt horrible'. [P15-2] mentioned 'I thought that I'm not controlling and somebody's here to control the hands, and it made me a bit angry'. Instances like these indicate that participants felt more at ease with sharing the motion when a common target was presented compared to multiple choices. Since participants weren't allowed to verbally communicate, they did not openly express these emotions to the other participants. They indicated that they would have liked to communicate to their partners during Task 2 in order to co-ordinate their motion more effectively. Nevertheless, participants also noted that Task 1 got repetitive sooner compared to Task 2 and that the engagement level was higher during Task 2.

5.2.3 MOTION SYNCHRONIZATION

There was a high level of motion synchronization observed during Task 1. In the video captured during one of the sessions, both participants started the experiment with a distinct hand motions, which continued for the first two trials. In the third trial, one participant started with the same motion as before but begins mimicking the hand motion of the other participant. Subsequently, both participants exhibited the same hand motion for the rest of the trials. This synchronization was observed during other sessions as well (Figure 51).

Similar observations were made by the participants who referred to these synchronizations as 'rhythms' or 'flows'. For example, [P1-1] mentioned 'After a few rounds it felt like we were getting into this rhythm', and [P2-2] stated 'I started with arc motion and (Player 1) was doing a different motion, then (Player 1) started moving with arc motion'. Several participants also expressed that they were able to synchronize their motion with their partners using the audio cue that was provided when the cubes would spawn.

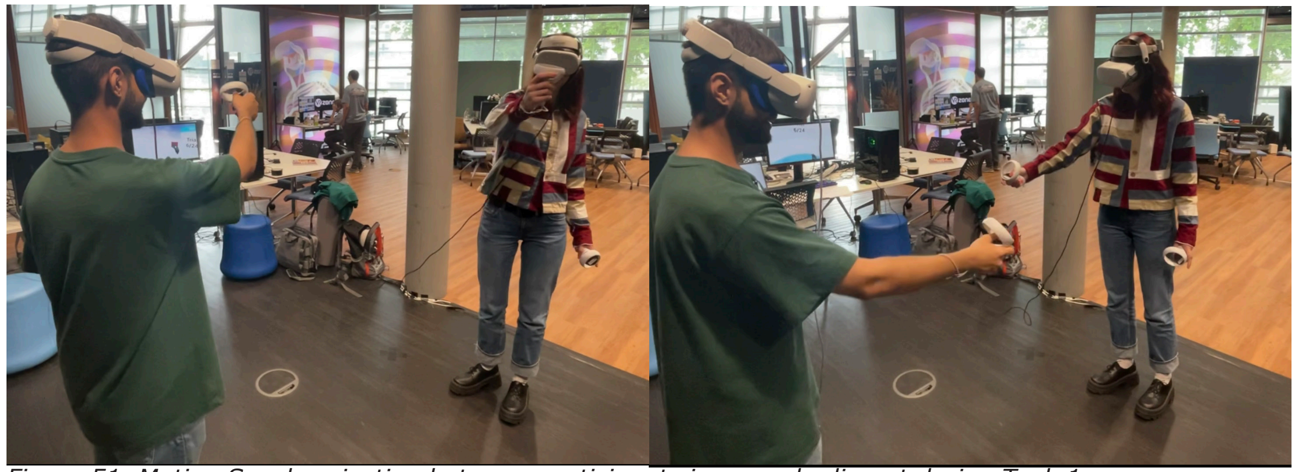


Figure 51. Motion Synchronization between participants in co-embodiment during Task 1

5.2.4 PERCEPTION OF VIBRATION PATTERNS AND ASSOCIATIONS

Most participants inferred negative associations with the haptic feedback during the study, based on their prior experience with vibratory feedback patterns. For example, comments such as 'I thought maybe I was wrong that's why the vibrations are coming to push me in another direction' [P6-2] and 'It felt very random, like it was malfunctioning' [P7-2] indicate negative association. However, some participants also had positive associations, mainly focused around video games such as 'I play the Nintendo switch and if you win in the game it will have vibration' [P18-2] and 'I connect those vibrations with Mario cart and you get them when you get off track' [P10-2]. Interestingly, only 4 participants understood during the experiment that haptic feedback would occur when their hands overlapped with their partner.

When the design of the haptic feedback mechanism was clarified to the participants, they expressed that they would use this in order to better coordinate their actions with their partners. They explained how they would use this condition to achieve synchronization with their partner if the goal of task would require mutual coordination.

Figure 52. Negative association of vibrations with smartphones (left) and positive with video games (right)

5.2.5 ROLES AND INTERACTION DYNAMICS

While performing the experiment participants naturally assumed leader and follower roles. Some participants said they were actively following their partners' movements, aiming to co-ordinate their actions better. For instance, [P11-1] stated 'During second task it felt like I had no control, So I thought I will follow whatever pattern in movement the other person was doing'.

These roles were adopted spontaneously by participants based on the perceived level of control during the trials and their desire to synchronize with their partners. Additionally, some participants noted that the relationship with their partners also influenced the degree of co-operation they were inclined to achieve, for example pairs that knew each other [P7] mentioned that they would be more attentive to the other persons movement if it was with an unfamiliar person.

Since participants were not instructed to complete the trail as fast as possible. They explored various strategies to ascertain if they could exert more control over their joint actions. For example, [P14-1] remarked 'If the other person wants to touch a different one (cube), and I don't want to, I can sort of limit other persons' actions and actually feel more in control.' This adaptive behavior underscores participants' dynamic strategies in response to their perceived control, their partners' movements, and their inter-personal dynamics.

5.2.6 ADAPTIVE STRATEGIES OF MOVEMENT

During the trials, when participants felt a diminished sense of control or when their partners' movements were not well coordinated, they always employed a strategy of reaching out more in the direction they desired the hand to move in. This strategy became more prevalent during the trials of task 2. By doing so, participants aimed to compensate for their partner's movement or their own perceived lack of control, effectively imposing their preferred choices on their partner's actions. For instance, [P8-1] remarked, 'When I moved my hand I noticed the hand didn't move that much, so to compensate for it I had to reach out more'

Figure 53. Participants extending their arms to gain more control over the shared hand during Task 2

This was particularly evident when there was a substantial difference in height between the pairs of participants. This led to an imbalance of control due to the taller participants' extended reach. Consequently, frustration increased for the other participant, and they expressed that it led to feelings of low control during the task. Therefore the interplay of control, co-ordination, and physical attributes also played a significant role in shaping the strategies the participants used and the experiences they had during the trials.

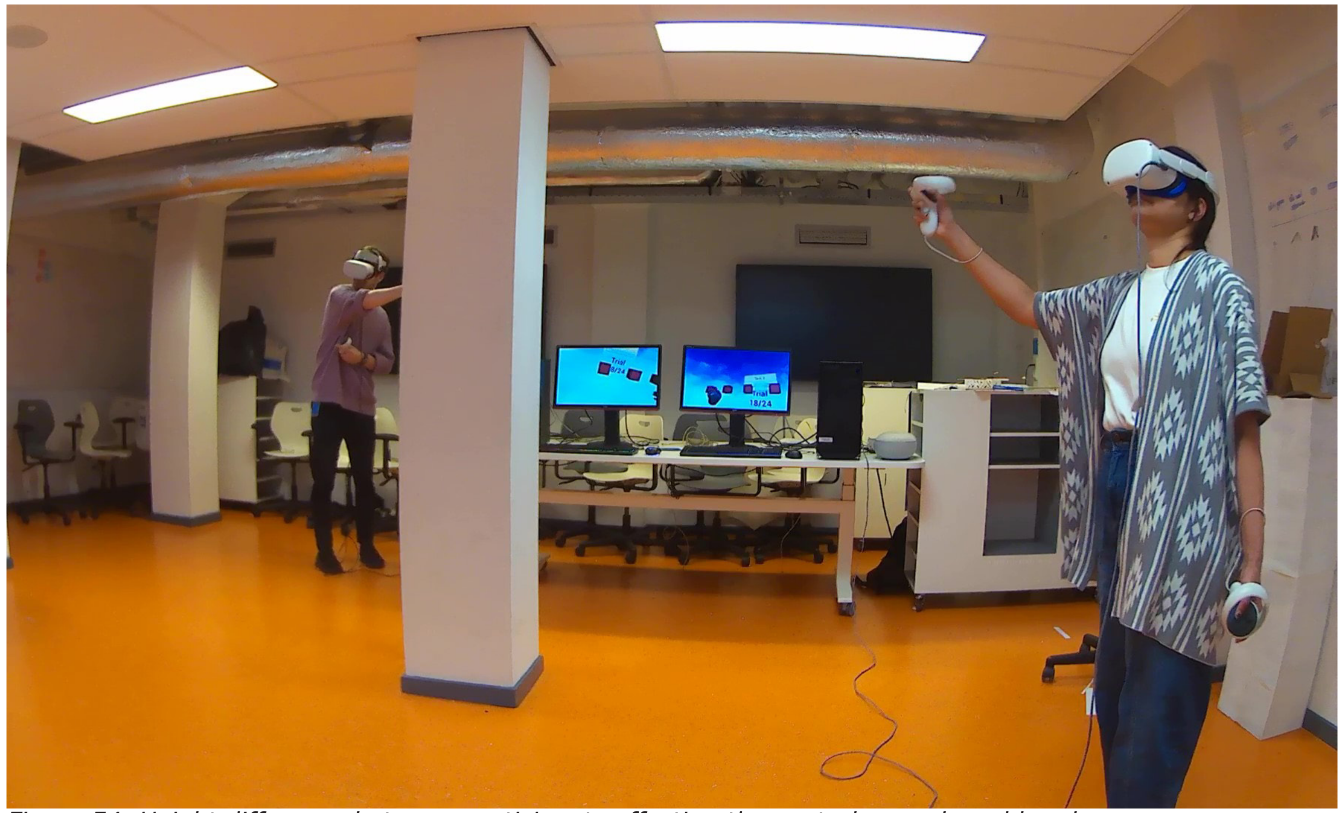


Figure 54. Height difference between participants affecting the control over shared hand

5.2.7 RESIDUAL IMPACT OF SHARED MOTION

Some participants also reported feeling disconnected from their hand movements after completing the experiment. Attempting similar movements to those performed during the trials resulted in an abnormal sensation. For instance, Participant 1 explained, 'It became disorienting, like you weren't fully in control of your hand, now it still looks weird when I see my hand moving away'. Participant 30 also stated, 'It took me a while to readjust because I feel like my hands were still not like my hands. I felt like movement of my hands was recalibrated according to the virtual hands'.

The degree and duration of this phenomenon's impact on the motor function remain unclear. However, the exposure to this type of motion over an extended period of time could potentially lead to latent effects, as observed in this experiment.

Chapter 6 Discussion

This chapter discusses the implications of the results from the experiment. In Section 6.1, results from the quantitative and qualitative analysis are compiled into insights, categorized under the following headings:

6.1.1 Reported versus actual control

6.1.2 Effect of haptic feedback on sense of agency

6.1.3 Effect of haptic feedback on co-presence and embodiment

6.1.4 Task performance

6.1.5 Task 1 versus Task 2

6.1.6 Impact of VR training

The limitations of this study and directions of future work are given in Section 6.2. This chapter ends with the conclusion of this research along with the findings.

6.1 DISCUSSION

This experiment investigates the impact of haptics on the sense of agency, co-presence and ownership (towards virtual hands) when two individuals perform two types of reaching tasks using a shared avatar in VR. The primary objective was to assess how the condition in which participants would receive haptic feedback when their hands overlapped would affect these three factors in scenarios involving common goal and multiple choices.

6.1.1 REPORTED VERSUS ACTUAL CONTROL

The results of the analysis of participants reported feeling of control with respect to actual control indicate that they were not able to accurately differentiate between the varying levels of control during the experiment. Participants sense of agency increased between 25% and 50% control conditions, while a decrease was observed between 50% and 75% conditions. This finding only partially support that control weight positively correlates with sense of agency [H1]. This outcome echoes the findings of Kodama et al., (2023), where a clear differentiation between control conditions was also not found.

6.1.2 EFFECT OF HAPTIC FEEDBACK ON SENSE OF AGENCY

The findings indicate that the presence of haptic feedback condition yielded a significant effect on sense of agency during the experiment. Participants' felt significantly greater sense of agency during conditions without haptic feedback compared to conditions with haptic feedback. It is important to note that this investigation solely examined the impact of haptics within the context of autonomous interaction processes during shared perceptual activities. This finding does not support that sense of agency is greater in haptic feedback conditions compared to conditions without haptic feedback [H2].

The findings also indicate that the vibratory type of haptic feedback was negatively associated during the experiment, likely due to its common use in devices such as smartphones and smartwatches. This could have led to the significant effects that has been observed in this experiment. However, further research is required to validate these findings.

6.1.3 EFFECT OF HAPTIC FEEDBACK ON CO-PRESENCE AND OWNERSHIP

The analysis shows a diminished sense of co-presence and ownership towards the virtual hand in haptic feedback conditions compared to conditions without haptic feedback. Although this finding is not statistically significant. Both the factors were examined only between blocks of haptic feedback conditions and not after every trial like the sense of agency measurement. This coupled with the shorter questionnaires could be the reason for the insignificant effect of haptic feedback observed during the experiment.

6.1.4 TASK PERFORMANCE

The time taken to complete each trial does not sufficiently capture the impact of haptics on task performance. The result shows that participants performance increased during co-embodiment compared to the training phase. However, this can be attributed to the fact that participants needed some time to get used to the experience (which was the purpose of the training phase). Therefore, this analysis does not conclusively support or reject that the task completion time was lower in the haptic feedback conditions compared to no haptic feedback conditions [H3]. As the task lacked the necessary constraints to comprehensively study task performance.

Nevertheless, it is imperative to consider the various strategies that participants employed to gauge how much control they possessed over the shared avatar during trials. Moreover, Participants exhibited leader and follower roles during the experiment, influenced by their perceived level of control over the shared avatar and their intent to reach a specific target. Combined with other strategies such as oversteering or non-compliance during movement, these observations highlight the intricate dynamics of this concept. Experiments of this nature contribute valuable insights toward refining the concept towards user-centric interactions.

6.1.5 TASK 1 VERSUS TASK 2

SENSE OF AGENCY

While participants successfully completed both the tasks under all three control conditions. The results also showed that participants felt significantly greater sense of agency in Task 1 compared to Task 2. Overestimation of control was apparent during Task 1. These findings align with the previous experiment by Fribourg et al., (2021), demonstrating that participants perceive greater sense of agency when the goal is shared compared to situations where participants pursue different goals. While motion synchronization is also observed, the influence of haptic feedback conditions on this synchronization remains unclear, necessitating a more detailed analysis of the collected motion data.

There was also significant interaction effects between the two tasks and haptic feedback conditions that were observed except for Task 1 with and without haptic feedback conditions. Interestingly this analysis reveals that the sense of agency is significantly greater in Task 2 without haptic feedback conditions compared to Task 1 with the haptic feedback conditions. While the sense of agency was generally higher during Task 1, the haptic feedback mechanism was able counter the effect of shared motion intentions.

CO-PRESENCE

Participants felt significantly greater sense of co-presence during Task 2 compared to Task 1, this is also supported by the participants that did not consciously realize that they were sharing the avatar with their partners during Task 1. Participants attention to their partners movement and need to explicitly communicate verbally with their partners during Task 2 also indicates that they were more inclined to consciously co-ordinate, compared to the more autonomous interaction that was observed during Task 1.

OWNERSHIP

Participants felt that the movements of the virtual hands were influencing their movements (Embodiment 2) significantly greater during Task 2 compared to Task 1. This is also supported by instances where participants actively strategized in order to either exert more control over the virtual hand or to follow its movements during Task 2.

6.1.6 IMPACT OF VR TRAINING

Participants also expressed during the interview sessions that they felt peculiar sensations with respect to their hand movements post-VR experience. This effect can be attributed to instances of motor skill learning and long term memory formation that have been investigated in the context of VR based movement training (Juliano et al., 2022).

6.2 LIMITATIONS & FUTURE WORK

While the experiment investigated the effects of haptic feedback on sense of agency, co-presence and ownership towards a virtual hand and provided interesting insights about how participants perceive these different conditions during co-embodiment. There are also limitation of this work that is highlighted along with some recommendations in the following sections.

6.2.1 EXPERIMENTAL CONDITIONS

The experimental conditions were not controlled adequately to also measure the impact of haptic feedback on the task performance of participants leading to inconclusive results. More task specific constraints such as freedom of movement and time limits need to be added. The full questionnaires of co-presence and embodiment were also not implemented in the study and could have contributed to the lack for more concrete results on the respective factors. It would be interesting to also investigate if the control variable could have impacted participants' sense of co-presence and ownership in future experiments. For assessing sense of agency, a simple question that could be understood was used same as Jeunet et al., (2018), instances from the experiment showed that participants sometimes judged the question to be related success in the task rather than actual control over the movements. Therefore other methods of evaluating sense of agency should be considered in future experiments.

To validate the findings that negative association of haptic feedback and its effect on participants sense of agency from this experiment, it is necessary to investigate if the same effect is observed when participants are consciously aware of the conditions triggering the feedback. However, it is advisable to explore alternative types of on-body feedback such as thermal and force feedback to make a clear distinction with vibratory feedback. Since vibrations are very commonly associated with other types of devices that people use.

6.2.2 SYNCHRONY

The anecdotes of mimicry and motion synchronization observed during the experiment are intriguing; the influence of haptic feedback conditions on this synchronization remains unclear, necessitating a more detailed analysis of the collected motion data. This analysis of synchronization could not be completed within the stipulated time of this project. Therefore, this will be taken up as future extensions of this work.

6.2.3 AVATAR REPRESENTATIONS

Another limitation of this work is that a realistic full body avatar representation was not implemented in the experiment. Replicating this experiment with a full body avatar might provide different results with respect to embodiment. The height differences between people and their reach should also take into account while designing the system, methods to generate avatar body characteristics that can adapt to variable heights of participants can be used (Ye et al., 2022), in order to ensure that control is distributed precisely between the participants. This can also be implemented using different levels of avatar representations since previous studies by Fribourg et al., (2020) have shown that realism of the avatar impacts sense of embodiment.

CONCLUSION

This research started with the idea of integrating haptics into the concept of co-embodiment to enhance the sense of embodiment of the user. The methodology applied in this research provides a novel paradigm for implementing feedback mechanisms within embodied interaction between two users. Insights from this work provides a deeper understanding of the dynamics between users during co-embodiment and its impact on the perceptions of their sense of agency, co-presence and ownership (towards a virtual hand).

The results showed that haptic feedback given to participants when their hands overlapped led to diminished sense of agency during co-embodiment. The results showed that shared intention impacted both co-presence and embodiment. The findings also provide insights into the different strategies that participants adopted depending on the perceived control over the shared avatar. While some findings are in line with previous work, through this research, certain challenges of achieving co-embodiment concept were identified and recommendations of possibles extensions of the paradigm are also highlighted.

To conclude, the core design of the system developed for the experiment can facilitate exploration of other directions on co-embodiment, while the project's code can also serve as a template to build co-embodiment applications or games for VR. Thus, opening up possibilities of the further development of the concept of virtual co-embodiment.

Chapter 7 Reflection

This chapter offers a reflection on the lessons and challenges encountered throughout the project, providing actionable recommendations for enhancing the effeciency of the process in Section 7.1. Finally, a perspective into the personal journey of conducting this research is provided in Section 7.2 to conclude the thesis.

7.1 NAVIGATING THE RESERACH PROCESS

The learnings from this project in terms of design contributions and reflections on the process of conducting the research are highlighted in this section

7.2.1 INSIGHTS AND CONTEMPLATIONS

The process of conducting research may appear intimidating due to the complexities of the methodologies and requirements necessary to establish the credibility of the outcomes. Achieving this endeavor without encountering roadblocks is an unrealistic expectation. Overcoming these challenges can provide valuable insights into the problem at hand. Nevertheless, certain factors need to be taken into consideration during this process in order to break down the challenges into smaller, manageable components.

RESEARCH FRAMEWORK

Defining the scope, research questions and structure of the process really helped in keeping the overall picture of the work in mind during each step. Taking inspiration from previous research and analyzing the methodology that was used, provided a good foundation to build from. This way, efforts could be focused in extending the work through a different perspective. This also helped with validation at later stages of the process.

LITERATURE REVIEW

The literature review phase in the process influenced the direction of the research. Interdisciplinary approach towards this phase provided key insights and gaps in existing research that guided a lot of the choices that were made in the process.

EXPERIMENT DESIGN

The methodology used in the experiment was clearly defined through the process of drafting an experiment protocol. This was an important step that provided an outline of the different variables under consideration and the measures that needs to be taken. This protocol was used as a guide during the development stage of the system, this way the different components that needs to be implemented along with its functionality could be managed effectively. An iterative approach towards development made the architecture of the system easier to handle, adding features sequentially helped in ensuring all the components are working together and identifying any bugs in the code.

TESTING

There are a lot of assumptions that can be made during the research process, sometimes these can lead to challenging situations at later stages of the process if it is not tested early on. Testing assumptions reveals these inconsistencies with respect to how the problem is perceived compared to what it actually is.

In addition to this, pilot testing the experiment was also critical in reviewing the procedure and data collection process of the experiment. This helped in identifying potential issues that would come up while conducting the experiment and during analysis.

7.2.2 CHALLENGES

MULTIPLAYER

Development of a VR application that requires multiplayer functionality is very challenging process compared to single player. The understanding of the networking framework proved to be a major challenge in this project. There are a lot of resources available that can be used to make this process simpler. However, it is recommended to start the implementation during the initial stages of the development process.

DEVICE FAILURE

The malfunction of computers, HMD's and motion controllers are unfortunately unavoidable in these types of situations, especially when running custom applications. If it possible, it is advised to keep components on standby and have all the data backed up at all times. This ensures no data loss during development and while running experiments.

LOGISTICS

The logistics of setting up the experiment, recruiting and managing participants also proved to be challenging. Specifically since this experiment required multiple participants at the same time. Scheduling tools (Calendly) helped in making this smoother to handle. It is also recommended to start early during the planning phase of the experiment to already consider what is required for the final setup of the system.

CONDUCTING THE EXPERIMENT

Conducting an experiment that takes an hour requires a considerable amount of effort. Buffer times between sessions helps in managing this more effectively, giving enough time to extract the recorded data and store them correctly. It is also suggested to use checklists to ensure all steps of the experiment take place in each session in the correct order.

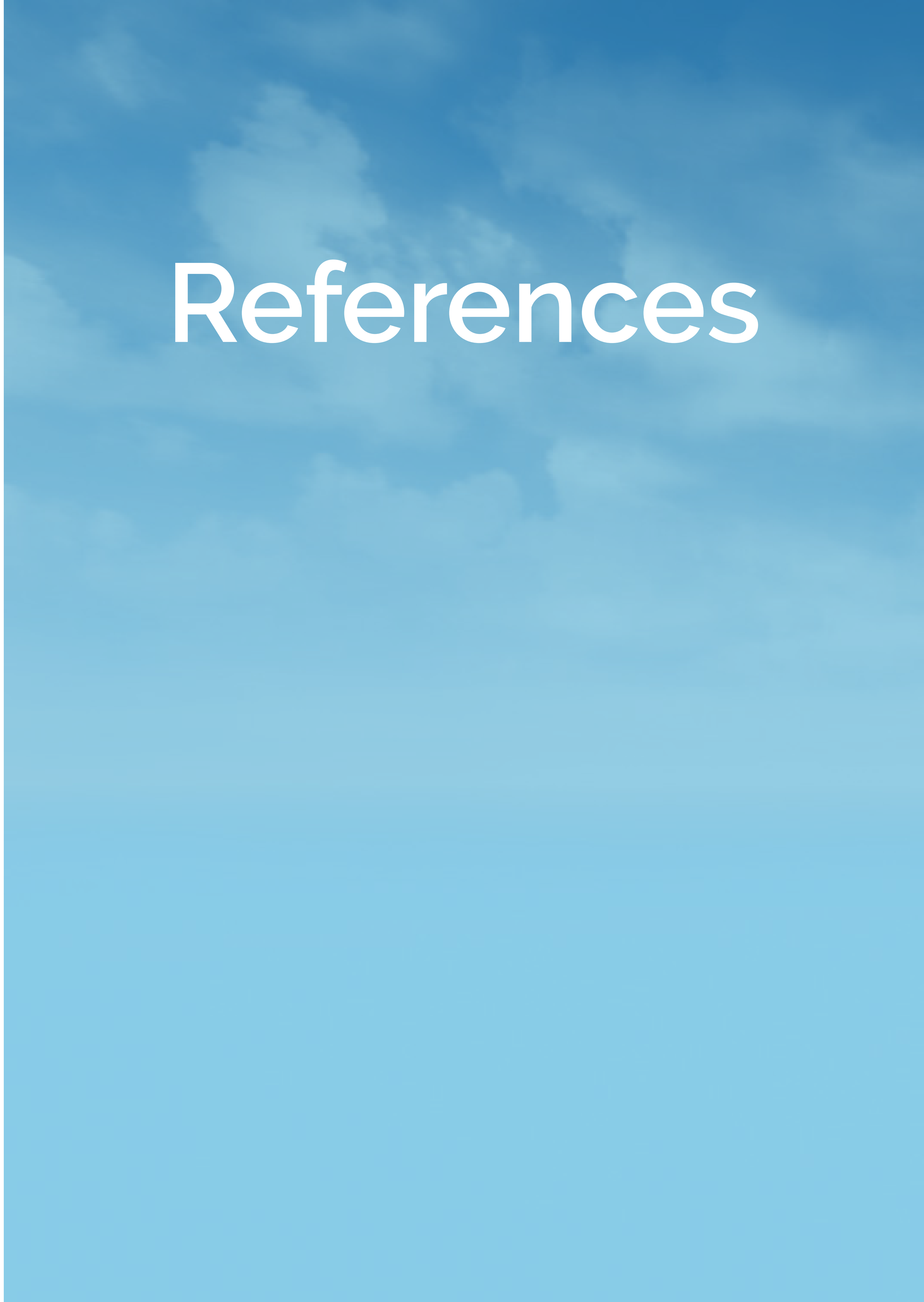
7.2 PERSONAL REFLECTION

Until now, I had never tried to develop any type of software applications or conducted research. These were among the top of the numerous challenges that I had to undertake during the course of this project. There were many instances where it felt like I might not succeed, but now that I've reached other side, I feel proud that I did not give up and managed to deliver. As a result, the learnings from this process has been significant.

I embarked this graduation thesis with an interest in researching the translation of the perceptual crossing paradigm into a 3D space and validate it through an experiment. Initially, this task seemed straightforward, and with this notion, I delved into the extensive literature on the topic. This type of literature was new to me, but I found myself captivated by the philosophical undertones and the implications they had on human behavior. However, as the problem became more defined, it unraveled in complexity. Consequently, my efforts were redirected towards leveraging the insights from this exploration to pursue an alternative research direction, shaping the scope of the current body of work. Reflecting on the insights, I'm certain that the outcome is a result of this initial exploration.

Contemplating the results of this research, I realize that the creation of human behaviors is an intricate process of social coordination that we develop through experiences. From infants mimicking their mothers' facial expressions to crowds in stadiums cheering together, we constantly strive to synchronize with those around us. This synchronization became evident during this experiment, and I became intrigued by how this process emerges autonomously. If given the opportunity, I would want to continue to explore this aspect of social cognition in future projects.

To conclude, there are aspects of the project that have not been executed perfectly, and I aim to refine these aspects in my workflow. I found myself constantly fighting against time to ensure that everything is finished on time. There were instances when the application glitched during the experiment and I had to fix it to complete the sessions. Despite these obstacles, I am very happy and satisfied with the end result of this project. I now eagerly look forward to the new-found love for research that I personally discovered as the most rewarding aspect of this thesis.



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Appendix

APPENDIX - A

QUESTIONNAIRE IMAGES

Sense of agency questionnaire

Feeling of control

How much did you feel in control of the virtual hands?

1 Not at all | 2 | 3 | 4 | 5 | 6 | 7 Fully in control

Sense of co-persence questionnaire

Co Presence 1

I felt that I was in the presence of the other person

1 Strongly disagree | 2 | 3 | 4 | 5 | 6 | 7 Strongly agree

Co Presence 2

I felt that the other person and I were together in the same space

1 Strongly disagree | 2 | 3 | 4 | 5 | 6 | 7 Strongly agree

Co Presence 3

I felt that the other person responded to shifts in my movement (e.g posture, position)

1 Strongly disagree | 2 | 3 | 4 | 5 | 6 | 7 Strongly agree

Sense of embodiment questionnaire

Sense of embodiment 1

I felt as if my (real) hands were drifting toward the virtual hands or as if the virtual hands were drifting toward my (real) hands

1 Strongly disagree | 2 | 3 | 4 | 5 | 6 | 7 Strongly agree

Sense of embodiment 2

I felt as if the movements of the virtual hands were influencing my own movements

1 Strongly disagree | 2 | 3 | 4 | 5 | 6 | 7 Strongly agree

Sense of embodiment 3

At some point it felt as if my real hands was starting to take on the posture or shape of the virtual hands that I saw

1 Strongly disagree | 2 | 3 | 4 | 5 | 6 | 7 Strongly agree

APPENDIX - B

HAPTICS PRE-STUDY RESULTS

Perceived Intensity ratings

Level	Variation		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	Average
L1	Intermittent	20	4	5	3	5	3	4	4	3	2	4	3	4	3	4	3	3.60
L2	Sinusoidal	40	5	3	3	4	4	4	5	3	3	5	5	6	5	5	4	4.27
L3	Heartbeat	10	2	3	1	2	1	2	2	1	1	2	2	3	2	2	1	1.80
L4	Intermittent	40	5	6	5	4	5	6	7	4	4	6	5	5	6	6	5	5.27
L5	Sinusoidal	10	4	3	2	5	3	4	6	2	2	3	3	5	3	3	4	3.47
L6	Heartbeat	20	3	2	3	3	3	6	5	3	2	4	3	4	1	3	5	3.33
L7	Sinusoidal	30	6	5	5	4	4	6	7	5	5	5	5	6	6	6	6	5.40
L8	Constant	40	6	7	6	7	7	6	7	7	6	7	7	7	7	7	7	6.73
L9	Intermittent	30	3	4	4	6	6	5	6	4	5	4	4	4	4	4	5	4.53
L10	Constant	20	5	4	6	6	6	6	5	4	5	6	5	6	5	5	6	5.33
L11	Heartbeat	30	3	4	4	2	4	5	4	3	3	3	5	5	1	2	4	3.47
L12	Constant	10	4	4	3	4	3	6	4	2	3	4	4	6	2	4	5	3.87
L13	Heartbeat	40	2	5	5	3	3	5	6	3	4	3	5	5	2	5	4	4.00
L14	Sinusoidal	20	4	6	4	5	4	5	4	3	3	4	4	5	3	5	5	4.27
L15	Intermittent	10	3	3	3	4	3	5	3	3	2	3	3	4	2	4	3	3.20
L16	Constant	30	6	6	7	6	7	7	7	6	6	7	6	7	7	7	7	6.60

Perceived Comfort ratings

Level	Variation		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	Average
L1	Intermittent	20	3	2	5	6	5	5	4	2	6	4	4	5	4	6	5	4.40
L2	Sinusoidal	40	3	4	4	3	4	5	2	2	5	4	3	4	2	6	3	3.60
L3	Heartbeat	10	5	5	6	7	4	5	1	6	6	5	6	3	6	7	6	5.20
L4	Intermittent	40	4	4	4	3	3	3	5	3	4	3	3	4	1	6	2	3.47
L5	Sinusoidal	10	5	6	6	2	6	4	6	6	5	6	5	3	6	7	4	5.13
L6	Heartbeat	20	3	2	4	5	6	4	3	5	6	5	5	6	1	7	2	4.27
L7	Sinusoidal	30	4	4	4	3	4	3	4	4	4	2	3	4	6	5	4	3.87
L8	Constant	40	4	2	3	1	2	2	3	2	2	1	1	3	3	4	1	2.27
L9	Intermittent	30	4	6	4	4	3	3	3	4	3	4	4	4	2	7	3	3.87
L10	Constant	20	4	5	2	4	2	1	4	4	3	2	6	1	2	6	2	3.20
L11	Heartbeat	30	5	3	1	6	5	4	3	5	5	3	5	4	2	5	3	3.93
L12	Constant	10	5	2	5	5	4	2	4	6	5	3	4	2	5	6	5	4.20
L13	Heartbeat	40	4	2	5	6	5	3	4	1	5	4	5	3	3	4	3	3.80
L14	Sinusoidal	20	4	5	4	2	3	3	5	5	5	6	4	4	6	7	3	4.40
L15	Intermittent	10	5	6	5	2	3	4	6	3	6	6	6	4	1	6	3	4.40
L16	Constant	30	2	1	2	1	2	2	4	2	3	1	2	2	5	6	1	2.40

APPENDIX - C

INTERVIEW GUIDE

OVERALL EXPERIENCE

1. How was the overall experience of the experiment ?
2. How did it feel sharing your motion with another person ? Was it comfortable/ uncomfortable ?
3. Does the type of relation with your partner affect your answer ?
4. What is your overall impression of using a shared avatar?

CONTROL + PRESENCE

1. How did the control over the virtual hands influence your movement ?
2. Did you feel as if you had full/no control while doing the task at any point ?
3. Were you aware of your partner's movement during the task ?
4. Were you influenced by your partner's movement ?Or did you try to influence your partner's movement ?
5. Were you aware of your partner's presence while performing the experiment ?

HAPTICS

1. How did the vibrations influence your movement during the task ?
2. Did you feel distracted by the vibrations while performing the tasks ?
3. Was there any difference while performing the task with and without vibrations ?

TASK

1. Were both the tasks engaging during the experiment ?
2. Was there a difference in how you approached the 2 different tasks?
3. What was the difficulty level in performing both the tasks ?
4. Do you have any pain points while performing the experiment ?
5. How natural did it feel while interacting with the objects?
6. What use cases do you feel are useful while interacting this way ?

APPENDIX - D

CONTRASTS TEST RESULTS

Feeling of control

Response Variable	Factor	Contrast	Estimate	SE	df	t.ratio	p	sig.
Feeling of control ratings	Task	**Task 1 - Task 2**	193.75	14.77	909	13.12	0.000	***
	Haptics	**No Haptics - Haptics**	56.44	15.69	909	3.60	0.000	***
	Task x Haptics	**Task 1, No haptics - Task 1, Haptics**	-25.04	20.39	909	-1.23	0.220	
		Task 1, No haptics - Task 2, No haptics	129.12	20.39	909	6.33	0.000	***
		Task 1, No haptics - Task 2, Haptics	239.59	20.39	909	11.75	0.000	***
		Task 1, Haptics - Task 2, No haptics	154.16	20.39	909	7.56	0.000	***
		Task 1, Haptics - Task 2, Haptics	264.63	20.39	909	12.98	0.000	***
		Task 2, No haptics - Task 1, Haptics	110.47	20.39	909	5.42	0.000	***

Co-presence

Response Variable	Factor	Contrast	Estimate	SE	df	t.ratio	p	sig.
Co Presence 1 ratings	Task	**Task 1 - Task 2**	-25.10	4.89	117	-5.13	0.000	***
Co Presence 2 ratings	Task	**Task 1 - Task 2**	-27.98	4.77	117	-5.86	0.000	***
Co Presence 3 ratings	Task	**Task 1 - Task 2**	-28.08	5.28	117	-5.32	0.000	***

Embodiment

Response Variable	Factor	Contrast	Estimate	SE	df	t.ratio	p	sig.
Body Ownership 1 ratings		**No Main effects**						
Body Ownership 2 ratings	Task	**Task 1 - Task 2**	-19.28	5.98	117	-3.22	0.002	**
Body Ownership 3 ratings		**No Main effects**						

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DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

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STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Venkatraj

initials: K P given name: Karthikeya Puttur

student number: 5535581

street & no.:

zipcode & city:

country:

phone:

email:

Your master programme (only select the options that apply to you):

IDE master(s): (★) IPD ( ) Dfl ( ) SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: ( ) Honours Programme Master

specialisation / annotation: ( ) Medisign ( ) Tech. in Sustainable Design ( ) Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Gijs Huisman dept. / section: HCD

** mentor: Wo Meijer dept. / section: SDE

2nd mentor: Abdallah El Ali

organisation: Centrum Wiskunde & Informatica

city: Amsterdam country: The Netherlands

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

TU Delft

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair: date: 23 - 02 - 2023 signature:

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 30 EC

Of which, taking the conditional requirements into account, can be part of the exam programme: 30 EC

List of electives obtained before the third semester without approval of the BoE:

*- Variant for Engineers

( ) YES all 1st year master courses passed

(X) NO missing 1st year master courses are:

ID4010 Design Theory and Methodology (3,0)
ID4170 Advanced Concept Design (21,0)

name: Robin den Braber date: 27 - 02 - 2023 signature:

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: (V) APPROVED ( ) NOT APPROVED

Procedure: ( ) APPROVED (V) NOT APPROVED

- the missing course ID4010 should be finished before the green light meeting
- ID4170 has been finished according to the course coordinator

comments

name: Monique von Morgen date: - KE 6/3/2023 signature:

Initials & Name: K P Venkatraj Student number: 5535581

Title of Project: Design of 3D Haptic Virtual Reality system for Perceptual Crossing

Design of Haptic Virtual Reality for Perceptual Crossing in 3D   project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 20 - 02 - 2023   06 - 08 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Background :

De Jaeghar (2009) describes a dyadic interaction between people in a narrow corridor, where they try to walk past each other but end up in a synchronized mirroring of sideways movement. In this type of interaction people remain in a state of engagement without any conscious involvement of either of the interactors as a consequence of the evolving dynamics of the interaction.

Auvray et al.'s (2009) perceptual crossing paradigm offers a foundation to build a system that is capable of studying the factors involved in recognition between people in an online interaction. In the original experiment, pairs of blindfolded human participants are placed in separate rooms, the only medium of interaction between the participants is through a common virtual one-dimensional perceptual space. Each participant can move along the 1D line using a mouse on one hand, only the horizontal component of the movement is captured for the motion of their avatar. Along with the 2 avatars of the participants, a fixed object and a shadow object that is attached at a fixed distance to both the avatars are present within the virtual space. The characteristics in terms of shape and movement were identical for all 3 objects. The interaction of the participants avatar with these objects produced a tactile stimulation to the free hand of the participant. An important constraint in this experiment is that the interaction of the participant with the partner's shadow object produced a tactile stimulation only for the participant. The partner does not get any stimulus for this type of interaction. The task of each of the participants was to click the mouse button when they perceived the presence of the other participant.

This study, as well as extensions of the same paradigm in a 2D experiment (see Lenay et al. (2011)) showed an emergent coordination between participants as a result of the mutual search of the interaction partner, in the severely impoverished virtual environment. This demonstrates that autonomous coordination can evolve without individual intention of subjects within such a minimal environment i.e. during a perceptual interaction, some of the mechanisms underlying the process of recognition of an intentional subject is intrinsic to the shared perceptual activity (Auvray et al. (2009)).

So far numerous studies and experiments have been conducted to understand the perceptual crossing paradigm (Auvray, 2012), however there has not been an investigation of this phenomenon in a Immersive Virtual Environment (IVM) that provides 3 dimensional space to facilitate interaction between participants and objects. This project aims to design a system that translates the minimalistic conditions of the original perceptual crossing experiment into an IVM. This will provide a tool to study the factors that are involved in the evolution of the interaction dynamics between participants and any co-ordination that may arise. Experiments using such a system will provide valuable insight into user behavior and social cognition that occurs within an online interaction in a 3D environment. This will help in research and development of virtual reality(VR) and augmented reality(AR) systems and the overall enhancement of user experience for these systems.
The IDE faculty will support this project with resources that will help integrate principles and methodologies of design theory into the system, while CWI (Centrum Wiskunde & Informatica) will provide the technical knowledge and infrastructure required to design the system and evaluate its performance.

space available for images / figures on next page

introduction (continued): space for images

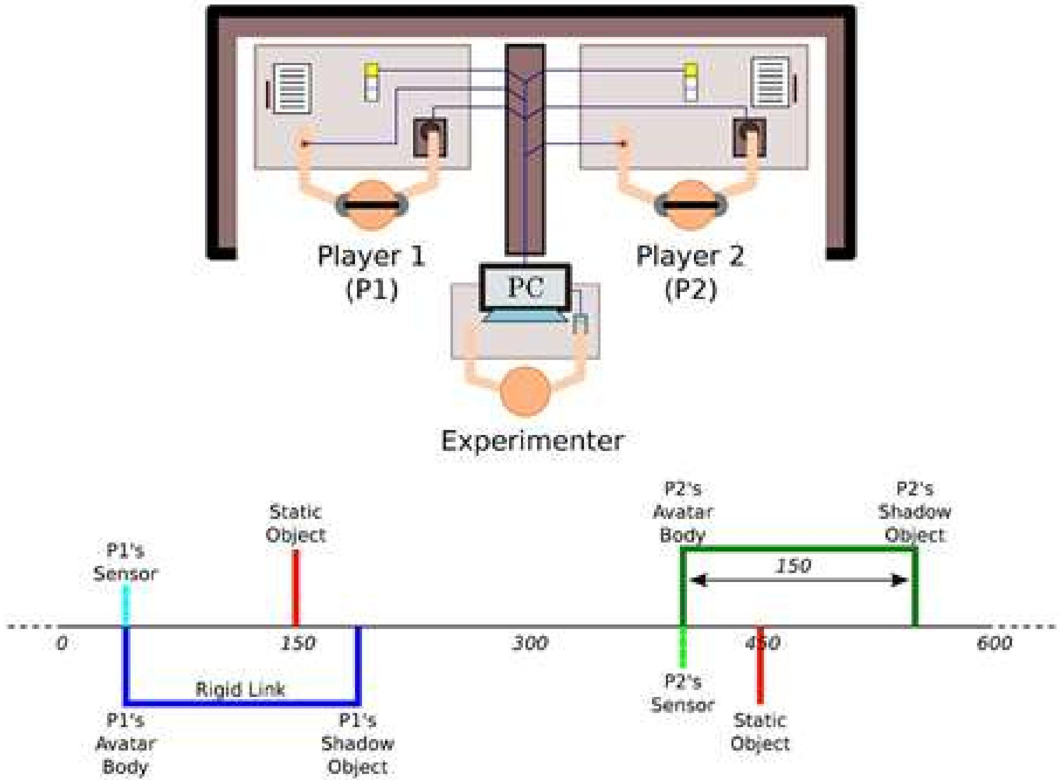


image / figure 1: The original perceptual crossing experiment in 1D by Auvray et al (2009).

image / figure 2: Senseglove interaction technology with haptic feedback integrated with VR Headset

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

With growing interest in academia and industry towards development of VR and AR technologies, there is a need for a system to study interaction between people within these technologies in a minimalistic way. The original perceptual crossing paradigm allows this by reducing the complexity of the behaviors to be measured. Therefore this system can enable further research on the processes of interaction and its effects on social cognition within such online platforms.

Scope of the project:
- The system should effectively translate the constraints of the minimalistic perceptual crossing paradigm into 3 dimensional space.
- The system should allow for real time synchronous interaction between participants.
- The system should provide haptic feedback to the participants during the interaction.
- The system should allow for measurement of the dependent variables during the interaction (e.g., number of correct clicks, displacement trajectories of avatars etc.)

Based on this scope, certain design and technical challenges are identified :
Design Challenges-
- Embodiment of the partner,shadow and fixed object in the virtual space (representation for each type of object)
- Definition of contact requirements (collision boundary) to enable haptic feedback.

Technical Challenges-
- Creation of the IVR without inducing any form of discomfort/ cybersickness.
- Synchronization of the two participant avatars in a common virtual space.
- Measurement of the dependent variables of both the participants during the interaction.
- Errors that may arise due to performance breaks/ glitches.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

To design an interactive haptic VR system that facilitates the perceptual crossing paradigm in 3 dimensional space and evaluating the efficacy of such a system. The system should sufficiently translate the original perceptual crossing paradigm into a Immersive Virtual Reality environment in 3D space while maintaining a minimalistic approach.

The literature on original experiment and the numerous extensions of the perceptual crossing paradigm will provide the theoretical foundation on which the characteristics of the system will be defined. Important factors that will be the focus of the literature study will be to effectively transform the interactions between the participants, constraints of the environment, type of haptic feedback and experimental setup from the 1D, 2D experiments into the 3D environment.

Using the developed theory as a guideline, state of the art software and hardware technologies in the domain of VR and AR will be analyzed to make an informed selection on the required components needed to design the system. The different hardware and software components will then be integrated together to design a working prototype that will be tested and optimized for an experiment.
The experiment will be conducted for a small sample size and results will be analyzed to benchmark the efficacy of the designed system with respect to the original experiment.

The final outcome the project will be a prototype of a baseline system that will provide a platform to perform research on interaction between people in a 3D virtual reality environment. Using this system researchers can understand what improvements can made to make user interactions in VR more immersive.

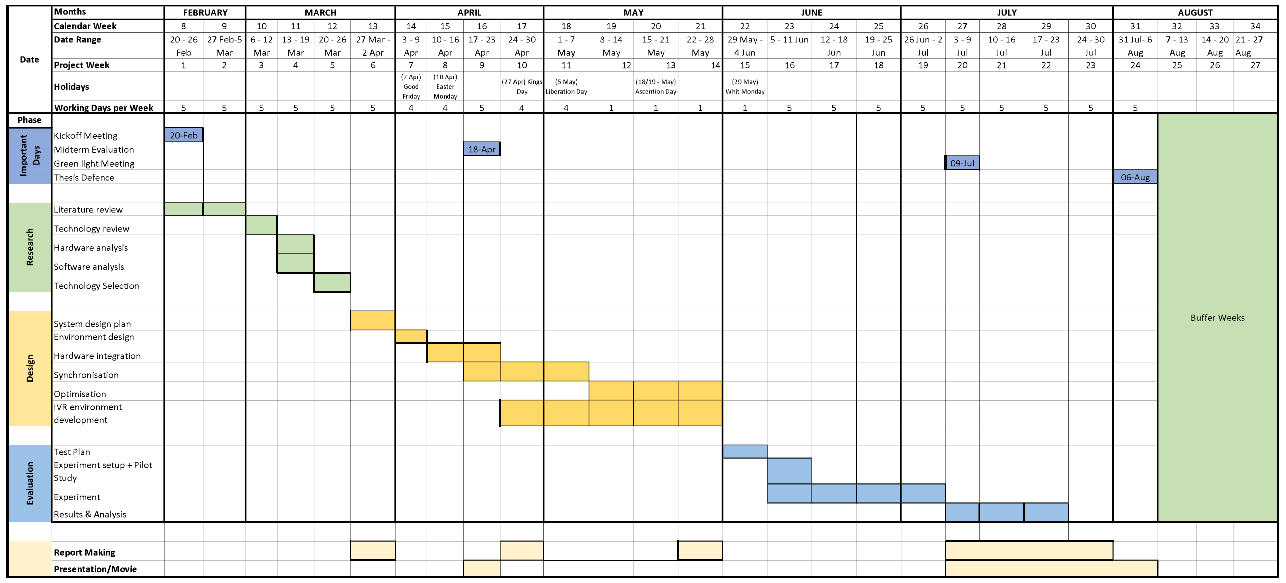
Initials & Name ______ Student number ______

Title of Project Design of Haptic Virtual Reality for Perceptual Crossing in 3D

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 20 - 2 - 2023 6 - 8 - 2023 end date



The project consists of 3 primary phases: Research, Design , Evaluation.

Research (4 weeks)
-Literature review on Perceptual crossing experiments and Social presence in online interactions.
-Hardware analysis of head mounted display technologies and haptic technologies.
-Software analysis of VR development engines and computing systems.
-This phase ends with comprehensive review and selection of required components for development.

Design (9 weeks)
-Technology procurement and drawing out plans for the design of the system.
-Design of the IVR environment, applying boundary conditions and appropriate constraints
-Integration of HMD and haptic technologies into the system
-Synchronization of inputs from multiple users into common virtual space
-Iterative tests to optimize the performance of the system.

Evaluation (8 weeks)
-Participant recruitment and plan logistics for experiment
-Experiment setup and conduct pilot study
-Conduct experiment and collection of data
-Compile, analyze and report results.

Initials & Name ______ Student number ______

Title of Project Design of Haptic Virtual Reality for Perceptual Crossing in 3D

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

As an IPD student with a background in mechanical engineering, I have always been engaged with projects that are technically inclined with an undertone of creative and interactive aspects. Gaining experience in systems design was one of the main drivers to pursue this masters degree.

This graduation project offered by CWI provides the best opportunity, where I can combine my technical and design knowledge to develop an innovative system. This further helps me move into the industry where I wish to continue as a professional.

Through the courses such as Advanced embodiment design and Advanced concept design along with my own interest in 3D modeling and animation, I have acquired knowledge on rapid prototyping, coding and using game engines for the design of VR environments. This will provide the background experience required to face the technical challenges that will arise during this project.

Another motivation for this project is the integration of haptic technologies, I have only had very limited exposure to this so far, through this project I can experiment with different types of haptic feedback and its impact on social interactions. This will give me extensive knowledge on the subject and will help me in future projects.

Lastly, this project also provides the opportunity to conduct research on a growing technology and possibly publish the results of the experiment in the form of a paper. This will add a lot of value to my profile as I shift from a student and move into the industry as a professional.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name ______ Student number ______

Title of Project Design of Haptic Virtual Reality for Perceptual Crossing in 3D