The Influence of an Embodied Coxswain on the Social Presence within Virtual Reality Rowing

Frederique Voskeuil
MSc Interaction Technology

Supervisors
Dr.Ir. D. Reidsma
Dr. A. Karahanoglu

November, 2023

Abstract

Social presence, defined as the degree of feeling connected to others, enhances the overall quality of an exercise experience in virtual environments (VEs). It boosts enjoyment and engagement [1], [2], friendships [3], and can even increase the efficiency in training [2]. This thesis aims to stimulate social presence between rowers in Virtual Reality (VR) rowing. The research began with describing a comprehensive framework of the facets of presence, its measurement methods, and its determinants. Additionally, we gain a deeper knowledge of the social dynamics within rowing teams by observing rowing teams. Next, we explore design possibilities through a brainstorming session and by creating storyboards. This led to the decision to design an embodied coxswain, aiming to enhance the social presence between two rowers in a VR rowing system. The rowing setup consisted of two RP3 rowing machines, two VR headsets, multiple trackers, and other hardware components and software platforms. A total of 22 participants tested the setup with two conditions: the embodied coxswain or agent and a non-embodied agent. After each condition, the participants completed the Networked Minds Measure questionnaire and a questionnaire about the anthropomorphism of the agents. Statistical linear mixed effects regression (LMER) analysis showed that the embodied coxswain significantly affects the perceived social presence ($p = 0.00176$). Moreover, post-experiment discussions revealed that the participants perceive the agents differently, primarily on an emotional level. This research suggests potential research directions, specifically in identifying the key characteristics of the coxswain that enhance social presence, and by enriching realism of the appearance, movements, and interactions of the embodied coxswain.

Keywords: Social presence - Presence - Virtual Reality (VR) - Rowing - Embodied coaching - Sports interaction technology - NeosVR

Acknowledgements

First and foremost, I would like to thank my supervisor, Dr. Ir. Dennis Reidsma. His guidance, knowledge, and time have helped enormously throughout my thesis. Moreover, he provided many valuable insights and offered motivational support.

Secondly, I would like to express my gratitude to my second supervisor Dr. Armagan Karahanoglu. I would like to thank her for her constructive feedback, which significantly helped me elevate my thesis. Together with Dr. Ir. Dennis Reidsma, our weekly meetings were a source of inspiration and often led to stimulating discussions.

I would like to extend my appreciation to Jordi Weldink, a fellow student on the project, for his assistance in developing the virtual coxswain in NeosVR. His patience and friendly support helped me enormously and kept me motivated throughout the process. Also, I enjoyed working with the other fellow students on the VR rowing project and I like to give my best wishes to Mirka, Timo, and all the other students as they carry out the rest of their theses.

Additionally, I would like to thank Dr. Dees Postma for connecting me to this intriguing thesis assignment. I am pleased to say that we discovered a topic that truly sparks my interest. Moreover, I wish to thank him for evaluating my statistical analyses.

I would like to thank Tomas Diepenmaat for his assistance in recording the animations and sounds of the virtual coxswain. His dedication and passion greatly contributed to the success of the coxswain. In addition, I appreciated his mental support during the entire process of the thesis.

Moreover, I would like to thank the rowing team of DRV Euros for allowing me to observe one of their training sessions. I greatly appreciated their enthusiasm and interest in my thesis.

Besides, I would extend my gratitude to the participants who willingly joined the experiments. Their enthusiasm to try my installation was very pleasant and contagious. I thank them for their honest and detailed feedback during our discussions. Also, I would like to thank the HMI lab team for their help and assistance during the building process.

Finally, I would like to express my gratitude to my family and friends for their unconditional support during this process. Their support encouraged me through the long weeks at the university, especially when facing technological challenges while building the installation of the virtual coxswain.

Contents

List of Figures

List of Tables

List of Listings

1 Introduction

In recent years, the realm of virtual collaborative sports experiences has gained significant attention. These experiences involve users to exercise in a virtual environment, ranging from jogging with a fitness app, such as RunKeeper[1] or Strava[2], to more immersive virtual experiences that use Augmented or Virtual Reality (VR) headsets or haptics. Many of these applications frequently use social features to engage their users actively. For instance, Zwift[3] is an indoor cycling platform that enables users to train and compete with other cyclists in an online community. Similarly, iFit[4] offers interactive workouts, allowing users to participate in collaborative running, cycling, and yoga classes.

Within the social context of these applications, the concept of "social presence" appears to be an essential element. Social presence is a multifaceted construct and can be defined as the degree of awareness or connectedness with other users in a (virtual) environment [4]. It contributes to the overall experience of exercising in virtual environments, as it enhances enjoyment and engagement [1], [2], fosters friendships [3] and can even increase the efficacy of training and therapy programs [2]. Moreover, the perception of presence generally improves learning, efficiency, planning, and cognitive or sensorimotor performance, and facilitates the transfer of training to real-world situations [5].

Enhancing social presence can offer many benefits, given the significant influence of social relationships in team-oriented sports, such as rowing. Consequently, this thesis introduces a virtual platform that enhances social presence between rowers. To achieve this, we explore different design possibilities and introduce an embodied coxswain or coach to boost the team dynamics within a rowing team. The combination of VR and embodied coaching has demonstrated the potential to improve social presence and could increase team dynamics within rowing.

1.1 Study motivation and problem statement

Social presence holds the potential to enrich many facets of virtual collaborative sports experiences, such as improving performance and attracting broader user participation [6]. When a user achieves a state of full immersion, "hyper-presence" can occur, in which the user feels that his "truer' self fully emerges in a virtual environment [7]. Hyper-presence can cause people to feel more present to others, and others feel more present to them compared to real-life experiences [7], [8].

While the influence of social presence in virtual collaborative sports experiences has been researched in the fields of cycling [9], [10], volleyball [11], jogging [12], [13], boxing [14] and other sports [15], it remains a compelling topic to explore further. Team sports, such as rowing, often rely heavily on social interaction among team members. Since physical interaction is not always possible, virtual collaborative sports experiences can provide an alternative solution. For instance, virtual collaborative rowing experiences offer the possibility to row regardless of weather conditions, allow more flexibility, and give access to various additional information that cannot be provided on

[1] Runkeeper - `https://runkeeper.com/cms/`
[2] Strava - `https://www.strava.com/?hl=nl-NL`
[3] Zwift - `https://us.zwift.com/`
[4] iFit - `https://www.ifit.com/connected-fitness`

a display of a rowing machine. Most notably, it allows users to row with other teammates while being geographically distributed [15]. This phenomenon is called "sport over a distance" and it is a common topic in current literature [3], [9], [12], [14]–[18]. Besides removing geographical boundaries, more people can join virtual collaborative sports exercises [16], and these installations have proven to enhance fun, engagement, and social bonding [9], [18].

With this context in mind, the primary aim of this thesis is to enhance social presence between rowers in a VR rowing session by employing a virtual coxswain. The study is motivated by the aspiration to unlock the potential of embodied coaching for the purpose of enhancing team dynamics within rowing teams and hopes to significantly contribute to the realm of virtual collaborative sports experiences.

1.2 Main research question

Given the motivation outlined above, our research aims to fulfill the demand for a system designed to boost social presence in virtual rowing by means of virtual coaching. From this motivation, the following research question is formulated:

To what extent does the presence of an ***embodied coxswain*** *enhance the* ***social presence*** *between two rowers during a* ***Virtual Reality rowing*** *session?*

1.3 Outline of this thesis

Before starting on the design of this virtual coach, a more comprehensive understanding of (social) presence and the factors that contribute to (social) presence is needed. This knowledge is assembled in Chapter 2 and serves as a foundational framework for the final design. Afterward, Chapter 3 studies the dynamics within a team by analyzing observations from rowing teams. It also offers a brainstorming session and storyboard sketches with potential design solutions. The chapter concludes with a detailed description of the final design of the virtual coxswain. To assess the effectiveness of this design, we will perform experiments. Chapter 4 will illustrate the experimental study design, while the results will be shared in Chapter 5. Finally, Chapter 6 discusses the findings and makes recommendations for future work. Concluding, Chapter 7 reflects on the thesis and provides a general summary.

2 Context Analysis

The context analysis aims to gain the information needed to design a rowing experience that stimulates social presence. The first section focuses on (social) presence. This section will examine the facets of (social) presence, how it can be measured, and the determinants of (social) presence. Next, Section 2.2 gives background information on rowing. This section will discuss the rowing stroke, the dynamics of rowing in a team, and the role of VR in rowing. Lastly, Section 2.3 presents related work in the field of Virtual Reality rowing. This chapter ends with a conclusion.

2.1 Presence

This section investigates existing literature using academic resources such as the ACM library[5] and Google Scholar[6]. The "snowballing method" is implemented to review the literature. This method consists of an initial search for references, and new papers are identified within the reference lists of these papers. This process iterates until a substantial amount of literature on a specific topic is collected. In addition to browsing through the reference lists of papers, new literature is collected by exploring studies that have cited the original paper and by searching for papers that are written by the same author. This method poses an advantage by simplifying the process to find a substantial volume of research papers [19].

2.1.1 Definitions of presence

The overarching theme of presence should be clarified before diving deeper into the measurement methods and the determinants of presence. Thus, this section will discuss the different definitions of presence. Presence is a versatile concept which is expressed in different terms, such as telepresence [1], [2], [20], social presence [1], [2], [4], [11], [21]–[25], or connectedness [1], [2], [4], [9], [21], [23], [26]. A comprehensive analysis of the existing literature unveils four repeating themes that define presence. These themes are "perception and understanding", "(emotional) connectedness", "space", and "interaction". We have constructed these categories to identify potential differences and similarities between the definitions of presence. The different categories will be discussed below.

Perception and understanding
(Social) presence is often characterized by the perception and understanding of other (virtual) humans. Existing literature reveals that (social) presence is described as the feeling "of not being alone" [23], but "being together with other (virtual) humans" [4], [27]. This not only includes the awareness of the presence of other (virtual) users [11], [22], [23], but also experiencing the thoughts and emotions of the other person [27]. According to Heidicker [22], this entails the exchange of verbal, nonverbal, conscious, unconscious, and visual cues. In alignment with this statement, Lombard et al. [26] state that (social) presence is the degree to which users respond to social cues provided by others. Besides exchanging social cues, Harms and Biocca [23] express the need to understand other (virtual) humans. They propose that presence can be defined by the degree to which the user understands messages, and the emotional and attitudinal state to and from other users. This is supported by Heidicker et al. [22], who affirm that understanding messages to and from others in

[5]ACM Digital Library - `https://dl.acm.org/`
[6]Google Scholar - `https://scholar.google.nl`

virtual environments is an important element of social presence. In summary, the theme “perception and understanding” is defined by the awareness of the presence of other (virtual) humans and understanding messages to and from these humans.

(Emotional) connectedness

(Emotional) Connectedness can be seen as a subjective experience or relation between the user and other (virtual) humans and includes the degree to which users feel united with others. Consequently, social presence is characterized as the perception of “being together with others” [1], [2], [4]. It should be highlighted that some papers exclusively describe the concept of social presence within the context of virtual environments, such as Souza et al. [2], Hai et al. [4] and Bentvelzen et al. [9]. They state that social presence is defined by “being together or feeling connected with other virtual humans”. Additionally, the term “connectedness” is used in other papers as well, including the studies posed by Lombard et al. [26] and Nunez et al. [21], where social presence is defined as “feeling connected to others”. Moreover, some studies draw a connection between emotional states and social presence, such as Harms and Biocca [23]. They express that social presence entails not only influencing the emotional and attitudinal state of others, but also affecting the behavior of each other. Lombard et al. [26] and Nunez et al. [21] delve deeper into this emotional connection between users and add that social presence relies on the degree of warmth, sociability, personalization, sensitivity, or intimacy of a medium when it is employed to interact with others. Conclusively, (emotional) connectedness entails the subjective experience of “being with” or “feeling (emotionally) connected to” other (virtual) humans.

Space

Social presence or telepresence is often characterized as “the experience of being in one place, while physically being located in another” [26]–[30]. For instance, Lombard et al. [26] suggest that presence entails the transportation of users, objects, environments, or other individuals to another reality. In contrast, other studies describe social presence or spatial presence as “feeling present or being in another world” without mentioning the transportation from the physical world to a virtual world [1], [2], [4], [11]. Moreover, some define this “other world” by stating it is a “non-physical world” [4], “virtual environment” [2], [11], [26] or “computer simulated environment” [5]. As other studies primarily see presence as the subjective experience of the environment [4], Oh et al. [27] mention that social presence can also be described as the subjective connection one feels to their virtual body, emotions or identity, and the degree in which the users virtual self is experienced as their actual self. Heeter et al. [30] underscore the significance of the transition from the physical body to the virtual body. This perspective aligns with Lombard et al. [26], who state that presence goes beyond the transportation of the body and expresses that senses are extended to the virtual environment as well. The degree of presence is determined by whether these senses feel natural in the virtual environment. Moreover, he emphasizes that realism plays a substantial role in social presence. To achieve high levels of social presence, the environment should feel or look “true to life” [26]. In summary, the theme “space” is defined by the experience of feeling present in another place. Some studies stress the transportation to an alternate world. In contrast, others emphasize the subjective sense of being present in a different world, including a connection to their own virtual body and emotions.

Interaction
The concept of presence can be placed in the context of the interaction among (virtual) users. It can have many different forms, such as communication through audio or text [9], exchange of messages between users [23], a variety of verbal, nonverbal, visual, conscious, and subconscious signals [22], and social cues [26]. Moreover, some studies link emotional values to the interaction, such as Nunez et al. [21] characterize interactions as "positive, social and warm", while Lombard et al. [26] add that interaction can be "personal, sensitive, intimate", and sometimes "illogical". For this thesis, the theme "interaction" will be defined as the interaction between the user and other (virtual) humans. We decided to exclude the emotional state of the users that comes with the interaction, but simply define whether there is interaction. The reason for this is that this is already covered in the theme "(emotional) connectedness".

The existing literature separates two different forms of presence: the overarching construct of presence, and social presence. When looking at the papers that utilize the term "presence", especially the category "space" seems to be an important aspect [1], [2], [4], [5], [24], [26], [28]. These papers frequently describe presence as "feeling present in a virtual environment while physically being located in another" [2], [4], [11], [26], [28] or as "going into a virtual environment" [5]. In contrast, "social presence" is often defined using principles like "(emotional) connectedness" and "interaction" [2]–[4], [9], [12], [14]–[16], [21], [23]–[26]. In this case, social presence is often defined as "feeling connected with other virtual humans" [2]–[4], [9], [12]–[16], [24], [25] or "exchanging messages between users" [1], [6], [9], [23], [26]. It also covers all terminology of presence that belongs to the social context, including terms like "social play", "sense of community" and "social interaction".

All definitions of (social) presence can be found in Table 5 in Appendix A. In addition, while some papers do not define the term "presence" explicitly, they are of value due to their interesting measurement methods and determinants of presence. Therefore, they are included in this thesis. They can be found in Table 6 in Appendix A.

2.1.2 Measuring presence

There are many different methods for measuring presence. In the reviewed literature, psychological measures are used more frequently compared to physiological/physical measures. Psychological measures encompass questionnaires, surveys, and interviews that refer to the user's perception of (social) presence, while physiological/physical measures often involve more objective and quantitative data. An example of physiological/physical measure can be found in the study of Nunes et al. [13], in which they monitor the heart rate of their participants. Additionally, the deployment of the measuring methods differs, as some studies use existing technology, while other studies focus on creating and validating their own devices, games, or virtual environments. Moreover, the methodology of the studies ranges from controlled experiments to semi-structured interviews, literature reviews, and questionnaires.

In the area of "social presence", the Networked Minds Measure questionnaire of Harms and Biocca [23] is often utilized, as can be seen in the studies of Beelen et al. [24], Van Delden et al. [25] and Heidicker et al. [22]. Besides, (co-)presence questionnaires are frequently used to evaluate social presence [1], [4], [5], [21], [28]. In addition, interviews present a commonly used method for gaining qualitative information about social presence [9], [12], in contrast to the quantitative methods used in the previous sentences. Researchers also employ other measurement methods for examining social presence, such as the Attraction Questionnaire [21], the Engagement Questionnaire [31], the NASA TLX Questionnaire [22], the Slater Usoh Steed presence questionnaire [22] and the OIS scale [25]. Lombard et al. [26] have even created a Temple Presence Inventory to examine presence. Finally, some methods are not commonly used to measure social presence, however, they can be used to measure presence as a whole, like the Immersive Tendencies questionnaire [28] and Old-new Memory Test [5]. An overview of the measurement methods can be found in Table 7 in Appendix B.

2.1.3 Determinants of presence

There are various factors that influence social presence. Identifying these determinants of social presence can assist when creating a design that effectively improves social presence. The determinants identified in the literature are associated with the different facets of social presence and can be found in Figure 1 and are further elaborated below.

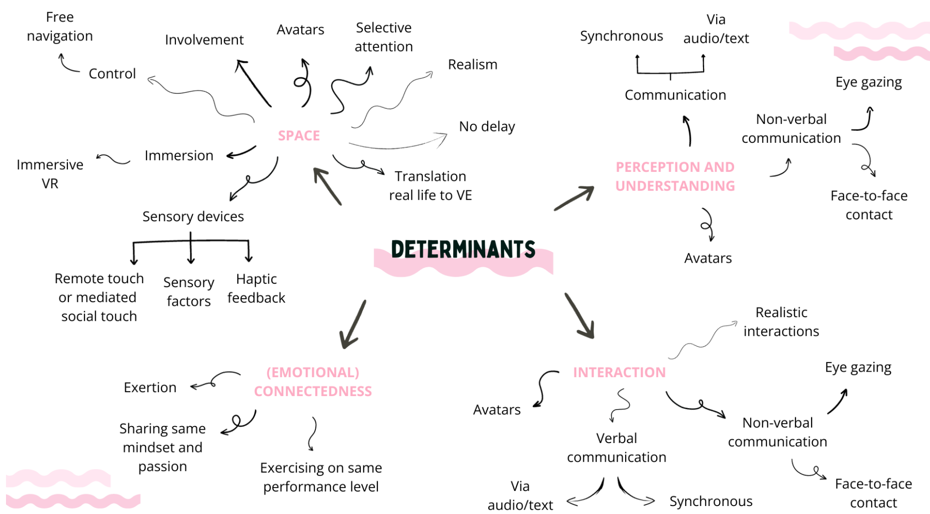


Figure 1: Mind-map of the determinants of social presence ordered by the categories of presence

Firstly, the category "space" revolves around the difference between virtual and physical space when users are immersed in a virtual environment. Therefore, it can be stated that "involvement" and "immersion" can increase feelings of social presence [28]. This finding is in alignment with Kolkmeier et al. [20], Thalmann et al. [11], and Hoffman et al. [5] who express that immersive VR can significantly enhance social presence, especially when compared to conventional devices. Furthermore, "selective attention" can amplify feelings of immersion, which indirectly contributes to social presence [28]. Moreover, realism is another key factor in improving social presence. Mueller et al. [3] state that social interaction or play is enhanced when real-life actions are translated to virtual environments. Conversely, a "delay" in the virtual experience can decrease realism and can thus diminish the feeling of "being in a virtual environment" [3]. Besides the importance of realism of the environment, realism in interactions seems to increase (social) presence as well [4], [28]. Additionally, using realistic avatars with a complete body and movement that are correctly plotted from the user's movements positively influences co-presence [22]. Moreover, a critical determinant of (social) presence and telepresence is the ability to control the virtual environment [11]. This implies that users can actively interact with the environment and can modify their surroundings. This also includes free navigation [20]. Furthermore, sensory devices, such as remote touch/mediated social touch [24], haptic feedback [27] or other sensory factors [28], are frequently cited as reinforcing factors for social presence. These sensory influences enable users to experience physical stimuli in real life while being immersed in a virtual environment.

The next category of presence, "perception and understanding" includes communication, as it can play a crucial role in clearly perceiving others and understanding messages to and from others. For instance, Bentvelzen et al. [9] show that "communication via audio or text" can enhance a sense of community. Nunez et al. [21] also demonstrate that synchronous communication can improve co-presence and social presence. Moreover, "avatars" can contribute to a better perception and understanding of others, primarily because they can facilitate non-verbal communication [22], such as eye gazing [4] and face-to-face contact [23].

The third category of presence is "(emotional) connectedness" and involves the relationship between the user and other (virtual) humans. Within this category, determinants like "sharing the same passion and mindset" and "exercising at the same performance level" play a crucial role, since both increase the feeling of being connected [9]. Besides, Bentvelzen et al. [9], Mueller et al. [12] and Lindley et al. [31] underline the positive influence of "exertion" on a sense of community and social interactions.

The last category of presence, "interaction", encompasses all interactions between users or (virtual) others. This includes verbal communication, like "communication through audio or text" [9] and "synchronous communication" [21], as well as non-verbal communication, such as "eye gazing" [4] and "face-to-face contact" [23]. These forms of communication can be facilitated by "avatars" representing either oneself or others [22]. Moreover, this category overlaps with the realism construct, since "realistic interactions" enhance (social) presence [4], [28].

It is worth noting that some determinants fit multiple categories, such as realism factors, which are included in the categories "space" and "interaction". Similarly, communication seems to be a vital element for "perception and understanding", as well as "interaction". This underlines that realism and communication are crucial factors for enhancing various facets of social presence. Finally, it is notable that some determinants are mentioned frequently throughout the literature, such as exertion, communication, immersive VR, realistic interactions, control, and sensory factors. In the design phase, these determinants should get extra attention. A complete list of the determinants of presence can be found in Table 8 in Appendix C.

2.2 Rowing

This section will discuss rowing techniques, the dynamics of rowing in a team, and the advantages of Virtual Reality in rowing systems.

2.2.1 Rowing stroke

A rowing stroke consists of four phases. Phase one is called the "catch". In this phase, the back of the rower is straight, his body is bent forward, his legs are compressed, and his arms are extended. In the second phase, the "drive", the body of the rower is bent forward, his arms are extended, and he drives with his legs. The next phase is the "finish" phase, in which the legs of the rower are straight, his shoulder blades are squeezed, and his arms pull the handlebar to his chest. In the last phase, the "recovery", the rower extends his arms, the handlebar reaches past his knees, and he slides forward with his legs[7]. Figure 2 shows these four phases.

The ideal stroking rate is 20 strokes per minute, which is once every three seconds. For novice rowers, a lower stroke rate is advised to maintain a good technique. The drive and recovery phases should have a ratio of 1:2, meaning that the drive should last relatively one second and the recovery two seconds[8].

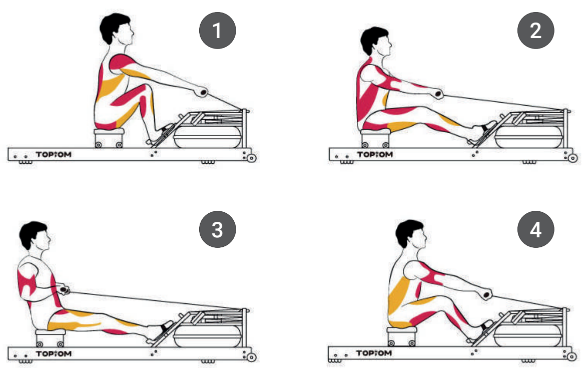


Figure 2: The four phases of a rowing stroke. Based on the Figure of Topiom[7]

2.2.2 Rowing in a team

Rowing can be categorized into two primary types: sculling and sweeping. Sculling involves using two oars per rower and these boats typically do not have a coxswain. The oars are approximately 9.5 feet. A sculling boat is designed for one rower (a single scull), two rowers (a double scull), or four rowers (a quad scull). In contrast, sweep rowing involves each rower using a single oar, which is 12 feet. The presence of a coxswain in smaller boats may vary, but in the case of eights, which are the largest boats, a coxswain is always present. A sweep boat is built for two rowers (a pair with or without coxswain), four rowers (a straight four or coxed four), or eight rowers (a coxed eight)[9].

Each rower has a specific role in the boat. The first person in the boat, the "bow", forms a pair with the second person in the boat. This pair is called the "bow pair", and they are accountable for balancing the boat. Typically, the bow pair has a fluid and smooth rowing technique and may be a bit lighter in weight. Next, the third, fourth, fifth, and sixth rowers are called "the engine room". These are known for their strength and might be heavier in weight. Then, the seventh and eighth

[7]Topiom - https://www.topiom.com/uk/indoor-rowing-techniques-for-rowing-workout-beginners/
[8]Stroke Rate Explained - https://tinyurl.com/strokerate
[9]Unionville - https://tinyurl.com/rowingexplained

rowers are referred to as the "stern pair", with the eighth rower called the "stroke". The stroke is responsible for setting the rhythm and is usually the best racer. Moreover, this rower communicates with the coxswain. Lastly, the coxswain is seated in the bow-facing direction and is the only boat member who does not row. He is responsible for steering the boat and communicating with the rowers[9]. Besides, a good coxswain motivates the rowers and ensures the game plan of the coach is executed [57]. The positions of the rowers can be found in Figure 3.

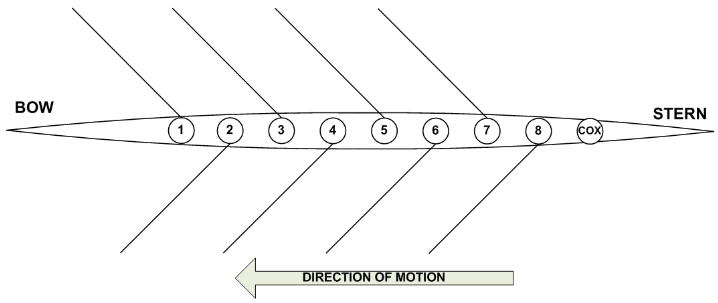


Figure 3: Rowing positions in a boat, in which the first rower is the bow and eighth rower is the stroke[10]

2.2.3 Rowing in Virtual Reality

Injuries are common in rowing, particularly in the lumbar spine, due to intense training schedules and incorrect techniques of beginner rowers. Coaching is crucial for proper technique, however coaches may have limited time to work with each rower or may be biased towards certain athletes. Additionally, weather conditions can sometimes restrict training on water, making indoor rowing on a rowing machine an integral part of the sport. Even so, interpreting data from rowing machines can be challenging for beginners, and even experienced rowers may struggle to optimize their technique based on the displayed data. Thus, there is a need for improvement to make this information more accessible and valuable for rowers of all skill levels [32]. Virtual Reality rowing can provide an alternative solution. Moreover, the study by Murray et al. [33] demonstrates that immersive VR rowing can increase performance and enjoyment compared to rowing without VR.

2.3 Related work

This section describes the current state-of-the-art of VR rowing systems.

Holofit[11] is a VR rowing fitness app that users can download onto their VR headset. The app offers exercises for rowing, cycling, running, skiing and workouts. In the rowing exercises, the user can explore different environments from real-world locations, such as Paris and San Francisco, or imaginative realms, such as Saturn and a Cyberpunk world. Holofit offers the possibility to row against other users as well as to row individually.

[10]Academic Accelerator, Boat Positions - `https://tinyurl.com/boatpositions`
[11]Holofit - `https://www.holodia.com/`

Figure 4: Images of the Holofit application[12]

Quiske[13] is a mobile application that can be used for on-water rowing or for rowing on a rowing machine. The app employs motion-tracking devices to provide real-time feedback to rowers about their performance. It displays the rower's speed during their performance and provides feedback on their stroke, speed, and rhythm afterward. Furthermore, the application includes a virtual coach function that sets targets for the rower. After the exercise, the rower can view whether these goals have been achieved.

Figure 5: Images of the Quiske application[13]

BioRowTech[14] provides equipment and technology for optimizing rowing performance. Their technology is created for rowing machines, and utilizes sensors that can be attached to the rower's clothes, handle, and seat. It provides visual feedback on common errors, like incorrect arm movements, bending the back too early, and excessive back movement at the finish. The technology is created to help rowers improve their technique, efficiency, and overall performance. The system can be found in Figure 6a.

[12] Holofit - https://www.holodia.com/
[13] Quiske - https://www.rowingperformance.com/
[14] BioRowTech - https://tinyurl.com/biorowtech

The M3 (Multi-Modal Motion synthesis) simulator[15] offers an immersive rowing experience in which the user rows on a rowing machine and in which a virtual world surrounds him on large screens. This system combines haptic oar movement with visual and auditory feedback, and guides the path of the oar of the rower. The system increases resistance when the rower tries to deviate from the ideal rowing path. The system can also identify the zones where the rower is prone to make mistakes and increases the force in this area. The system can be found in Figure 6b.

(a) (b)

Figure 6: Images of two rowing systems. The Figure on the left shows the BioRowTech application[16] and the Figure on the right presents the M3 (Multi-Modal Motion synthesis) simulator[15]

The University of Twente possesses multiple VR rowing setups that are continuously improved. Various students and teachers have contributed to these setups, significantly improving different aspects of VR rowing. Recently, the VU Amsterdam has introduced a rowing setup, enabling the possibility to row over a distance with multiple rowers. In the following sections, projects within VR rowing are described.

Vogel [34] conducted a comparative study to analyze the impact of VR on the rowing performance. The results showed a slight increase in enjoyment and improved engagement when using the VR system. Additionally, the study showed a tendency towards better performance with VR, although this finding was not statistically significant. Further research with a larger sample size and a more robust methodology is necessary to confirm these preliminary findings.

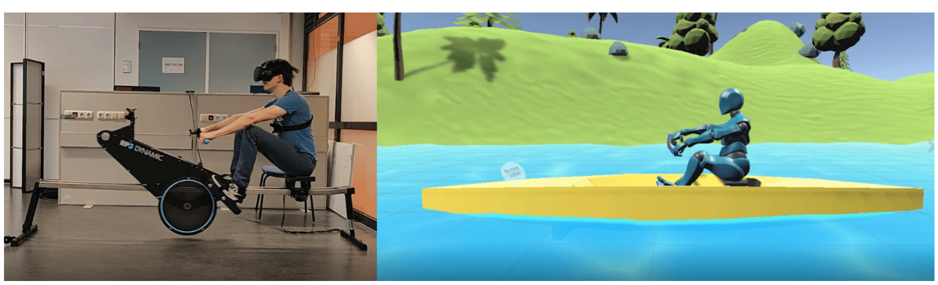


Figure 7: VR rowing installation created by Vogel [34]

[15]Multi-Modal Motion synthesis) - `https://www.rowing.ethz.ch/`
[16]BioRowTech - `https://tinyurl.com/biorowtech`

Van Delden et al. [32] built upon the research of Vogel [34] as they integrated multi-model feedback in the VR rowing system. For their installation, they employed the HTC Vive headset and related motion-tracking devices. Moreover, the VR environment was created with Unity and SteamVR. They also provided a software platform featuring instructions and calibrations that can be used for future projects. The system can be found in Figure 8.

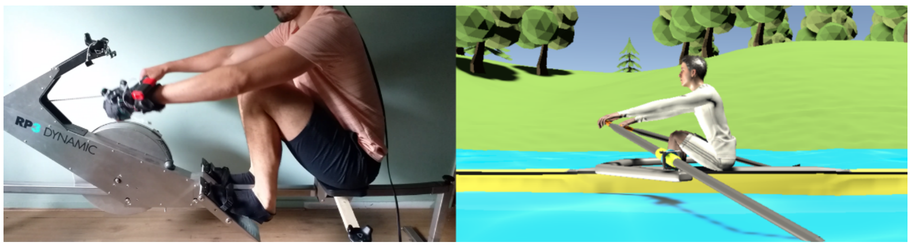


Figure 8: VR rowing installation of Delden et al. [32]

Blom [35] recently integrated sonification into VR rowing and demonstrated its potential to improve performance. Additionally, the virtual environment that contained sonification was frequently perceived as engaging and immersive. In contrast, no significant effect was found on the effect of sonification on the stroke form and angular velocity. Despite this, these findings offered an interesting approach to the potential of sonification for enhancing VR performance and engagement.

Currently, Weldink and Sikkens are investigating the use of VR as a potential tool to facilitate training of interpersonal coordination in sports, with a focus on crew rowing. They have designed and developed a virtual rowing environment that can host co-located rowers. In addition, they have crafted and implemented visually augmented feedback tailored to the respective roles of the rowers. Lastly, they have migrated the rowing environment to the program NeosVR. Since these theses still need to be published, no associated publication is available yet. However, this thesis will expand upon their work.

2.4 Conclusion

This chapter aimed to create a framework for the concept of "(social) presence". The chapter began by exploring the different facets of presence, which can be categorized into four groups according to the reviewed literature: perception and understanding, (emotional) connectedness, space, and interaction. Moreover, the measurement methods of presence were reviewed, revealing a preference for psychological measurements, such as the Networked Minds Measure questionnaire [23] or other (co-)presence questionnaires. Upon inspecting the determinants of social presence, it became evident that various elements are essential when stimulating social presence, such as exertion, communication, immersive Virtual Reality, realistic interactions, control, and sensory factors. Afterward, the chapter examined the current state-of-the-art of VR rowing, which showed that the rapidly evolving area of VR rowing offers many different research directions. These studies have shown the potential for VR in rowing exercises in terms of performance, enjoyment, and engagement.

In conclusion, Chapter 2 sets the foundation for the research and design chapters by establishing a comprehensive framework of (social) presence and its significance in the context of rowing.

3 Towards a Design of a Virtual Coxswain

This thesis focuses on creating a design for a VR rowing experience that enhances social presence. A more comprehensive framework of the dynamics within a rowing team and the current VR rowing setup should be described to determine an optimal design approach. Therefore, this chapter entails observations and rowing expert meetings. Additionally, the current VR rowing system will be described. Thereafter, the thesis moves towards an ideation phase containing a brainstorming session and storyboard sketches. This results in the final design of the virtual coxswain.

3.1 Observations DRV Euros

Observations could provide a way to gain a deeper insight into the dynamics of a rowing team, allowing one to identify behavioral patterns within the team. This section will discuss the observations at the local rowing club in Enschede, DRV Euros.

3.1.1 Method

DRV Euros was contacted via mail and asked about the possibility of observing a rowing training session or a game. In response, the club confirmed that joining the rowing training of a lightweight category team was possible. The team consisted of eight male rowers, a coxswain, and a coach who were aged from 18 to 25 years old.

Before the observations, an information brochure and consent forms are sent to the rowing club and team (see Appendix D). Upon arrival at the rowing club, the rowers are informed about the research and the observation session. Afterward, the rowers are instructed to sign the consent form. Next, the rowers are explained to behave normally during the rowing training and to ignore my presence. Then, the rowing training starts. During the session, the rowers row along the Twentekanaal. This gives an opportunity to observe the training by cycling next to the boat. Since it is difficult to write notes while cycling, verbal notes are recorded with earphones and saved to a smartphone. At the same time, the coach is interviewed about rowing in general and the dynamics of a team. This interview is a non-structured interview with no prepared questions in advance. Additionally, quick notes are documented using the notes application on the smartphone. For the analysis, notes from the observations and interview recordings are categorized and grouped into similar topics using the thematic analysis method proposed by Braun and Clarke [36]. Following this, reoccurring patterns or trends are identified, interpreted, and analyzed. Upon completion of the training, a debriefing session takes place, in which participants are thanked for their involvement in the study.

3.1.2 Results

During the observation, a reoccurring topic was "communication", which had multiple facets, including "communication during training" and "communication pre- or post-training". During the training or match, it was noticed that only the coxswain and the coach used verbal communication. The coxswain spoke in a rhythmic pattern and took the role of the coach within the boat. Additionally, the coach used a megaphone to communicate instructions to the coxswain. Notably, the rowers interacted very little with each other during rowing, because they were often to exhausted to talk. They communicated a lot with each other pre- and post-training, and these interactions were often casual in nature. Another observation within this topic is that the coach actively provided feedback during intermediate discussions. In addition, a reoccurring theme revolved around "interactions before, during, or after a match". Similarly to the training session, the rowers did not communicate much during rowing matches, however they did engage in casual interactions pre-matches. On the other hand, there was minimal interaction observed post-matches. When the rowers experienced victories or losses in the race, there were limited occurrences of shared celebrations or grief among the rowers. This entails a variety of verbal or non-verbal interactions between the rowers as a result of them winning or losing. The last topic implies the "dynamics within the team". In this topic, it was seen that the rowers were very friendly to each other pre- and post-training and matches.

3.1.3 Discussion and conclusion

During the training session or matches, it was observed that verbal communication only occurred between the coach and the coxswain. Rowers were often too fatigued to speak and listened carefully to the instructions. This stresses the fact that the coach and coxswain play a big role in the team dynamics. In contrast, the rowers engaged in enthusiastic and friendly interactions with each other pre- and post-training and matches. Hence, a strong sense of team spirit was evident within the teams. Concluding, these observations provided valuable insights into the structure of a rowing training and the dynamics within a team.

3.2 Symposium

A symposium was organized in Amsterdam to investigate the multi-person VR rowing platform. This symposium was arranged by the University of Twente and the VU Amsterdam. During the symposium, several presentations presented information about rowing in VR, synchronization in rowing, the design and development of the RP3 rowing simulator and the rowing platform, and the future possibilities offered by the "Rowing Reimagined" platform. The symposium concluded with a poster session in which discussions emerged about current studies in VR rowing and future platform opportunities. Within these discussions, rowing experts suggested looking at online rowing sessions or matches to gain a more profound knowledge of the rowing team dynamics. Considering this advice, the next section will provide the findings of the observations of online rowing sessions.

3.3 Observations online

In addition to previous observations of rowing training sessions and matches, online rowing matches are analyzed to further enhance an understanding of team dynamics within rowing.

3.3.1 Method

The participants in the videos are both male and female Olympic rowers. The dataset includes videos of two men's eight boats, one men's two boat, three women's eight boats, two women's two boats, and a video of a coxswain during a match. Furthermore, this analysis employs the platform

YouTube, and a reference list containing the links to all YouTube videos can be found at the end of this thesis. To gain more insights into the dynamics of a rowing team, we select videos featuring Olympic rowing teams, as these matches are often well-recorded and have a high video quality. The videos frequently start a bit before and end a bit after the match, allowing for a complete observation and facilitating a detailed analysis. Olympic rowing teams, composed of professionals, are expected to present strong team dynamics. Therefore, they can provide valuable learning opportunities. The videos are viewed while taking written notes. Both qualitative and quantitative data are collected. Concerning qualitative data, interested quotes are documented, and in terms of quantitative data, the frequency of specific events is notated, such as interactions among team members. Subsequently, the observations are categorized, and reoccurring patterns are identified using the thematic analysis method proposed by Braun and Clarke [36]. Lastly, these patterns are analyzed and discussed.

3.3.2 Results

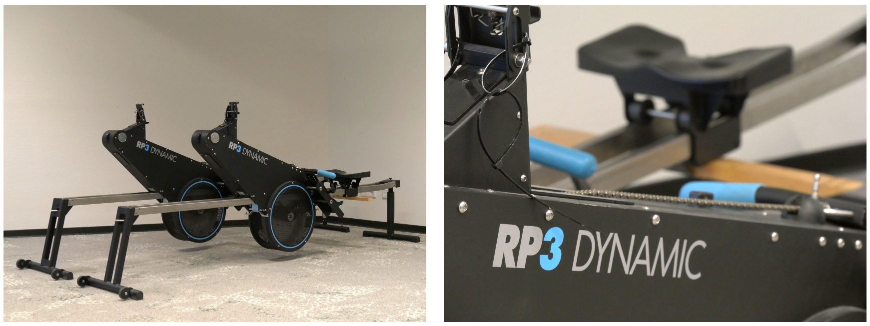
During the analysis of Olympic rowing match videos, several reoccurring topics are evident, such as "shared celebrations", "shared grief", and "communication of coxswain". These videos show that rowers often use non-verbal communication when they win, such as high-fives, handshakes, and shoulder taps. The celebration methods that male rowers use have a wide range of diversity [58]–[60]. Especially shoulder taps (four times) and hugs (three times) are the most frequently observed methods, followed by handshakes (two times), sometimes even with opponents (two times), and taps on other body parts, such as the head or knee (two times). In contrast, female rowers primarily hug when celebrating (seven times) [61]–[64]. Moreover, they exchange taps on the shoulder or knees (five times), while handshakes are less commonly observed (one time). When examining the topic of "shared grief", male rowers tend to tap on each other's knees during moments of grief (two times), whereas there is almost no interaction between female rowers [59]. Only an occasional tap on the knee is observed (one time) [62]. An analysis of the coxswain's video [65] makes it apparent that the coxswain communicates a lot, especially in contrast to the rowers who minimally engage in communication. It is observed that a coxswain says rhythmic and motivational sentences, which are different every time. She constantly reminds the rowers how important it is to win and how hard they have trained. Notably, the coxswain occasionally gives a rhythm, especially during pace adjustments, and to remind the rowers to manage their rhythm. Moreover, she addresses the rowers as a team and keeps them informed on the positions of other boats. Lastly, the coxswain gives updates on the distance until the finish line.

3.3.3 Discussion and conclusion

When analyzing the videos, it became apparent that shared celebrations are commonly used in Olympic teams. This is an interesting result, as this was not noticed during the in-person observations at DRV Euros. A common shared celebration method was hugs, which both male and female rowers used. Moreover, taps on the knee, shoulder, or head were also often employed. However, there seemed to be less interaction between the rowers in states of grief. Consequently, it is not advised to focus on the method of "shared grief" for the final design. In addition, similarly to the observations at DRV Euros, the rowers demonstrated minimal communication while rowing. Lastly, the observations at DRV Euros and the video observations showed the importance of a coxswain during rowing sessions. A good coxswain can genuinely motivate and push rowers over the finish line.

3.4 Current VR rowing setup

The current rowing setup uses two RP3 rowing machines[17] (see Figure 9). These are dynamic rowing machines that can mimic on-water rowing. Besides, dynamic rowing machines are also kinder towards the joints and back than static rowing machines[18]. The two rowing machines can be used at the same time.



(a) (b)

Figure 9: The rowing machines in the current VR rowing setup

The system uses Tundra trackers to track the movements of the rowing machine[19] (see Figure 10a). These trackers are placed on the front, the handle, and the seat of the rowing machine. The trackers are tracked by the Valve Base Stations[20] (see Figures 10b and 10c). Two, three, or four base stations are needed per rowing setup, and they track the position of the VR headset, controllers, and Tundra trackers. The system captures the movement of the two rowers in real-time.

(a) (b) (c)

Figure 10: Base stations and trackers of the current VR rowing setup

[17] RP3Rowing - `https://rp3rowing.com/`
[18] Rowing Performance: Dynamic vs. Static Indoor Rowing - `https://tinyurl.com/rowingperformance`
[19] Tundra trackers - `https://tundra-labs.com/`
[20] Valve Base Stations - `https://www.valvesoftware.com/en/index/base-stations`

The rowing environment can be experienced using VR technology. The HTC Vive Pro[21] and the Valve Index[22] headsets are utilized in the current setup. This setup visualizes the real-time movements of the rowers in VR. The users can communicate verbally via the headphones in the VR headsets.

(a)

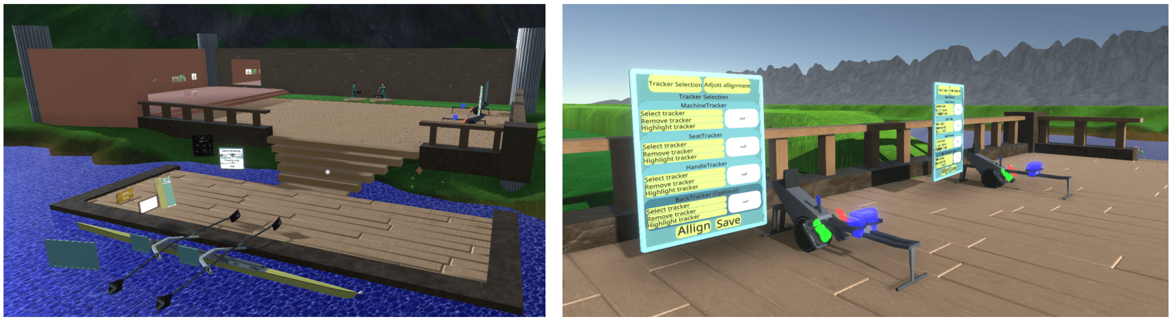
(b)

Figure 11: The Figure on the left shows the HTC Vive headset with controllers[21], and the Figure on the right demonstrates the Valve Index with controllers[22]

The VR technology software runs on SteamVR[23], which is a VR platform developed by Valve. It provides valuable options for VR, like tracking the position of VR headsets and controllers, and handling VR hardware and software. SteamVR supports many VR headsets, such as the HTC Vive, Valve Index, and Oculus headsets. The platform allows one to easily explore VR environments at home.

Besides SteamVR, the current system uses NeosVR[24] as well. This VR platform, created by Solirax, allows users to create, modify, and engage in collaborative virtual environments. NeosVR provides compatibility with both desktop setups as well as VR devices. Moreover, it has a significant and active community on Discord[25], where users share knowledge and experiences with each other. For the collaborative rowing project, a NeosVR rowing environment has been created. In this environment, multiple rowers can join, walk around, and row together in a boat.

[21] HTC Vive Pro VR headsets - `https://www.vive.com/eu/product/vive-pro/`
[22] Valve Index VR headsets - `https://www.valvesoftware.com/nl/index`
[23] SteamVR - `https://store.steampowered.com/app/250820/SteamVR/`
[24] NeosVR - `https://neos.com/`
[25] NeosVR Discord - `https://discord.gg/neosvr`



(a) (b)

Figure 12: The Figure on the left shows the rowing platform in NeosVR, and the Figure on the right shows the menu for selecting and adjusting the trackers on the rowing machines

3.5 Brainstorm session

Given that the social dimension is essential in team rowing, we will focus on “social presence”. The findings from chapter 2 demonstrate that the categories “(emotional) connectedness” and “interaction” are important within social presence. Therefore, the accompanying determinants will serve as guidance for the brainstorming session (see Figure 13).

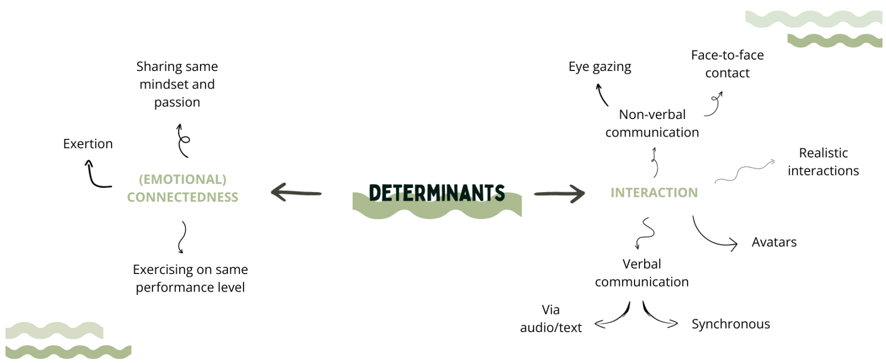


Figure 13: Determinants of the categories “(emotional) connectedness” and “interaction”, derived from Figure 1

Considering the in-person and online observations, we hold a brainstorming session. This session aims to generate potential design solutions that stimulate social presence within a VR rowing experience. Initially, an extensive list of brainstorming ideas is produced. Next, unrealistic ideas and concepts that lack alignment with the topic are excluded. Finally, a mind-map of the most suitable ideas is generated and can be found in Figure 14.

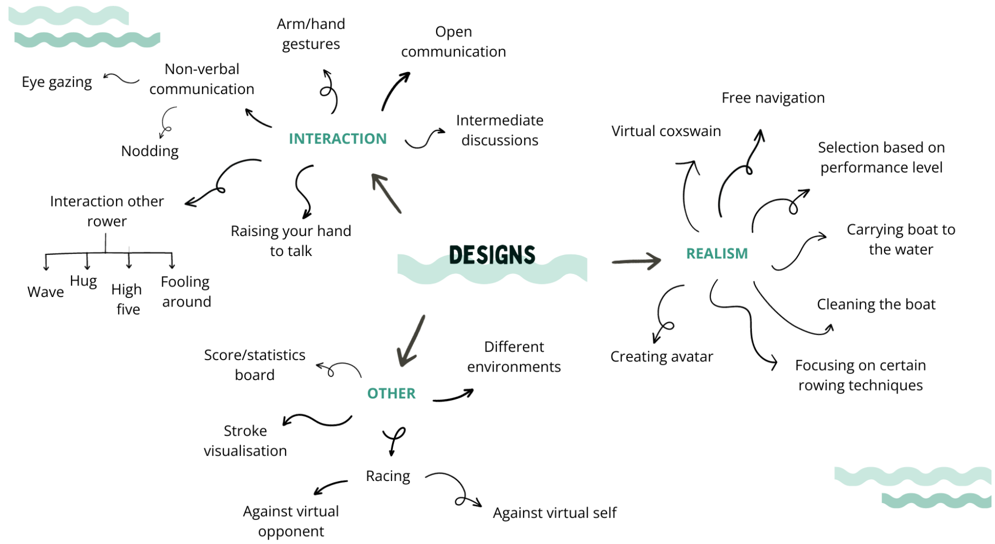


Figure 14: Mind-map of the possible design solutions

During the brainstorming session, it becomes evident that there are many approaches to influence social presence. One approach is to create a design that directly impacts the social presence between the rowers, however another approach could involve affecting the social presence between the rowers using a third virtual person, such as a coxswain or coach. For instance, adding "arm/hand gestures" to the avatars of the rowers can facilitate non-verbal communication between the rowers, hence this design enhances social presence directly between the two rowers. In contrast, the idea of "racing against a virtual opponent" uses the opponent as a mediator to improve social presence between the two rowers. The social presence is therefore indirectly influenced. Both approaches give interesting design options.

3.6 Storyboard sketches

The first step after brainstorming is to create a low-fidelity storyboard, which is a practical way to assess the usability of a design. The low-fidelity storyboard is made by sketching on paper. This makes storyboarding quick and easy. Additionally, they facilitate the generation of multiple scenarios and ideas and enable rapid iterations. Moreover, storyboards generally allow for the possibility to easily convey ideas, as explaining a story solely through text might be difficult [37]. The low-fidelity storyboard is created by reviewing and sketching the ideas of the brainstorm. The storyboard can be found in Figure 15.

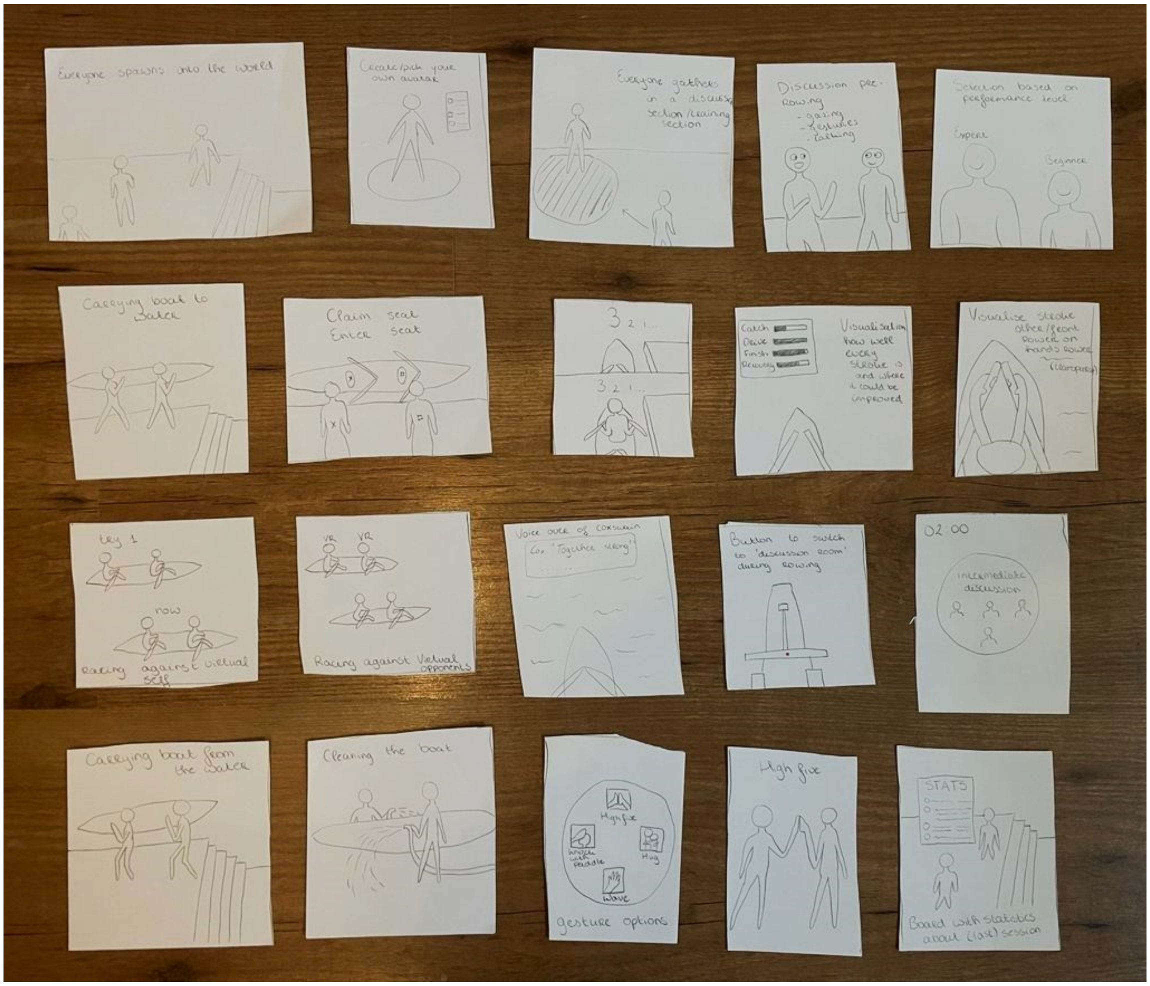


Figure 15: Various storyboard scenarios derived from the design solutions of Figure 14

The low-fidelity storyboards, constructed by cutting and assembling paper scenarios, offer flexibility to show different scenarios by adding, removing, and merging different scenarios. Figure 16 shows the possibility of creating a smaller scenario derived from the more extensive collection of scenarios.

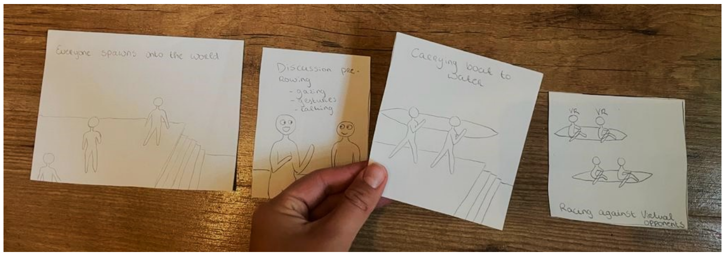


Figure 16: An example of a storyboard by merging different scenarios

All scenarios from the storyboard are reviewed, and for this thesis, we choose to design a virtual coxswain who stimulates social presence between two rowers. This choice is supported by the observations at DRV Euros (see Section 3.1), as they demonstrated that the coxswain plays a significant role within a rowing team. Besides the coach, the coxswain is the only person involved in verbal communication during training sessions and matches. Additionally, online observations (see Section 3.3) illustrate that a good coxswain can motivate the rowers and enhance the team spirit. Lastly, this idea was discussed and approved by the supervisors of this thesis. Several paper scenarios are merged to create the final low-fidelity storyboard of the virtual coxswain and can be found in Figure 17. The design of the coxswain is discussed in the following sections.

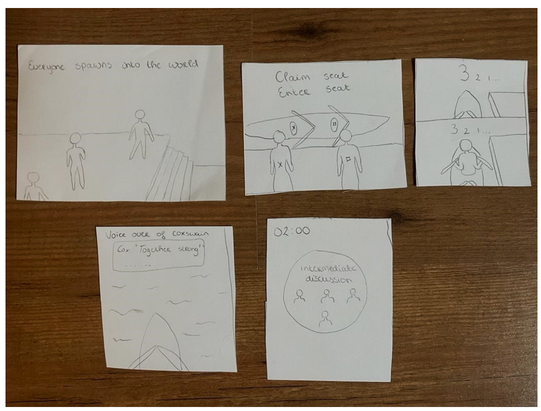


Figure 17: The final low-fidelity storyboard of the virtual coxswain scenario

The low-fidelity storyboard is expanded and refined, including two scenarios: one with an embodied coxswain enhancing social presence and one without a coxswain. In the coxswain scenario, the coxswain has an avatar and a name. As revealed by the findings of the context analysis, this enhances realism, which improves social presence. Besides, this choice aims to foster a more personal connection between the rowers and the coxswain. In addition, the findings of the context analysis, the observations at DRV Euros, and the online observations indicate that employing different verbal cues enhances social presence, for instance, stimulating communication between the rowers, addressing the rowers as a team, and empathizing that the rowers are a team. Moreover, non-verbal cues, such as eye contact, nodding, and arm and hand gestures, are integrated into the coxswain to improve social presence further. The storyboard of the virtual coxswain can be found in Figure 18.

The concept of the "non-embodied agent" is introduced in the scenario without coxswain. This agent lacks personal characteristics, such as a name, an avatar, and a personalized voice-over. Additionally, this coxswain refrains from using the pronoun "I" to avoid a personal relationship with the rowers. This agent strictly provides instructions for rowing and does not stimulate communication between the rowers or does not address them as a team. The storyboard of the second scenario can be found in Figure 19.

Figure 18: Storyboard of the embodied coxswain scenario

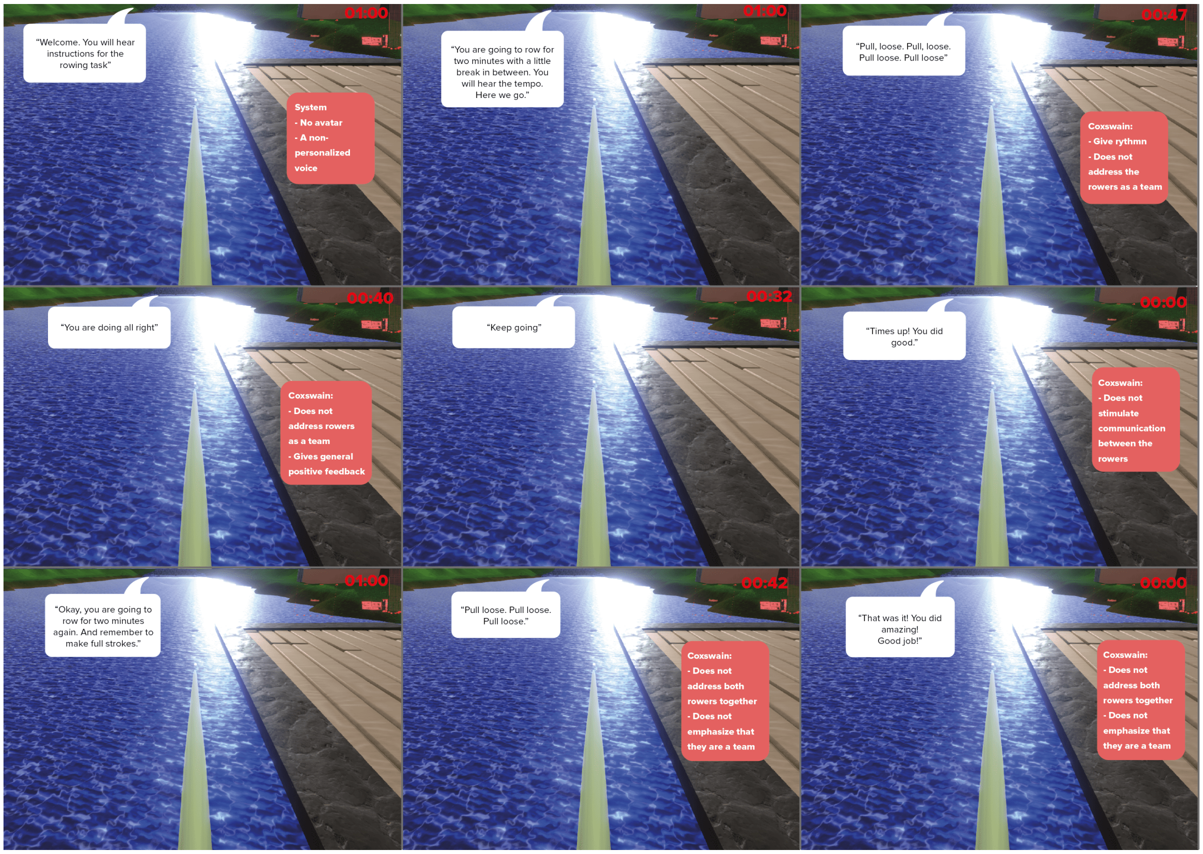


Figure 19: Storyboard of the non-embodied agent scenario

3.7 The final design of the coxswain

The final design of the coxswain will be explained through the use of system requirements that are essential to achieve a design that improves social presence.

Given that realism enhances social presence, one of the requirements of the system is a realistic coxswain. Therefore, the animation of the coxswain will be created using motion tracking technology, meaning that the real-time movement and position of a person are monitored and captured. The base stations already track the positions of the VR headset and the controllers, and they are mapped on the head and hands of a virtual avatar. Moreover, Tundra trackers are placed on the body to ensure a realistic animation of the coxswain. Multiple locations of the trackers were explored, such as the elbows, chest, hips, knees, and feet. Eventually, the most optimal real-time translation of the movement was obtained by placing the trackers on the chest, hips, and feet. The final tracker placement can be found in Figure 20a.

Besides real-time motion tracking, incorporating face tracking offers several benefits, such as adding a higher level of realism to the coxswain. Moreover, face tracking allows the virtual coxswain to make eye contact with the rowers and nodding movements when the rowers are communicating. To achieve this requirement, the Vive Facial Tracker will be employed. This tracker can record up to 38 different facial movements and can be easily attached to the Vive Pro Headset (see Figure 20b). To utilize the Vive Facial Tracker, the Vive Console software should be downloaded from the Steam library[26].

(a) (b)

Figure 20: The Figure on the left shows the tracker placement for the animation of the virtual coxswain, and the Figure on the right shows the real-time facial tracking from the Vive Facial Tracker

The next requirement of the system is translating the movements to NeosVR. A program that allows you to do this is MetaGen[27], which is a plugin that facilitates users to record and playback animations within NeosVR. MetaGen not only supports the recording of body animations, but can also be used for recording face animations and voices. This tool is developed by Guillefix, who also contributes to multiple NeosVR projects. Once the recording of the animation is complete, MetaGen generates a copy of the avatar within the virtual world, together with options to manipulate the animation. These options enable the user to place the animation anywhere in the world with the possibility to mute the sound.

[26]VIVE Facial Tracker - `https://www.vive.com/eu/accessory/facial-tracker/`
[27]Metagen - `https://github.com/MetaGenAI/MetaGenNeos`

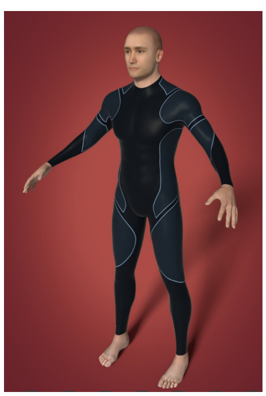
(a)

(b)

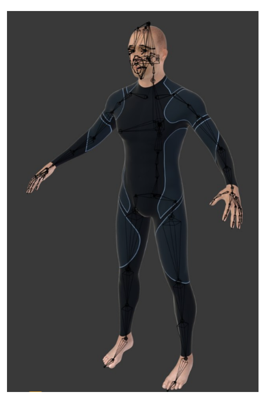
(c)

Figure 21: The movements are captured in real-time and translated to a virtual avatar

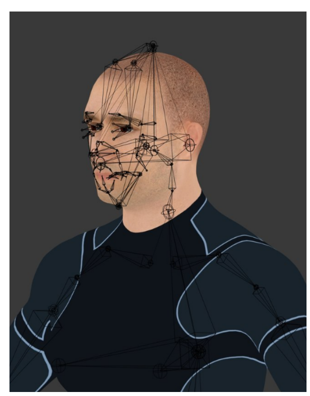
First, the animations are tested on a free character from the NeosVR library (see Figure 20b and 21). This character is already equipped for face tracking. After considering the number and positioning of the trackers, animations with this character are recorded and reviewed. Once the animations seem satisfactory, a more suitable avatar is searched. Multiple characters are inspected, and a male, sporty character is eventually chosen. This character contains a mesh, textures, and a rig (including the face) and is ready for animation. This character can be found in Figure 22. In conclusion, this fulfills one of the requirements that indicates that the coxswain has an avatar and that the avatar and animations of the coxswain look realistic.



(a) Mesh of the avatar



(b) Rig of the body of the avatar



(c) Rig of the face of the avatar

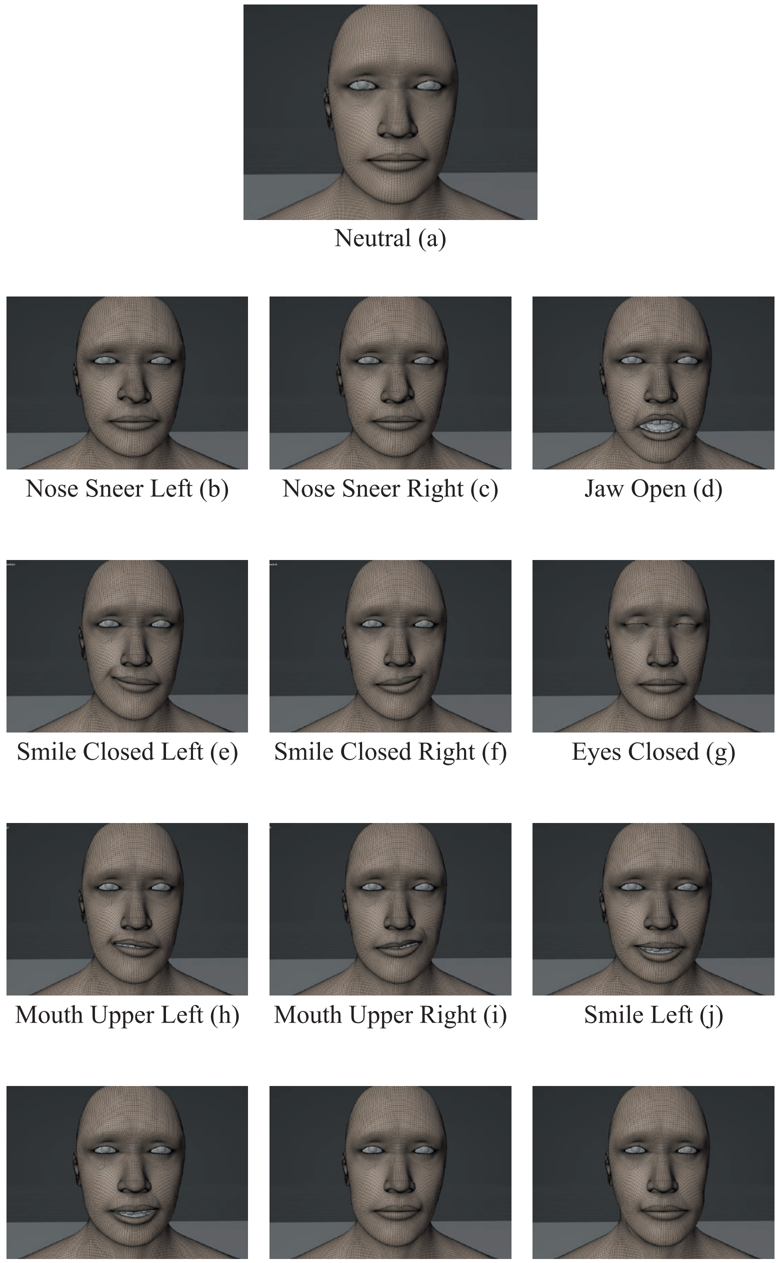
Figure 22: 3D model of the virtual coxswain. The character is downloaded from Turbosquid[28]

[28] 3D model from Turbosquid - `https://www.turbosquid.com/3d-models/3d-surfer---swimmer-1555465`

Figure 23: Real-time body and facial movements translate to the coxswain avatar

While exporting the character to NeosVR, it becomes evident that the face tracking is not performing optimally. While basic face-tracking functions are executed correctly, such as eye tracking and opening the mouth, more complex facial animations, such as smiling or expressions, are not implemented yet. To improve realism, the character is edited in Blender[29]. Blender makes use of blendshapes which are facial movements, such as a frown, a closed smile or an open jaw. These blendshapes could have minimal expressions, such as a nose sneer, or pronounced expressions, such as opening the jaw and sticking out the tongue. These blendshapes can be exported as visemes to NeosVR. NeosVR recognizes 58 different visemes. A selection of crucial visemes is made based on the visemes of the free avatar in NeosVR (see Figure 20b and 21). This avatar also serves as a testing character for the body animations in the previous section. The most important visemes are established by equipping this avatar, generating several facial expressions (e.g., talking and smiling), and analyzing the inventory. The inventory highlights the visemes that are mostly used during the expressions. Accordingly, the initial creation involved five different visemes: neutral, open jaw, smile with the left side of the mouth, smile with the right side of the mouth, and eyes closed. After testing these visemes, it is noted that more visemes were needed to achieve a realistic appearance. Additional visemes are added to the coxswain and iterated until a satisfactory level of realism is reached. The final coxswain contains 13 different visemes (Figure 24). Figure 25 demonstrates the appearance of the visemes within NeosVR.

[29]Blender blendshapes - `https://docs.unity3d.com/Manual/BlendShapes.html`


Neutral (a)

Nose Sneer Left (b) | Nose Sneer Right (c) | Jaw Open (d)

Smile Closed Left (e) | Smile Closed Right (f) | Eyes Closed (g)

Mouth Upper Left (h) | Mouth Upper Right (i) | Smile Left (j)

Smile Right (k) | Jaw Left (l) | Jaw Right (m)

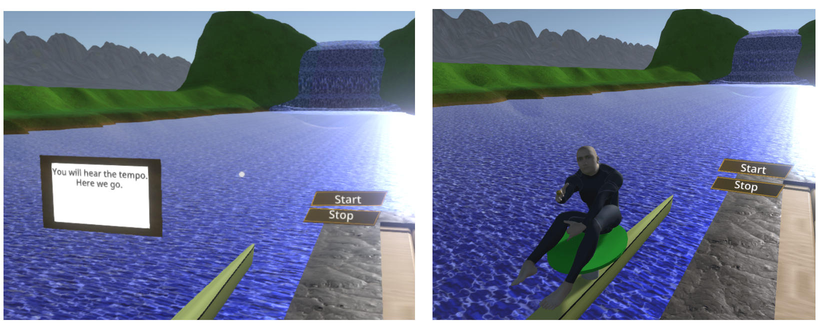
Figure 24: Blendshapes of the face of the coxswain

(a) (b)

Figure 25: Real-time facial movements translate to the coxswain avatar

In addition to a realistic appearance, the coxswain should have a realistic voice. A 21-year-old male provides the voice, as a male 3D model is employed to portray the coxswain. A system requirement entails that the participants should be able to hear the coxswain and the other rower via the VR headsets.

Furthermore, a few technical requirements should be implemented. Firstly, the system must track the positions and movements of the rowers on the rowing machine in real time and map these correctly to NeosVR. This is needed to preserve realism and engagement. Moreover, it is essential to have an option to activate, deactivate, and pause the animations. This is required due to sudden scenarios, for instance, when a participant is not ready or when the wrong animation is accidentally started.



(a) (b)

Figure 26: Captures from the condition with the non-embodied agent (left) and the embodied coxswain (right)

4 Study Design

This chapter provides an overview of the study design utilized for the experiments. It will include a description of how the experiments are structured, such as the participant recruitment, the materials, the conditions that will be tested, the procedure, and the methods applied for the data analysis.

4.1 Participant recruitment

The participants in this study are recruited from our social network and consist exclusively of University of Twente students. The selection of participants from the same university as us facilitates the recruitment process. Over 100 people are invited to join the experiments. All participants who join the experiments are informed about the experiment in advance, and the informed consent is sent to them in advance as well.

Prior knowledge of rowing or Virtual Reality is not a requisition for the participants. As two participants are involved in each experiment, there is a possibility that the participants already know each other. Consequently, the participants are asked to indicate whether they know the other participant. It is assumed this factor will not significantly impact the experiment, as the goal of the experiment is to measure the social presence between the two conditions rather than the overall social presence levels.

An evident limitation of this thesis is that it has a small sample size, and the participant pool lacks diversity in terms of rowing experience, prior knowledge of VR, and familiarity between participants. Besides, the study only contains participants from a certain age group and academic background.

4.2 Materials

For the experiments, computers, rowing machines, VR headsets, controllers, trackers, and base stations are needed (elaborate description in Section 3.4). Moreover, a third computer is needed to make notes during the experiment and to start, stop, and reset the conditions in NeosVR. A limitation of the technology is that the audio was not working in three experiments, which caused issues in communication between the rowers (experiments one, two, and five). For these experiments, the solution involved using the mobile phones of the participants to call each other and placing the phones close to them.

Furthermore, the informed consent forms are printed for the experiments. During the experiments, participants are instructed to fill in the questionnaires in Google Forms[30], a platform selected for its ease of data transfer to other programs. Moreover, the experiment procedure is written down on whiteboards in the rooms, ensuring that participants are well informed.

[30]Google Forms - www.google.com/intl/nl_nl/forms/about/

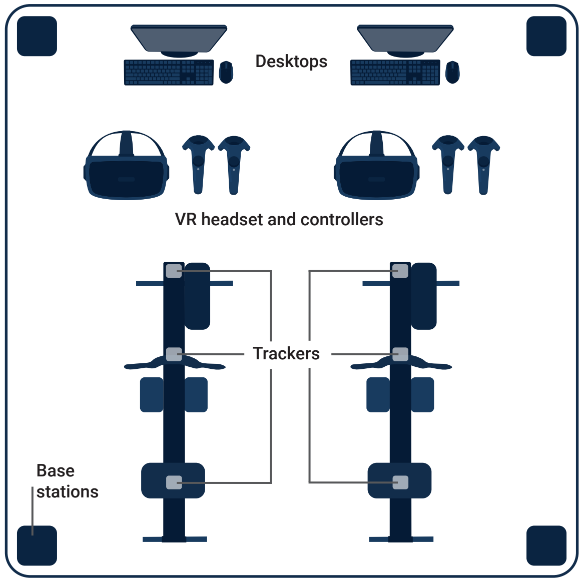
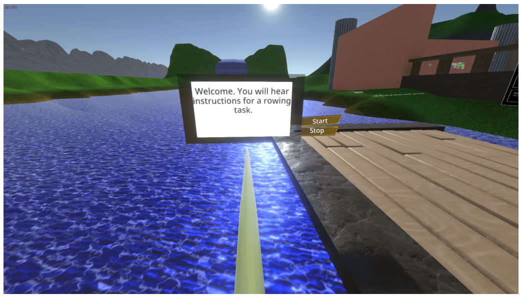


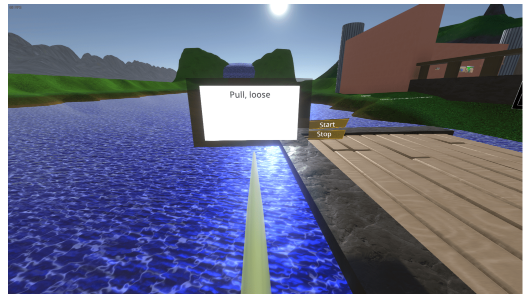
Figure 27: Experimental setup

4.3 Conditions

For the experiment, we choose to test two conditions. In the condition involving the non-embodied agent, verbal instructions are provided, which can also be read on a screen (see Figure 28). In the condition with the embodied agent/coxswain, the agent provides verbal instructions (see Figure 29). The reason for choosing two conditions instead of more, such as a condition without VR or without instructions, is that fatigue might become an issue when participants are rowing for a while. Also, it is unsure what the effect is of spending more time together on social presence, as spending time together might enhance social presence. Lastly, testing more conditions can increase the amount and amplitude of random variables and might augment a learning effect.



(a) Non-embodied agent introduction



(b) Non-embodied agent giving a rhythm

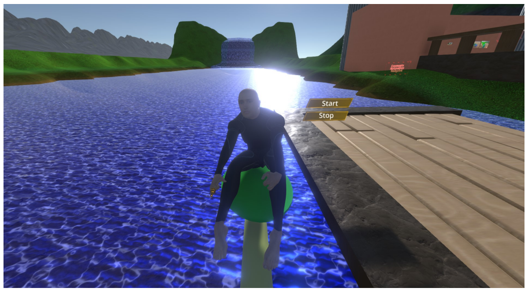
(c) Non-embodied agent providing positive feedback

(d) Non-embodied agent instructions

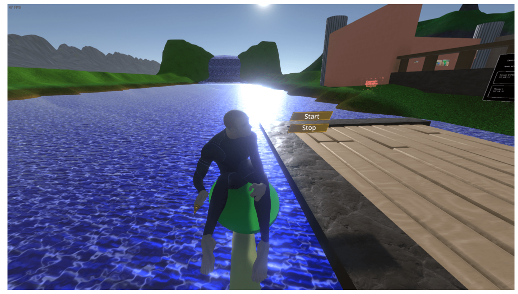
(e) Non-embodied agent providing positive feedback

(f) Non-embodied agent end of training

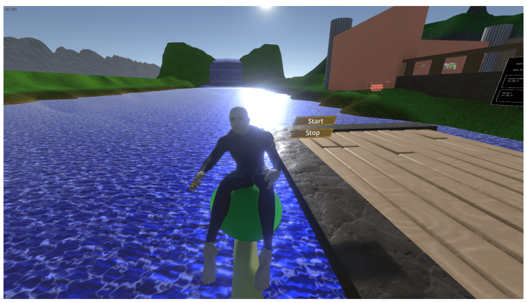
Figure 28: Captures of the non-embodied agent in various moments



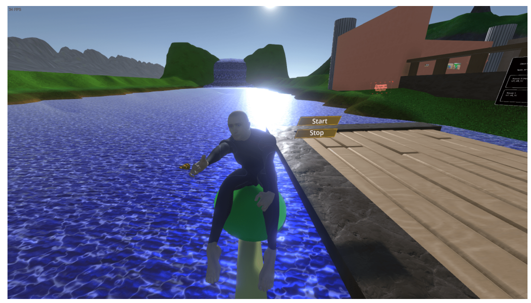
(a) Front view of embodied agent



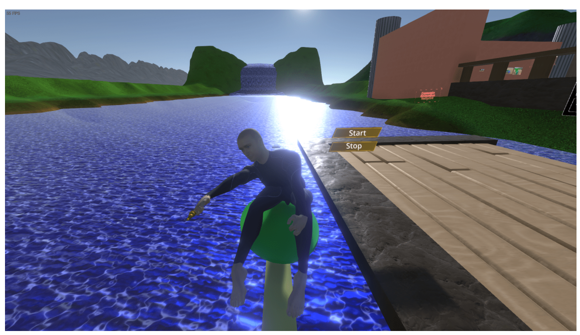
(b) Embodied agent reflecting on progress



(c) Embodied agent communicating non-verbally by using gestures



(d) Embodied agent gesturing to front rower



(e) Embodied agent gesturing to back rower

Figure 29: Captures of the embodied agent in various moments

We choose a within-subject design, meaning that every participant tests both conditions. This decision is made to diminish the impact of individual differences, since these differences are relatively small in a within-subject design compared to a between-subject design. A within-subject design also requires fewer participants. Nevertheless, learning effects and bias can play a role in a within-subject design. To address these issues, the conditions are tested in a random order (see Table 1). Moreover, fatigue could cause inaccuracies in the results. Therefore, the experiments should not be excessively long. Lazar et al. [38] advise to have experiments that do not exceed 90 minutes. Furthermore, the participants should indicate their fatigue level between testing the first and second condition.

Table 1: Randomized order of the conditions during the experiments

Experiment	Condition 1	Condition 2
Pilot	Embodied agent	Non-embodied agent
1	Embodied agent	Non-embodied agent
2	Embodied agent	Non-embodied agent
3	Embodied agent	Non-embodied agent
4	Non-Embodied agent	Embodied agent
5	Embodied agent	Non-embodied agent
6	Non-embodied agent	Embodied agent
7	Non-embodied agent	Embodied agent
8	Non-embodied agent	Embodied agent
9	Embodied agent	Non-embodied agent
10	Non-embodied agent	Embodied agent
11	Non-embodied agent	Embodied agent

4.4 Procedure

Prior to the experiment, participants are informed of the date, time, and location of the study. Also, they are briefly informed about the research and what is expected from them. Upon their arrival, the participants are guided to a room with one of the rowing setups. They are requested to read and sign the informed consent form (see Appendix D). Following this, the participants are briefed on the procedure of the study and informed on their rights as a participant (see Appendix E). Next, one of the participants is instructed to go to a separate room. There is a small window between the rooms, hence it is possible to observe both participants at the same time. Then, they are asked to fill in the IOS Scale (see Figure 30). This subjective measurement method indicates the level of perceived closeness between the participants. There are seven circles, with one representing the least close and seven representing the most close. Additionally, participants are asked about their prior experience with VR and rowing. Thereafter, the first condition of the study is tested, and upon completion, they are asked to fill in a questionnaire about social presence. The questionnaire that is used is the Networked Minds Measure questionnaire by Harms and Biocca [23], which consists of six different constructs and contains questions concerning social presence (see Appendix F.2). This questionnaire shows internal consistency and suits the intended measure. Besides, the participants are asked to fill in a questionnaire regarding the anthropomorphism of the agent (embodied or non-embodied agent). This questionnaire is conducted to examine how the participants perceive the agents and to determine whether the participants see the embodied agent as a social entity, while viewing the non-embodied agent differently. If the participants perceive the agents similarly, this may indicate design deficiencies or lack of effect of the embodied agent. The agent questionnaire is a combination of the Rapport Scale of Acosta and Ward [39], and the ASA questionnaire of Fitrianie et al. [40] (see Appendix F.3). Lastly, the participants are asked to rate their fatigue on a Likert scale from one to seven, where one represents "not fatigued at all" and seven represents "extremely fatigued". Afterwards, the participants experience the second condition. Once again, they are asked to complete the questionnaires and indicate their fatigue using the Likert scale. Throughout the experiment, the users are expected to row without assistance or supervision. This ensures the preservation of a consistent experimental condition throughout all experiments. Moreover, instructions can distract the rowers from the experience. After testing the second condition, a subsequent post-experiment discussion is conducted (see Appendix F.4). The post-experiment discussion is a group discussion during which participants are presented with questions about the experiment. During this discussion, the participants are given pictures that they need to associate with the agents (see Figure 31). They are asked to associate each agent with a picture displaying the least resemblance and a picture with the most resemblance to that agent. The objective is to analyze the descriptions of the participants about the agents. For instance, if the participants perceive the avatar as social, they will use social terms to describe the agent. However, if they perceive the avatar primarily as something technical, they will especially use technical words to describe the agent. Moreover, conducting this post-experiment simultaneously with two participants offers advantages, such as it requires less time for conducting and analyzing than individual interviews. Besides, it allows for discussions that reveal similarities or differences between opinions. Group discussions also stimulate interactivity between the participants, leading to more in-depth conversations. Moreover, it gives the possibility to dive deeper into specific topics, which is not possible with questionnaires alone. In cases where topics are unclear or require further elaboration, additional questions can be asked. Essentially, group discussions allow for the investigation of more interesting topics [38]. Finally, the participants are debriefed and thanked for their participation.

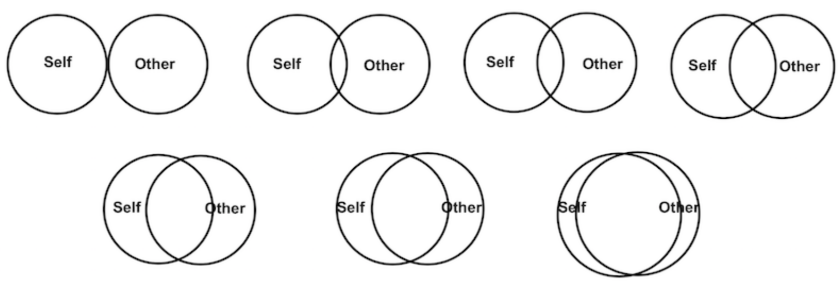


Figure 30: IOS Scale by Aron et al. [41]

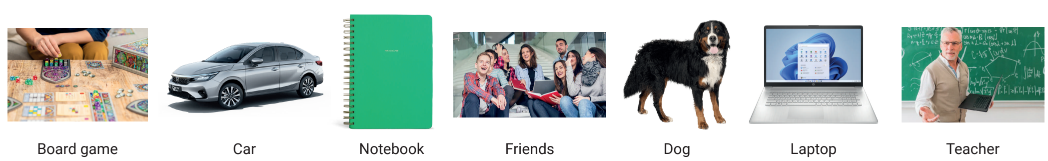


Figure 31: Pictures used in the post-experiment discussion, adapted from Escobar-Planas et al. [42] from a pediatric to an adult audience

This procedure was pilot-tested with two participants to identify potential areas for adjustment in preparation for the actual experiments. Several problems emerged during the pilot test that are in need of change. First, there was an ordering error when conducting the questionnaires, leading to uncertainty regarding which questionnaire corresponded to which condition. Therefore, a more organized approach when administering the questionnaires is required for the actual experiments. Furthermore, the back of the rowing machine was damaged, for this reason the front of the rowing machine is secured for the actual experiments. This modification will change the dynamic rowing machines into static ones. Additionally, it was observed that the sound from the third laptop must be turned off to prevent echoes during the experiments. Moreover, participants experienced confusion when they did not receive instructions for some time. As a solution, participants should be informed to continue rowing in the absence of instructions. Also, the pictures for the post-experiment discussion (see Figure 31) must be printed on a larger paper as they were scarcely visible during the pilot test. The positioning of the participants in the boat was sometimes incorrect, as they were skewed to the side. This positioning should be improved for the actual experiments. Lastly, the cables of the headset and the rowing machine should be positioned correctly during the experiment, as there were uncomfortable situations and a risk of accidental disconnection during the pilot test.

4.5 Analysis

The questionnaires provided a lot of data for analysis. The data is organized using the programming language R and the platform RStudio[31]. In the case of the Networked Minds Measure questionnaire [23], each participant responded to 36 questions for both conditions, resulting in a total of 72 outcome values per participant. This resulted in the first dataset containing 1584 data points, including the following variables: participant number (ranging from one to 22), question number (ranging from one to 36), category number (ranging from one to six, indicated by Harms and Biocca [23]), outcome (measured on a Likert scale from one to five), previous VR experience ("yes" or "no"), previous rowing experience (ranging from one to five), IOS scale ratings (indicating familiarity with other participant), condition (embodied coxswain or non-embodied agent), order of testing (sequence of conditions), the participants position in the boat and a self-reported fatigue level after every condition (ranging from one to five).

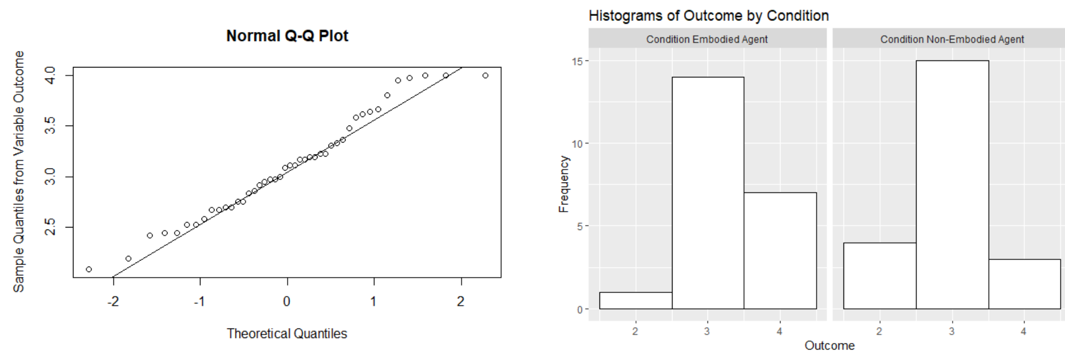
In R, all numerical values are seen as numeric variables. However, certain variables, including "condition", "category number", "question number", "indicator of previous VR experience", "position in the boat" and "order" should not be treated as numeric variables and are converted to nominal variables. Moreover, the variables regarding the previous rowing experience of the participants and their ratings of each other on the IOS scale are handled as ordinal variables (see Appendix H.1, Listing 1).

Looking at the dataset, it is noted that the Networked Minds Measure questionnaire is a survey, and therefore there is a connection between all individual questions. All questions combined should measure only one construct per condition, since the data should be assessed on a "survey" level [43]. This led to a new dataset containing a total of 44 data points available for analysis. This entails two data points for each participant, with one data point for each condition. This dataset contains the following variables: participant number (ranging from one to 22), condition (with coxswain or

[31] RStudio - `https://posit.co/download/rstudio-desktop/`

non-embodied agent), and the mean outcome values per participant for each condition.

One of the main objectives of this thesis is to see if the condition significantly affects the outcome. To determine the suitable statistical test, the dataset is assessed. Firstly, the normality of the data is inspected. The Q-Q plot, histogram, and Shapiro Wilk"s test ($W = 0.97$, $p = 0.273$; for calculations see Appendix H.1, Listing 2) suggest that the dataset is approximately normally distributed (see Figure 32).



(a) Q-Q plot of the variable outcome

(b) Histogram of the outcome per condition

Figure 32: Visualisation of variables "condition" and "outcome" to check normality. The calculations can be found in Appendix H.1, Listings 3 and 4

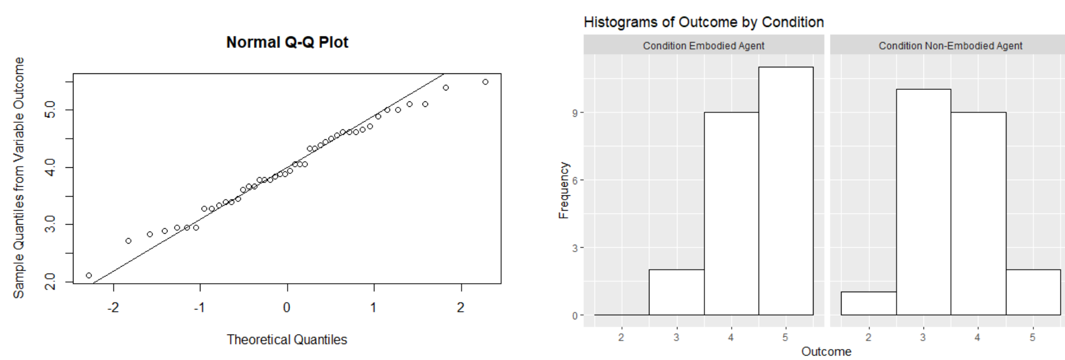
Next, it is worth noting that the observations of the participants are not independent of each other. The study uses a within-subject design in which every participant evaluates both conditions. This likely causes their responses on one survey to be correlated to the responses of the other survey. Therefore, this results in data dependency, meaning that the data points are not independent of each other. Besides, the participants in the same group may influence the responses of the other participant, further enhancing data interdependence. Neither the t-test nor ANOVA accounts for this data dependency, hence linear mixed effects regression analysis (LMER) emerges as a suitable alternative. LMER is a highly flexible statistical test and can account for within-subject variability [44]. Additionally, it allows the inclusion of fixed and random effects, which are factors that might influence the responses of the participants, such as their previous VR experience or their rowing experience. These factors cannot be included in other statistical tests, such as a t-test or ANOVA. Consequently, LMER is a more powerful tool for analyzing correlated data with a range of fixed and random effects [45], [46]. As a result, we choose to perform a LMER analysis. Due to computational issues, the analysis excludes several other variables, including prior VR or rowing experience. However, "participant" is included as a random variable to account for its impact.

Winter [44] poses the assumptions of LMER, accordingly they are verified for this dataset. The calculations can be found in Appendix G.1. Given that all assumptions of the LMER analysis are met, this test is used to analyze the experiment outcomes. The null hypothesis of a LMER analysis assumes that there is no significant effect of the predictor variable on the response variable, while the alternative hypothesis suggests that there is a significant effect of the predictor variable on the response variable. The hypothesis for the experiment is as follows:

H_0 : There is no significant effect of the condition with an embodied agent/coxswain on the outcome variable.
H_a : There is a significant effect of the condition with an embodied agent/coxswain on the outcome variable.

Regarding the agent questionnaire (see Appendix F.3), participants completed 18 questions for each condition, producing 36 data points per participant. This resulted in 392 data points in total. However, the dataset should again be treated as a survey, and therefore the mean outcome for every 18-question survey is taken. This leads to a dataset of 44 data points containing two data points for each condition for every participant. The dataset consists of the following variables: participant number (ranging from one to 22), condition (embodied coxswain or non-embodied agent), outcome (measured on a Likert scale from one to seven), and question number (ranging from one to 36). The variables “participant”, “condition” and “question number” should be considered as ordinal data instead of numeric variables, hence they are converted (see Appendix H.4, Listing 10).

Next, the normality of the data set is examined. The Q-Q plot, histogram, and Shapiro Wilk”s test ($W = 0.98$, $p = 0.7699$; for calculations see Appendix H.5, Listing 11) suggest that the data is approximately normally distributed (see Figure 33).



(a) Q-Q plot of the variable outcome

(b) Histogram of the outcome per condition

Figure 33: Visualisation of variables “condition” and “outcome” to check normality, for calculations see Appendix H.5, Listings 12 and 13

We decided to perform a LMER analysis for the agent questionnaire, driven by the same reasons as provided for the Networked Minds Measure questionnaire. The assumptions described by Winter [44] are evaluated and documented in Appendix G.2. All assumptions are satisfied. Subsequently, to assess whether the participants perceive the agents differently, the following hypothesis is formulated:

H_0 : There is no significant effect of the condition with an embodied agent/coxswain on the outcome variable.
H_a : There is a significant effect of the condition with an embodied agent/coxswain on the outcome variable.

Both hypotheses, from the Networked Minds Measure and the agent questionnaire, are tested in Chapter 5.

Additionally, the post-experiment discussion is examined using a thematic analysis. According to Braun and Clarke [36], there are five steps of thematic analysis: familiarizing with the data, generating initial codes, searching for themes, reviewing the themes, defining and naming the themes, and producing the report. These steps are executed in Chapter 5.

5 Experiment: the Effect of an Embodied Coxswain on Social Presence

This chapter presents the results of the experiments conducted for this thesis. The aim of the experiments is to investigate whether an embodied coach/coxswain enhances the social presence between two rowers. In this chapter, the agents will be referred to as the embodied agent, the coxswain aimed to enhance social presence, and the non-embodied agent, the verbal instructions and the text screen.

5.1 Participant demographics

The participant pool consists of 22 individuals, with 14 males and 8 females. The age of the participants ranged from 19 to 25 years old, and they are all students at the University of Twente. Besides, all participants live in Enschede. Additionally, 21 participants are Dutch, and their native language is Dutch. One participant does not have the Dutch nationality and exclusively speaks English. Consequently, the experiment including the non-Dutch participant is conducted in English, while all other experiments are carried out in Dutch. Lastly, all participants are physically able to join the rowing exercises.

5.2 Results Networked Minds Measure questionnaire

The Networked Minds Measure questionnaire is analyzed using a linear mixed effects regression model (LMER) in R. The results are presented in Table 2.

Table 2: Outcomes of the LMER analysis; standard errors are denoted by SE; confidence intervals are denoted by CI; standard deviations are denoted by std. dev.; see calculations in Appendix H.3

Fixed effects	**Estimate**	**SE**	**T-value (40)**	**P-value**	**95% CI**
(Intercept)	2.98	0.11	27.86	$<.001$	[2.76, 3.19]
Condition [2]	0.23	0.07	3.58	$<.001$	[0.10, 0.37]
Random effects	**Variance**	**Std. dev.**			
Participant	0.20	0.45			

We fit a LMER model to predict the variable "outcome" with "condition". In the model, "participant" is included as a random effect, and the explanatory power of the test is substantial (conditional $R = 0.82$). The p-value of the LMER analysis is $p = 0.00176$ ($t(40) = 3.58$), which is lower than the significance level of $alpha = 0.05$. This demonstrates that the variable "condition" can predict the variable "outcome". Thus, we can reject the null-hypothesis and conclude there is a statistically significant effect of "condition" on the "outcome", indicating a difference in outcome between the condition with the embodied agent and the condition with the non-embodied agent. The mean outcome for the conditions is $\bar{x} = 2.98$ for the condition with the non-embodied agent, and $\bar{x} = 3.21$

for the condition with an embodied agent, hence the mean difference is $\Delta = 0.23$. Therefore, it is concluded that the condition with an embodied agent has a significant positive effect on the outcome compared to the condition without a non-embodied agent.

An exploratory research is conducted to see whether there is a perceived difference in social presence between the front and the back rower. The explanatory power of the test is substantial (conditional $R = 0.74$), and the results of the LMER model show no significant difference between the two positions ($p = 0.719 > a = 0.05$, $t(40) = 0.36$), for calculations see Appendix H.7). However, it is noteworthy that this analysis is exploratory, and further research is required.

5.3 Results agent questionnaire

The agent questionnaire is analyzed using a LMER model, and the results can be found in Table 3.

Table 3: Outcomes of the LMER analysis; standard errors are denoted by SE; confidence intervals are denoted by CI; standard deviations are denoted by std. dev.; see calculations in Appendix H.6

Fixed effects	**Estimate**	**SE**	**T-value (40)**	**P-value**	**95% CI**
(Intercept)	3.56	0.14	24.76	$<.001$	[-0.90, -0.16]
Condition [2]	0.84	0.18	4.65	$<.001$	[0.60, 1.53]
Random effects	**Variance**	**Std. dev.**			
Participant	0.09	0.31			

The model includes the random variable "participant", and the results show that the power of the test is substantial (conditional $R = 0.43$). It is also observed that the variable "condition" can predict the variable "outcome", as the p-value is $p = 0.000139$ ($t(40) = 4.65$), which is lower than the significance level of $alpha = 0.05$. Thus, the null-hypothesis is rejected and it is concluded that there is a statistically significant effect of "condition" on the "outcome", indicating that the participants perceive the embodied and the non-embodied agent differently. The mean outcome for the conditions is $\bar{x} = 3.56$ for the condition with the non-embodied agent, and $\bar{x} = 4.40$ for the condition with the embodied agent, accordingly the mean difference is $\Delta = 0.84$. This shows that the embodied agent has a higher level of anthropomorphism. The difference can also be spotted when looking at the boxplots of both conditions (see Figure 34).

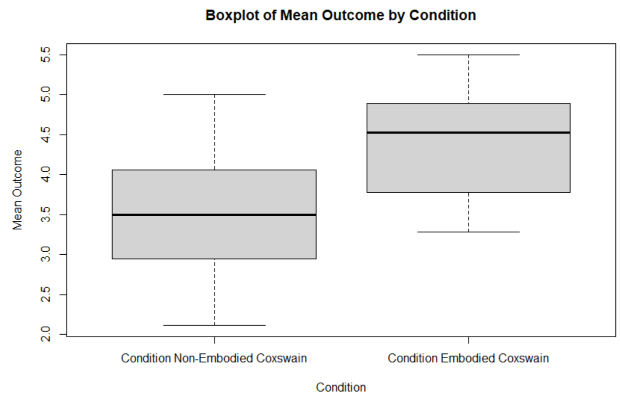


Figure 34: Boxplot displaying the distribution of responses of the agent questionnaire for each condition, showing that the responses to the questionnaire regarding the condition with the embodied agent are notably higher compared to those regarding the non-embodied agent

5.4 Results post-experiment discussion

The thematic analysis steps of Braun and Clarke [36] are executed, and the final themes for the thematic analysis can be found in Table 4. In addition, this table displays the amount of participants who provided feedback on certain topics. For instance, all twenty-two participants associated the agents with at least one of the presented pictures (see pictures in Figure 31), however only approximately half of the participants encountered technical issues during the experiment.

During the post-experiment discussion, thirteen of the twenty-two participants addressed the non-embodied agent with “it”, while the other participants referred to it as “he”. Conversely, it was the other way around for the embodied agent, since the majority of the participants often referred to the embodied agent as “he” (seventeen participants), while five participants addressed him with “it”. When looking at how the participants perceive the agents, it can be said that the non-embodied agent is often described as programmed (eleven participants), robot-like (eleven participants), and emotionless (eight participants), accordingly linking the picture of the laptop to the agent (twenty participants). Nevertheless, eight participants noted that the agent gives clear instructions. The embodied agent is often characterised by his friendly voice (ten participants), kind tone (five participants), and his good feedback (five participants), and therefore participants thought the embodied agent has the most similarities to a teacher (sixteen participants) or a friend (nine participants). However, nine participants noted that the embodied agent had a strange placement and movements, and eight participants mentioned that the feedback of the agent was not a result of their actions, causing a disconnect. The next section dives deeper into the reasoning behind the statements of the participants.

Table 4: The number of participants who provided comments or feedback related to a specific theme

Theme	Explanation	Amount of participants
Linking the picture	The extent to which a picture corresponds to the agent	22
Perception of agent	The participants' perception of the agent. The subthemes of this overarching theme are: human-like, computer-like, social, or not human nor AI-like characteristics. Moreover, it includes the reasoning behind the picture selection.	22
Feedback from the agent	The feedback given by the agent which is either positive, negative, or neutral	18
Feedback about the agent	The feedback about the agent which is either positive, negative, or neutral	19
Recommendations / ideal scenarios	Suggestions or ideal scenarios	18
Technical issues	Technical issues during the experiments, such as audio-related problems	9
Interaction between rowers	The dynamics and interactions between the two participants	12
Confusion	Moments in which the participants are confused or uncertain	8

5.4.1 Non-embodied agent

In the post-experiment discussion, the participants assigned various laptop-like characteristics to the agent, such as that "it" is perceived as programmed (eleven participants) and that it possesses robot or computer-like features (eleven participants). One of the participants stated: *"It was just like an instruction system, and you see that often with laptops. It also didn't have a face, it wasn't a person"* (t.8b: experiment 8 back rower). Another participant described the agent as "monotone" and "robot-like" (t.4b). The voice of the agent played a role in this perception, as one participant pointed out: *"It was a very computer-like voice, so you associate that with robots, laptops, computers, and such. A mechanical voice"* (t.2f: experiment 2 front rower). Also, five participants noticed that the agent was boring due to the voice. However, almost half of the participants thought the agent gave clear instructions (eight participants). A participant noted: *"I think this agent was much clearer than the other agent, but it was boring"* (t.2b). Moreover, there were less frequently mentioned traits linked to the agent, such as being perceived as positive (two participants) and the observation that the agent's feedback was not directly related to the actions of the user (three participants). A participant shared: *"He said "you are doing all right", but I know it is not because he is triggered by something that happened. It's not because he really understands what you do, I think"* (t.9b). Furthermore, four participants thought the agent had similarities with the notebook, while five participants thought it resembled a car, particularly a navigation system. A participant stated: *"It looked like a navigation system, that also tells you to go left here, go right now"* (t.3b). Finally, two participants associated the agent with images of a teacher or a board game.

Nearly all participants pointed out that the agent had the least similarities to a dog (seventeen participants). A key factor for this is that the participants are convinced that the system lacked emotions (eight participants), a characteristic that is often associated with dogs. One participant stated: *"It doesn't look like anything that lives. A dog is always cute, fun or happy, and an AI doesn't have any emotions, it is emotionless"* (t.10f). Another participant agreed: *"Dogs are very nice, spontaneous and sweet and the laptop wasn't"* (t.7b). In addition to a dog, almost half of the participants pointed out that the agent did not resemble as a friend. One participant expressed: *"I think a computer screen to be the farthest from a friend"* (t.5f). A third participant added: *"It is not human-like. It doesn't have emotions"* (t.1f). Further, another participant described the interaction with the agent as being static: *"I would say the least similarities with friends. It was a somewhat static interaction, which is absolutely not the case with friends"* (t.4f). These statements of the participant also pointed out that the agent is seen as a technological device, such as a laptop, computer screen, or AI. Lastly, a minority of the participants mentioned that the agent did not have any resemblance to a laptop (three participants), a board game (two participants), or a notebook (one participant).

5.4.2 Embodied agent

Among the conclusions, the participants correlated the agent to a teacher (sixteen participants), while two of them thought he lacked the authoritative traits expected of a teacher. Nine participants associated the agent with the picture "friends" and described him as being nice or friendly (six participants). A participant stated: *"His voice was very friendly and he gave a lot of compliments"* (t.10b). According to them, the agent had a friendly voice (ten participants), a kind tone (five participants), he gave good feedback (five participants) and was perceived as enthusiastic (two participants). Three participants also stated the agent was engaging. Also, two participants commented that the agent was pointing at them, which they liked (t.6b and t.8f). Additionally, one participant added that he would like for the agent to call him by his name (t.3f).

Yet, some participants considered the agent to be flawed, which added a human-like feature. A participant noted: *"Sometimes he had to correct himself, and therefore I would say friends instead of a teacher"* (t.1b). Another participant said: *"It is recorded by a real person, and you could see that very clearly"* (t.10f). Additionally, multiple participants sensed there was something off about the embodied agent (nine participants). A participant expressed: *"He tried to level with us. I would think he resembled a friend, not your best friend, but he tried to be"* (t.6f). The movements and placement of the agent were perceived as strange (nine participants), and three participants were even frightened of the agent. One of the participants stated: *"I thought he was human-like, however there was something off about the face and his posture. His voice was very human-like and nice to listen to, but the rest of the appearance wasn't real. Therefore, I thought he was scary"* (t.8b). Another participant agreed that the face and posture of the agent seemed inhuman and suggested that the animation could be improved (t.11b). Due to the odd facial expressions and posture, four participants stated that the agent resembled the picture of the laptop. Additionally, eight participants thought that the feedback of the agent was not related to their actions. A participant stated: *"It would be good if he could give specific points you can recognize in your actions. Maybe that would make him more human-like, or human-like by being interactive"* (t.3f). On the other hand, four participants did not realize that the embodied agent was pre-programmed. Three of the four participants thought that the responses of the agent were very well timed, and therefore it seemed like the agent responded to them. A participant asked: *"The coxswain was saying specific feedback for only one person at the time, right?"* (t.11f). When she heard that the embodied agent was scripted, she noted: *"He gave feedback for one person at the time, so that's why we thought that he sees differences between the first and the second person"* (t.11f). Finally, six participants commented the embodied agent gave clear instructions.

According to the participants, the agent had the least resemblance to a notebook (eight participants). One participant articulated: *"The notebook has the fewest similarities, because that is the least human-like and interactive thing here"* (t.9f). In a separate experiment, a participant remarked: *"I had more of a teacher on board than a textbook"* (t.3f). Nearly all eight participants stated that the agent resembled a human more than a notebook. Besides, four participants noted the agent is least similar to the car. A participant claimed: *"The car, notebook and the other things are not interactive and the coxswain is interactive"* (t.2b). Another participant agreed by expressing that a car operates the other way around, as the driver controls it, while in this scenario, the agent guides the participant (t.2f). Additionally, a participant added: *"A car has nothing personal, so it has nothing to do with a car"* (t.5b). Lastly, participants indicated the lowest level of resemblance between the agent and a board game (three participants), a dog (three participants), a teacher (two participants), friends (one participant) and a laptop (one participant).

5.4.3 Overall feedback

As can be seen in Table 4, participants frequently seemed confused throughout the experiments. This was especially the case when the embodied agent stopped providing a rhythm (five participants). A participant mentioned: *"I thought a coxswain would state the rhythm constantly instead of saying it only three times at the start"* (t.4f). Another participant agreed: *"At the start the coxswain said: Push, pull, push, pull, but then he stopped, and I thought, what now?"* (t.5f). Additionally, two participants suggested including an introduction to the rowing session (t.2b and t.10f). One participant recommended: *"I would add an explanation before you get into the boat, something like: "Hi, I am your coxswain, I will give the rhythm and I will sit in front of you." Now we started, and he said: "pull, loose", and I thought: what is pull and loose?"* (t.2b).

More than two-thirds of the participants preferred the condition with the embodied agent (fifteen participants). Four participants compared the two agents and observed that the embodied agent had higher levels of motivation, enthusiasm, and engagement (t.1f, t.6f, t.10f, and t.10b). In contrast, three participants favored the condition with the non-embodied agent, as they noticed that the embodied agent could be distracting. A participant stated: *"I didn't know where to look, at him or to still focus on the side of the boat to see the oars behind me"* (t.11f). During another experiment, a participant remarked: *"As soon as the coxswain started talking for a longer period of time, I found it a bit distracting. I responded to it, which is fun, but it does distract a bit from the task, rowing"* (t.8f). Another participant agreed and stated to be more focused on the environment when rowing with the non-embodied agent (t.9f). On the other hand, one participant mentioned to be more focused on the other participant when rowing with the embodied agent, as he was too busy reading the instructions during the non-embodied agent condition (t.5b). Furthermore, two participants did not have a preference and two participants suggested to have a combination of both conditions.

Some technical issues emerged throughout the experiments. During three experiments, audio-related issues arose, causing the participants to be unable to hear each other through the VR headsets. This occurred during experiments one, two, and five. Although the participants could hear each other via mobile phones, one participant noted that she could not hear the other person due to the noise of the rowing machine. During the other experiments, the participants could hear each other via the VR headsets. Another technical issue arose during the first experiment when rowers were unexpectedly thrown out of the boat during their rowing session. They were placed back in the boat, and the experiment could continue.

The interaction between the participants did not always go smoothly. Three of the eleven participants who were located in the front of the boat mentioned that they did not notice the other participant. A participant said: *"I really didn't know what the person behind me was doing"* (t.8f). Observing the rowers located in the back of the boat, four rowers pointed out that the animation of the front rower was flawed, since their oars moved unusually, there was an occasional delay, and there were inaccuracies in the movements of the front rower when turning around (t.4b, t.8b, t.10b, and t.11b). Therefore, two rowers suggested to rely on the voice of their fellow participant rather than trusting on their visual perception. These inaccurate movements are included as technical issues within Table 4. Furthermore, three of the eleven back rowers indicated that they had to change their rhythm in order to synchronize with the rower in front of them (t.6b, t.8b, and t.11b). Therefore, one participant proposed a possibility to request a reset of the rhythm to ensure synchronization (t.6b).

Four participants recommended that they would like to see an indication of how far they have come or they would like some feedback on their rowing behavior. One participant said: *"It wasn't clear for me where the finish was, and I didn't know if I was doing it right technically"* (t.4b). Two other participants added that they would like to see the same things that are visible on a rowing machine (t.6f and t.9b).

Finally, two participants commented that initiating rowing required significant effort, especially to start spinning the flywheel. As a result, they suggested to have a slower rhythm at the beginning (t.6).

6 Discussion

At the beginning of this thesis, the following research question was formulated: *To what extent does the presence of an **embodied coxswain** enhance the **social presence** between two rowers during a **Virtual Reality rowing** session?* This research question is evaluated by reviewing existing literature, conducting observation sessions, examining the current rowing setup, and performing an experiment in which an embodied agent was compared to a non-embodied agent.

It became evident that introducing an embodied coxswain significantly enhances social presence between two rowers in a VR rowing session. This conclusion was reinforced through the findings of the LMER analysis of the Networked Minds Measure questionnaire and was supported by the feedback of the participants. The participants frequently expressed having a different emotional connection to the embodied agent compared to the non-embodied agent, as the embodied agent was often perceived as more friendly, positive, and engaging. Moreover, the visual appearance of the embodied coxswain enhanced the experience, however the experience could have been improved when adding personalized feedback. In addition, realism in the appearance, movements, and interactions of an embodied coxswain can further improve social presence in rowing sessions. These statements will be elaborated in the sections below.

The participants perceive both agents differently when looking at the LMER analysis and the findings from the post-experiment discussion. This difference becomes evident in how participants addressed the agents, as most participants address the non-embodied agent with "it" and the embodied agent is mostly referred to as "he". This might indicate that participants perceive the embodied agent as a person and the non-embodied agent as more of an entity or object. Additionally, this suggests that participants have a different emotional connection with the agents. Half of the participants describe the embodied agent as friendly and enthusiastic, linking him to a teacher or a friend. These beliefs are reflected in the friendly voice and tone of the agent, as well as his provided positive feedback. In contrast, nearly half of the participants perceive the non-embodied agent as emotionless and robotic, and correlate the agent to a laptop. This emotional distinction aligns with the study by Lester et al. [47], who state several benefits for agents who can express lifelike emotions. According to them, these agents can provide clear problem-solving advice and keep learners highly motivated and engaged. These findings are supported by Graf et al. [48], who show that adding emotional elements to virtual coaches within exergames (VR games involving physical exercise) can enhance performance and motivation. Specifically, a happy coach contributes to a more positive gaming experience and can increase happiness and perceived competence. Additionally, he can enhance feelings of relatedness between the player and the coach. These results are likely caused by the positive feedback and praise provided by the cheerful coach. The post-experiment discussion of this thesis reinforces these statements, as some participants claim that the embodied agent had higher levels of motivation, enthusiasm, and engagement. Furthermore, it is noteworthy that more than half of the participants preferred the condition with the embodied agent. This preference suggests that the friendliness and positivity of the agent are plausible influences that contribute to the amplification of social presence. While the primary focus of this thesis did not lie on motivation and performance, the studies of Lester et al. [47] and Graf et al. [48], together with the post-experiment discussion show that the integration of a happy coach can bring positive changes in a gaming experience. Hence, it demonstrates an opportunity for future research to investigate whether the presence of an embodied agent can enhance motivation and performance in VR rowing.

Besides the difference in perceived emotional levels of the agents, the participants indicated differences in their visual appearance as well. In the experiments, the feedback from the participants accentuated their enhanced motivation and engagement when interacting with the embodied agent compared to the non-embodied agent. Moreover, Baylor and Ryu [49] emphasize that the visual representation of an agent is crucial for achieving motivational and affective outcomes. They comment that a voice alone, whether human or machine-generated, may not be sufficient and effective enough. Additionally, Mouatt et al. [50] indicate that high immersive virtual avatars or agents enhance motivation and engagement during exercise better than low immersive virtual avatars. Collectively, the studies of Baylor and Ryu [49] and Mouatt et al. [50], along with the findings of the experiments, suggest that high immersive avatars offer certain benefits. Primarily, the influence of high immersive avatars on motivation and engagement in VR rowing is an interesting focus point for future research.

Some participants observed that the embodied agent provided good feedback throughout the experiments. At the same time, they did not mention this for the non-embodied agent, even though both agents gave the same positive feedback. This observation could be explained by the research of Graf et al. [48], which posits that positive feedback could cause feelings of relatedness between the player and an embodied coach. Consequently, participants might have more awareness of the feedback of the embodied agent compared to the non-embodied agent. Nonetheless, it remains a topic for future research to assess, as it remains uncertain whether participants forgot to state this in the case of the non-embodied agent. Furthermore, almost half of the participants indicated that the feedback of the agents often seemed insincere, as it did not result directly from their actions. This caused a disconnect between the rowers and the agent. The participants advised to add genuine feedback. This aligns with the study of Covaci et al. [51], who express that personalized feedback could enhance performance, as it allows to take the current performance of the user and help them adjust it for the next trial. Besides, virtual situations can guide users by giving additional information and can easily adapt to different competitive situations. Within virtual environments, personalized feedback has the potential to strengthen the connection between the rowers and the coxswain, offering the users additional information to improve their performance. Therefore, this offers a starting point for future research.

Approximately half of the participants thought the posture and animations of the agent could be improved. Despite creating the different visemes in Blender, their visibility remained limited in the animation. This represents a limitation of the current design. Research by Lala and Nishida [52] has shown that computer agents can effectively improve communication and boost engagement through realistic verbal and non-verbal communication. Besides, observing the agent can aid in understanding and learning certain movements, like catching a ball in basketball. This aligns with the statements of Chapter 2, which suggest that realistic interactions can amplify social presence [4], [28]. Realism offers other potential benefits, for instance, training within realistic 3D environments has proven to effectively prepare users for real-world scenarios [53]. Hence, future research could explore the advantages of deploying embodied coaches who provide positive feedback and behave naturally.

Furthermore, participants frequently seemed confused during the experiments, specifically when the agents stopped providing a rhythm. This occurrence was remarkable, as the observations at

Euros made it clear that it is not the role of the coxswain to constantly provide a rhythm, since this is the responsibility of the first person in the boat (Chapter 3.1). Due to these observations, in the design phase, it was intentionally chosen not to provide a constant rhythm during the experiment. However, given that many participants had limited experience in rowing, they expected the coxswain to give the rhythm continuously. The more experienced rowers did not express the need for a constant rhythm, though they were in fewer numbers. Furthermore, half of the participants expressed that the non-embodied agent gave clear instructions, as this condition provided written instructions.

Some participants positioned in the front of the boat reported a lack of awareness of the rower behind them. However, an exploratory LMER analysis revealed no significant difference in social presence between the front and back positions. While this might imply that auditory factors have a stronger influence on social presence than visual factors, further in-depth analysis is needed to draw reliable conclusions.

Several technical issues arose correlated with the current VR rowing setup. During three experiments, the rowers could not hear each other effectively. Hence, the limited communication between these rowers could have influenced their perception of social presence. Another technical challenge emerged due to the many different hardware components and software programs currently in use within the system, which caused many issues during the rowing sessions. The trackers, in particular, could not always be properly tracked by the base stations, often lost connection with the computers, and sometimes even gave unpredicted shutdowns during the experiments. Also, the VR headsets frequently needed to be re-calibrated due to a skewed vision. Besides, the placement of the rower avatars in the boat was not always correct, as they were often positioned too much to the right or left and sometimes not even near the boat. Lastly, the setup contained a lot of cables, making the setup somewhat fragile. Therefore, future studies could benefit from considering wireless headsets.

Several interesting directions for future studies emerge from this thesis. Firstly, while this thesis studied social presence as a whole, it is crucial to mention that Harms and Biocca [23] divide social presence into six distinctive categories. It remains uncertain whether the effect of an embodied coxswain is significant for every category of social presence, and therefore it is likely that the design of the coxswain should be tailored to every different category, as a design aimed at improving co-presence might differ from a design that focuses on perceived message understanding. Moreover, while rowing with an embodied coxswain appears to enhance social presence, it is uncertain which characteristics of the coxswain cause this change. Future studies could focus on pinpointing which traits of the embodied coxswain have the most impact on social presence. Furthermore, it is recommended to research whether social presence already occurs when rowing in VR without an embodied coxswain. Additionally, an interesting approach would be to check the impact of an embodied coxswain on larger rowing teams with four or eight rowers. Finally, these findings might be interesting for other sports areas where coaches also play a significant role.

7 Conclusion

In this thesis, we demonstrated that including an embodied coxswain significantly enhances the social presence between two rowers compared to a non-embodied agent within a VR rowing experience. Reflecting on this report raises the question of whether VR offers the best training possibilities for rowing. However, compared to on-water rowing, VR can be used during all weather conditions, when rowers are geographically distributed and allows for personalized coaching. Studies by Li et al. [54] and Hoffman et al. [5] demonstrate that rowing with immersive VR improves performance, motivation levels, and energy management. Additionally, Mouatt et al. [50] and IJsselsteijn et al. [55] suggest that immersive VR can enhance enjoyment and engagement in exercise compared to non-immersive VR and without VR. As such, it can be stated that VR presents various benefits for rowing.

This thesis begins with examining literature to contextualize the definition of presence, its measurement methods, and its determinants. Next, it uses previous VR rowing projects, expert consultations, and observation sessions to understand the team dynamics within rowing teams better. This offers valuable ideas for possible design solutions and storyboards. Recognizing the substantial role of coxswains in rowing teams, we designed a virtual coxswain that stimulates social presence between rowers in VR rowing. Afterward, additional hardware and software components are integrated into the current VR rowing setup at the University of Twente. Consequently, the virtual coxswain is compared to a non-embodied agent in an experimental study. The analyses of the Networked Minds Measure questionnaire and an agent questionnaire were conducted using LMER, and the results reveal that the embodied coxswain significantly enhances social presence between rowers compared to the non-embodied agent. The participants perceive the embodied coxswain as friendly, positive, and engaging. However, the social presence could further be enhanced by enriching the realism of the appearance, movements, and interactions of the coxswain and by providing personalized feedback. Future studies could analyze the effect of an embodied coxswain on motivation, engagement, and performance. Lastly, they could investigate which characteristics of an embodied coxswain most significantly influence social presence.

Even though the influence of virtual embodied agents in rowing is a new exploration, future studies hold the potential to extend the use of embodied agents to different exercise fields. The combination of Virtual Reality technology and embodied coaching can be valuable for many sports areas, for instance, dancing or martial arts. Within these sports, coaches play a pivotal role, much like in the field of rowing. Embodied coaches not only enhance social presence, but can also be deployed to improve performance, skill development, motivation, and engagement. Recent research has already highlighted the effectiveness of virtual characters on motivation and performance levels [48]. In addition, they offer the advantage of customization and can be tailored to different situations and individuals. Moreover, virtual coaches are accessible at any moment, which might not be feasible with traditional in-person coaching. Lastly, trainers, coaches, and sports organizations could elevate their training sessions by utilizing virtual agents, such as coxswains or coaches, as supplementing training tools.

As this thesis concludes, it is time to set sail on a fresh chapter of rowing experiences by enhancing social dynamics through embodied coaching.

References

[1] K. M. Lee, "Presence, explicated," *Communication theory*, vol. 14, no. 1, pp. 27–50, 2004.

[2] V. Souza, A. Maciel, L. Nedel, and R. Kopper, "Measuring presence in virtual environments: A survey," vol. 54, no. 8, 2021, ISSN: 0360-0300. [Online]. Available: `https://doi.org/10.1145/3466817`.

[3] F. Mueller, L. Cole, S. O'Brien, and W. Walmink, "Airhockey over a distance: A networked physical game to support social interactions," in *Proceedings of the 2006 ACM SIGCHI international conference on Advances in computer entertainment technology*, 2006, 70–es.

[4] W. Hai, N. Jain, A. Wydra, N. M. Thalmann, and D. Thalmann, "Increasing the feeling of social presence by incorporating realistic interactions in multi-party vr," in *Proceedings of the 31st International Conference on Computer Animation and Social Agents*, 2018, pp. 7–10.

[5] H. G. Hoffman, J. Prothero, M. J. Wells, and J. Groen, "Virtual chess: Meaning enhances users' sense of presence in virtual environments," *International Journal of Human-Computer Interaction*, vol. 10, no. 3, pp. 251–263, 1998.

[6] F. Mueller, M. R. Gibbs, and F. Vetere, "Towards understanding how to design for social play in exertion games," *Personal and Ubiquitous Computing*, vol. 14, no. 5, pp. 417–424, 2010.

[7] U. Schultze, "Embodiment and presence in virtual worlds: A review," *Journal of Information Technology*, vol. 25, no. 4, pp. 434–449, 2010.

[8] J. M. Carroll, P. C. Shih, B. Hoffman, J. Wang, and K. Han, "Presence and hyperpresence: Implications for community awareness," *Interacting with Presence: HCI and the Sense of Presence in Computer-mediated Environments*, pp. 70–82, 2014.

[9] M. Bentvelzen, G.-L. Savino, J. Niess, J. Masthoff, and P. W. Wozniak, "Tailor my zwift: How to design for amateur sports in the virtual world," *Proceedings of the ACM on Human-Computer Interaction*, vol. 6, no. MHCI, pp. 1–23, 2022.

[10] C. Anderson-Hanley, A. L. Snyder, J. P. Nimon, and P. J. Arciero, "Social facilitation in virtual reality-enhanced exercise: Competitiveness moderates exercise effort of older adults," *Clinical Interventions in Aging*, vol. 6, pp. 275–280, 2011. [Online]. Available: `https://www.tandfonline.com/doi/abs/10.2147/CIA.S25337`.

[11] D. Thalmann, J. Lee, and N. M. Thalmann, "An evaluation of spatial presence, social presence, and interactions with various 3d displays," in *Proceedings of the 29th International Conference on Computer Animation and Social Agents*, 2016, pp. 197–204.

[12] F. Mueller, F. Vetere, M. R. Gibbs, S. Agamanolis, and J. Sheridan, "Jogging over a distance: The influence of design in parallel exertion games," in *Proceedings of the 5th ACM SIGGRAPH Symposium on Video Games*, 2007, pp. 63–68.

[13] M. Nunes, L. Nedel, and V. Roesler, "Motivating people to perform better in exergames: Competition in virtual environments," in *Proceedings of the 29th Annual ACM Symposium on Applied Computing*, ser. SAC '14, 2014, pp. 970–975. [Online]. Available: `https://doi.org/10.1145/2554850.2555009`.

[14] F. Mueller, S. Agamanolis, M. R. Gibbs, and F. Vetere, "Remote impact: Shadowboxing over a distance," in *CHI'08 extended abstracts on Human factors in computing systems*, 2008, pp. 2291–2296.

[15] F. Mueller, S. Agamanolis, and R. Picard, "Exertion interfaces: Sports over a distance for social bonding and fun," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, 2003, pp. 561–568.

[16] F. Mueller, G. Stevens, A. Thorogood, S. O'Brien, and V. Wulf, "Sports over a distance," *Personal and Ubiquitous Computing*, vol. 11, no. 8, pp. 633–645, 2007.

[17] M. Pallot, R. Eynard, B. Poussard, O. Christmann, and S. Richir, "Augmented sport: Exploring collective user experience," in *Proceedings of the Virtual Reality International Conference: Laval Virtual*, 2013, pp. 1–8.

[18] T. Y. Tang, P. Winoto, and R. Y. Wang, "Having fun over a distance: Supporting multiplayer online ball passing using multiple sets of kinect," in *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, 2015, pp. 1187–1192.

[19] J. D. Lecy and K. E. Beatty, "Representative literature reviews using constrained snowball sampling and citation network analysis," *Available at SSRN 1992601*, 2012.

[20] J. Kolkmeier, E. Harmsen, S. Giesselink, D. Reidsma, M. Theune, and D. Heylen, "With a little help from a holographic friend: The openimpress mixed reality telepresence toolkit for remote collaboration systems," in *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology*, 2018, pp. 1–11.

[21] E. Nunez, M. Hirokawa, A. Hautasaari, and K. Suzuki, "Remote communication via huggable interfaces-behavior synchronization and social presence," in *CHI Conference on Human Factors in Computing Systems Extended Abstracts*, 2022, pp. 1–7.

[22] P. Heidicker, E. Langbehn, and F. Steinicke, "Influence of avatar appearance on presence in social vr," in *2017 IEEE Symposium on 3D User Interfaces (3DUI)*, 2017, pp. 233–234. DOI: 10.1109/3DUI.2017.7893357.

[23] C. Harms and F. Biocca, "Internal consistency and reliability of the networked minds measure of social presence," in *Seventh annual international workshop: Presence*, Universidad Politecnica de Valencia Valencia, Spain, vol. 2004, 2004.

[24] T. Beelen, R. Blaauboer, N. Bovenmars, *et al.*, "The art of tug of war: Investigating the influence of remote touch on social presence in a distributed rope pulling game," in *International Conference on Advances in Computer Entertainment Technology*, Springer, 2013, pp. 246–257.

[25] R. W. van Delden, S. Gerritsen, D. Reidsma, and D. Heylen, "Distributed embodied team play, a distributed interactive pong playground," in *International Conference on Intelligent Technologies for Interactive Entertainment*, Springer, 2016, pp. 124–135.

[26] M. Lombard, T. B. Ditton, and L. Weinstein, "Measuring presence: The temple presence inventory," in *Proceedings of the 12th annual international workshop on presence*, 2009, pp. 1–15.

[27] C. S. Oh, J. N. Bailenson, and G. F. Welch, "A systematic review of social presence: Definition, antecedents, and implications," *Frontiers in Robotics and AI*, vol. 5, p. 114, 2018.

[28] B. G. Witmer and M. J. Singer, "Measuring presence in virtual environments: A presence questionnaire," *Presence*, vol. 7, no. 3, pp. 225–240, 1998.

[29] M. Slater and M. Usoh, "Representations systems, perceptual position, and presence in immersive virtual environments," *Presence*, vol. 2, pp. 221–233, Jan. 1993. DOI: 10.1162/pres.1993.2.3.221.

[30] C. Heeter, "Being there: The subjective experience of presence," *Presence: Teleoperators and Virtual Environments*, vol. 1, pp. 262–, Jan. 1992. DOI: 10.1162/pres.1992.1.2.262.

[31] S. E. Lindley, J. Le Couteur, and N. L. Berthouze, "Stirring up experience through movement in game play: Effects on engagement and social behaviour," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2008, pp. 511–514.

[32] R. van Delden, S. Bergsma, K. Vogel, D. Postma, R. Klaassen, and D. Reidsma, "Vr4vrt: Virtual reality for virtual rowing training," in *Extended Abstracts of the 2020 Annual Symposium on Computer-Human Interaction in Play*, 2020, pp. 388–392.

[33] E. G. Murray, D. L. Neumann, R. L. Moffitt, and P. R. Thomas, "The effects of the presence of others during a rowing exercise in a virtual reality environment," *Psychology of Sport and Exercise*, vol. 22, pp. 328–336, 2016.

[34] K. Vogel, "The feasibility of low-cost virtual reality motion tracking for rowing technique analysis," B.S. thesis, University of Twente, 2020.

[35] A. Blom, *Virtual reality rowing with sonification - an exploration of the effects of sonification in a virtual reality environment*, Jul. 2023. [Online]. Available: http://essay.utwente.nl/97159/.

[36] V. Braun and V. Clarke, *Thematic analysis.* APA handbook of research methods in psychology, 2012, vol. 2, Research designs: Quantitative, qualitative, neuropsychological, and biological, pp. 57–71. DOI: https://doi.org/10.1037/13620-004.

[37] K. N. Truong, G. R. Hayes, and G. D. Abowd, "Storyboarding: An empirical determination of best practices and effective guidelines," in *Proceedings of the 6th Conference on Designing Interactive Systems*, ser. DIS '06, University Park, PA, USA: Association for Computing Machinery, 2006, pp. 12–21, ISBN: 1595933670. DOI: 10.1145/1142405.1142410. [Online]. Available: https://doi.org/10.1145/1142405.1142410.

[38] J. Lazar, J. H. Feng, and H. Hochheiser, *Research methods in human-computer interaction.* Morgan Kaufmann, 2017.

[39] J. C. Acosta and N. G. Ward, "Achieving rapport with turn-by-turn, user-responsive emotional coloring," *Speech Communication*, vol. 53, no. 9-10, pp. 1137–1148, 2011.

[40] S. Fitrianie, M. Bruijnes, D. Richards, A. Abdulrahman, and W.-P. Brinkman, "What are we measuring anyway? -a literature survey of questionnaires used in studies reported in the intelligent virtual agent conferences," in *Proceedings of the 19th ACM International Conference on Intelligent Virtual Agents*, 2019, pp. 159–161.

[41] A. Aron, E. N. Aron, and D. Smollan, "Inclusion of other in the self scale and the structure of interpersonal closeness.," *Journal of personality and social psychology*, vol. 63, no. 4, p. 596, 1992.

[42] M. Escobar-Planas, V. Charisi, and E. Gomez, ""that robot played with us!" children's perceptions of a robot after a child-robot group interaction," *Proc. ACM Hum.-Comput. Interact.*, vol. 6, no. CSCW2, Nov. 2022. DOI: 10.1145/3555118. [Online]. Available: https://doi.org/10.1145/3555118.

[43] C. Goforth, "Using and interpreting cronbach's alpha," University of Virginia Library: Statistical Consulting Associate, Nov. 2015. [Online]. Available: https://library.virginia.edu/data/articles/using-and-interpreting-cronbachs-alpha.

[44] B. Winter, "Linear models and linear mixed effects models in r with linguistic applications," *arXiv preprint arXiv:1308.5499*, 2013.

[45] Z. Yu, M. Guindani, S. F. Grieco, L. Chen, T. C. Holmes, and X. Xu, "Beyond t test and anova: Applications of mixed-effects models for more rigorous statistical analysis in neuroscience research," *Neuron*, vol. 110, no. 1, pp. 21–35, 2022, ISSN: 0896-6273. DOI: https://doi.org/10.1016/j.neuron.2021.10.030. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S089662732100845X.

[46] D. A. Magezi, "Linear mixed-effects models for within-participant psychology experiments: An introductory tutorial and free, graphical user interface (lmmgui)," *Frontiers in psychology*, vol. 6, p. 2, 2015.

[47] J. Lester, S. Towns, and P. Fitzgerald, "Achieving affective impact: Visual emotive communication in lifelike pedagogical agents," *International Journal of Artificial Intelligence in Education*, vol. 10, Jan. 1998.

[48] L. Graf, S. Abramowski, F. Born, and M. Masuch, "Emotional virtual characters for improving motivation and performance in vr exergames," *Proc. ACM Hum.-Comput. Interact.*, vol. 7, no. CHI PLAY, Oct. 2023. DOI: 10.1145/3611063. [Online]. Available: https://doi.org/10.1145/3611063.

[49] A. Baylor and J. Ryu, "The effects of image and animation in enhancing pedagogical agent persona," in *Journal of Educational Computing Research*, vol. 28, 2003, pp. 373–394. DOI: https://doi.org/10.2190/V0WQ-NWGN-JB54-FAT4.

[50] B. Mouatt, A. E. Smith, M. L. Mellow, G. Parfitt, R. T. Smith, and T. R. Stanton, "The use of virtual reality to influence motivation, affect, enjoyment, and engagement during exercise: A scoping review," *Frontiers in Virtual Reality*, vol. 1, p. 564 664, 2020.

[51] A. Covaci, A.-H. Olivier, and F. Multon, "Visual perspective and feedback guidance for vr free-throw training," *IEEE computer graphics and applications*, vol. 35, no. 5, pp. 55–65, 2015.

[52] D. Lala and T. Nishida, "Joint activity theory as a framework for natural body expression in autonomous agents," in *Proceedings of the 1st International Workshop on Multimodal Learning Analytics*, ser. MLA '12, Santa Monica, California: Association for Computing Machinery, 2012, ISBN: 9781450315159. DOI: 10.1145/2389268.2389270. [Online]. Available: https://doi.org/10.1145/2389268.2389270.

[53] W.-L. Tsai, "Personal basketball coach: Tactic training through wireless virtual reality," in *Proceedings of the 2018 ACM on International Conference on Multimedia Retrieval*, ser. ICMR '18, Yokohama, Japan: Association for Computing Machinery, 2018, pp. 481–484, ISBN: 9781450350464. DOI: 10.1145/3206025.3206084. [Online]. Available: https://doi.org/10.1145/3206025.3206084.

[54] X. Li, Z. Wu, and T. Han, "Gamification-based vr rowing simulation system," in Jun. 2019, pp. 484–493, ISBN: 978-3-030-22642-8. DOI: 10.1007/978-3-030-22643-5_38.

[55] W. A. IJsselsteijn, Y. A. W. d. Kort, J. Westerink, M. d. Jager, and R. Bonants, "Virtual Fitness: Stimulating Exercise Behavior through Media Technology," *Presence: Teleoperators and Virtual Environments*, vol. 15, no. 6, pp. 688–698, Dec. 2006. DOI: 10.1162/pres.15.6.688. [Online]. Available: https://doi.org/10.1162/pres.15.6.688.

[56] M. Chen, B. E. Kolko, E. Cuddihy, and E. Medina, "Modeling and measuring engagement in computer games.," in *DiGRA Conference*, 2005.

Video References

[57] World Rowing, *Small, calm and in control - the rowing cox*, 2015. [Online]. Available: https://www.youtube.com/watch?v=Ok2MX3sCD9A&ab_channel=WorldRowing.

[58] Olympics, *Germany win men's eight rowing gold - london 2012 olympics*, 2021. [Online]. Available: https://www.youtube.com/watch?v=B7UOB4szsNs&ab_channel=Olympics.

[59] Olympics, *Murray & bond (nzl) win rowing men's pair gold - london 2012 olympics*, 2012. [Online]. Available: https://www.youtube.com/watch?v=jkeAPV-8ZBA&ab_channel=Olympics.

[60] Regaproject, *2015 world rowing championships aiguebelette, france men's eight*, 2015. [Online]. Available: https://www.youtube.com/watch?v=luiFz9zeRTI&ab_channel=regaproject.

[61] Olympics, *Rio replay: Women's eight rowing final*, 2016. [Online]. Available: https://www.youtube.com/watch?v=paRQ7IgYLhk&ab_channel=Olympics.

[62] Olympics, *United states win women's eight olympic gold | beijing 2008*, 2008. [Online]. Available: https://www.youtube.com/watch?v=kdTpCrqUGr4&ab_channel=Olympics.

[63] Olympics, *Rio replay: Women's double sculls final*, 2016. [Online]. Available: https://www.youtube.com/watch?v=Ge1ajQZz5dg&ab_channel=Olympics.

[64] Olympics, *Final - women's pair rowing replay – london 2012 olympics*, 2012. [Online]. Available: https://www.youtube.com/watch?v=Dt9W2NnQZQE&ab_channel=Olympics.

[65] B. Ratliffe, *Green lake crew wv8+ northwest rowing regionals, coxswain recording*, 2016. [Online]. Available: https://www.youtube.com/watch?v=GLSK_u5nKGc&ab_channel=WorldRowing.

A Definitions of Presence

Table 5: Definitions of presence that are used in literature

Author	Term	Description	Perception and understanding	(Emotional) connectedness	Space	Interaction
Harms and Biocca [23]	Co-presence	The user feels like they are not alone to a certain extent. This also includes the level of awareness of the users of each other.	X			
	Attentional allocation	The user sends and gets a certain amount of attention from other users during the interaction.				X
	Perceived message understanding	The degree to which the user understands the messages of other users and vice versa.	X			X
	Perceived affective understanding	The degree to which the user can understand another user's emotional and attitudinal state and vice versa.	X	X		X
	Perceived affective interdependence	The degree to which both user's emotional and attitudinal states are affected by each other.		X		X
	Perceived behavioral interdependence	The behavior of the users are affected by each other to a certain degree.		X		X
Hai et al. [4]	Presence, social presence	Presence is "having the feeling of being physically present in a non-physical world". Social presence is defined as "the sense of perception of being together with all the virtual humans".	X	X	X	
Witmer and Singer [28]	Presence	"The subjective experience of being in one place or environment, even when one is physically situated in another".			X	

Author	Term	Description	Perception and understanding	(Emotional) connectedness	Space	Interaction
Thalmann et al. [11]	Social presence, spatial presence	Social presence is "the degree of awareness of the surrounded virtual humans". Spatial presence is defined as "the subjective experience of being in the immersive virtual environment".	X		X	
Mueller et al. [6]	Social play	"Social play is a context for stylized communication, mediated through social interaction".				X
Bentvelzen et al. [9]	Sense of community, social relations, social communication	A sense of community can be described as "feeling connected to other users". Social communication is "(live) communication via audio or text messages"		X		X
Nunez et al. [21]	Social presence	"The degree of feeling connected to others through a medium, creating a positive, social and warm interaction."		X		X
Hoffman et al. [5]	Presence	Presence is "the sensation of going into a computer-simulated environment".			X	
Heidicker et al. [22]	Social presence	Social presence is "a measure of the perceived presence of another intelligent being and is determined by a variety of verbal, nonverbal, visual, conscious, and subconscious signals."	X			X

Author	Term	Description	Perception and understanding	(Emotional) connectedness	Space	Interaction
Lee et al. [1]	Presence, social presence, telepresence	Presence is “a media user’s subjective sensation, occurring during the virtual reality experience, which takes place in all types of media." Social presence and telepresence are aspects of presence. Social presence means “being together with others" or “communicating with other people or entities within the mediated environment," and telepresence includes “being there".		X	X	X
Lombard et al. [26]	Transportation	“The belief that users, objects, environments or other people have been transported"			X	
	Realism	“The extent of realism in objects, people and events produced by a medium”. Social realism represents “the degree to which a virtual environment is true to life”, and perceptual realism is “the degree to which the virtual environment looks real."	X		X	
	Immersion	“The degree to which the senses of the user are extended to the virtual environment and whether this feels natural."	X		X	
	Social richness	“The degree to which a medium is perceived as warm, sociable, personal, sensitive or intimate when interacting with other users."	X	X		X
	Social actor within a medium	“The degree to which users respond to social cues by others while this can be illogical or inappropriate."	X			X

Author	Term	Description	Perception and understanding	(Emotional) connectedness	Space	Interaction
	Medium as a social actor	“Users experience the technology or medium itself as a social actor and interact sometimes illogical with them."	X			X
Oh et al. [27]	Social presence	Social presence or co-presence is “the subjective experience of being present with another ‘real’ person and experiencing their thoughts and emotions.” Telepresence is defined as “the extent to which one feels present in the mediated environment, rather than in the immediate physical environment”. Lastly, self-presence is the extent to which the “virtual self is experienced as the actual self”.	X	X	X	
Souza et al. [2]	Presence, social presence/co-presence and telepresence	Presence is “the subjective perception of being in the virtual environment", social presence/co-presence is “the sense of being together with other(s) in a virtual world" and telepresence is “the sense of being at a real remote location"		X	X	

Certain studies do not provide a clear definition of presence. Despite this, these papers are valuable due to their interesting measurement methods and determinants of presence. Therefore, they are included in this paper. The categorization is determined based on the descriptions of presence given within each text. These papers can be found in Table 6.

Table 6: Literature that does not define presence

Author	Term	Perception and understanding	(Emotional) connectedness	Space	Interaction
Lindley et al. [31]	Social interaction or behavior				X
Mueller et al. [3] [15] [16] [14] [12]	Connectedness and social interaction/-play		X		X
Beelen et al. [24]	See Harms and Biocca 7	X	X		X
Kolkmeier et al. [20]	Telepresence			X	
Van Delden et al. [25]	Social connectedness/presence		X		X

B Measurement Methods of Presence

Table 7: Measurement methods to measure presence according to literature

Author	Presence type	Context	Measurement	Explanation	Deployment
Harms and Biocca [23]	Perception and understanding, (emotional) connectedness and interaction	Developing and testing a measure of social presence	Review of definitions and measures used in literature	Harms and Biocca have created and validated a new measurement method of social presence: the Networked Minds Measure questionnaire	Existing literature is used
Bentvelzen et al. [9]	(Emotional) connectedness and interaction	Zwift	Retrospective interview	Bentvelzen et al. conducted empirical, retrospective, semi-structured interviews with Zwift users. The interviews contained questions about the set-up, the exercising background, the motive to use Zwift, the training sessions, the virtual experience, the social interactions, and the understanding of the data that Zwift collects. This study used both physiological, such as questions about their Zwift set-up and background in exercising, as psychological measures, like their virtual and social experience with Zwift.	They used existing technology
Hai et al. [4]	(Emotional) connectedness and space	VR volleyball game	Presence questionnaire	They conducted a preliminary, empirical, comparative survey. The presence questionnaire contained eight questions about social presence.	They created the game themselves

Author	Presence type	Context	Measurement	Explanation	Deployment
Beelen et al. [24]	Perception and understanding and (emotional) connectedness	Haptic rope pulling game	The Networked Minds Measure questionnaire (see section 7)	They conducted empirical, controlled experiments and a questionnaire.	They created the game themselves
Harms and Biocca [23]	Perception and understanding, (emotional) connectedness and interaction	Measure of social presence	The Networked Minds Measure questionnaire (see section 7)	The participants in this study experienced either face-to-face interaction, mediated interaction by text-based low affordance media or mediated interaction via video-conferencing high affordance media.	They reviewed existing literature and created a new social presence measure
Witmer and Singer [28]	Space	VR game	Presence questionnaire (PQ) and immersive tendencies questionnaire (ITQ)	The participants had to execute simple psycho-motor tasks and to learn a complicated route through a virtual complex office building in a virtual environment. They performed four empirical experiments to test both questionnaires.	They reviewed existing literature and created a presence questionnaire and immersive tendencies questionnaire
Mueller et al. [12]	(Emotional) connectedness and interaction	Jogging and audio	Interviews	They created a jogging over a distance experience using a shared audio space. They conducted interviews and tracked the heart rate data of the participants.	They added an audio space to jogging

Author	Presence type	Context	Measurement	Explanation	Deployment
Nunez et al. [21]	(Emotional) connectedness and interaction	Haptics and social presence	Co-presence questionnaire and attraction questionnaire	Users should hug a device and a virtual agent is hugging them back. They conducted an experimental study. The questionnaires combined subjective scales that measure the perception of the other users' co-presence (psychological measure). Besides, they measured the amount and duration of hugs (physiological measurement).	They created and tested a device themselves
Lindley et al. [31]	Interaction	Body movement and social interaction	The engagement questionnaire	They performed an experimental, within-pairs study in which participants had to interact with a bongo or a standard game controller. They used the engagement questionnaire of Chen et al. [56].	The game controllers already existed. They compared traditional controllers against more interactive bongo controllers
Hoffman et al. [5]	Space	Presence in a VR chess game	Presence questionnaire and old-new memory test	They tested whether users feel present in VR chess games. They conducted a presence questionnaire and an old-new memory test in which they had to state whether they had seen the chess position before.	They have not invented a new tool, but used regular chess in VR

Author	Presence type	Context	Measurement	Explanation	Deployment
Heidicker et al. [22]	Perception and understanding, and interaction	Social presence and avatars in VR	The NASA TLX Questionnaire [32], the Slater Usoh Steed Presence Questionnaire [33] and the Networked Minds Measure questionnaire (see section 7)	They used a within-subjects experimental study design to test three different types of avatars. They conducted the NASA TLX Questionnaire to assess the cognitive load, the Slater Usoh Steed Presence questionnaire to analyze presence, and the Networked Minds Measure questionnaire to measure social presence.	They used existing VR systems to test (social) presence. They conducted the tests themselves
Lee et al. [1]	Space and interaction	Presence in virtual golf simulators	Survey questionnaire and physiological measures	The survey questionnaire is designed by Lee et al. to estimate presence using nine different elements. Also, physiological measures are used, such as heart rate.	Existing virtual golf simulators are used for this research. However, the experiments are conducted by Lee et al. themselves
Lombard et al. [26]	Perception and understanding, (emotional) connectedness, space, and interaction	Creating a measure of telepresence based on existing literature	The Temple Presence Inventory	This questionnaire has subscales for social presence: active and passive social presence, social richness, engagement, and social realism.	They created the questionnaire based on literature, and they tested it themselves

[32]NASA TLX Questionnaire - https://humansystems.arc.nasa.gov/groups/tlx/downloads/TLXScale.pdf

[33]Slater Usoh Steed Presence questionnaire - https://marketinginvolvement.files.wordpress.com/2013/12/sus-questionnaire.pdf

Author	Presence type	Context	Measurement	Explanation	Deployment
Oh et al. [27]	Perception and understanding, and space	Systematic review of social presence	-	They reviewed existing literature on the definition, determinants, and implications of social presence.	Existing literature is used
Thalmann et al. [11]	Perception and understanding, and space	Presence in virtual reality volleyball	Presence questionnaire	They performed an empirical study with a virtual reality volleyball game. They combined parts of several presence questionnaires to create their own presence questionnaire.	They created and tested the volleyball game themselves
Souza et al. [2]	Perception and understanding, (emotional) connectedness and space	Systematic review of presence	-	They reviewed existing literature on the measures that are used to measure presence in virtual environments	Existing literature is used
Van Delden et al. [25]	(Emotional) connectedness and interaction	Social presence in a distributed pong game	Questionnaire, OIS scale [41], and the Networked Minds Measure questionnaire (see section 7)	They conducted an empirical study in which they performed experiments with different variations and distributions of their game. They conducted a questionnaire including an OIS scale and the Networked Minds Measure questionnaire	They created and tested the pong game themselves

C Influencing Presence

Table 8: Determinants of presence

Author	Definition of presence	Determinant of presence
Bentvelzen et al. [9]	A sense of community	is increased by **exertion**
Mueller et al. [12]	Social interaction/play	is increased by **exertion**
Lindley et al. [31]	Social interaction/behavior and engagement	are increased by **exertion**
Bentvelzen et al. [9]	A sense of community	is increased by **communication (audio/-text)**. Especially outside of the sport exercise
Nunez et al. [21]	Co-presence and social presence	are increased by **synchronous communication**
Bentvelzen et al. [9]	A sense of community and motivation	are increased by **exercising at the same performance level**
Bentvelzen et al. [9]	A sense of community, involvement, motivation and enjoyment	are increased by **sharing the same mindset and passion**
Beelen et al. [24]	Social presence (as stated by Harms and Biocca, section 7)	is increased by **remote touch/mediated social touch** when being compared to general haptic feedback
Oh et al. [27]	Social presence	is increased by **haptic feedback** compared to no haptic feedback
Kolkmeier et al. [20]	Telepresence	is increased by **immersive virtual reality** compared to a conventional desktop
Thalmann et al. [11]	Spatial and social presence	is increased by **immersive virtual reality** compared to an auto-stereoscopic display, a stereoscopic display, and a 320 Immersive Room
Hoffman et al. [5]	Presence	causes **immersive virtual reality** to be effective
Kolkmeier et al. [20]	Telepresence	is slightly increased by **free navigation**
Souza et al. [2]	Presence	increases **enjoyment and engagement**
Harms and Biocca [23]	Co-presence, attentional allocation, perceived emotional understanding and perceived behavioral interdependence	are increased by **face-to-face contact**
Hai et al. [4]	Presence, social presence and realism	are increased by **eye gazing**

Author	Definition of presence	Determinant of presence
Hai et al. [4]	Presence and social presence	are increased by **realistic interactions**
Witmer and Singer [28]	Presence	is increased by **realistic interactions**
Witmer and Singer [28]	Presence	is increased by **involvement**
Witmer and Singer [28]	Presence	is increased by **selective attention** (i.e., focus on the stimuli in a virtual environment and neglecting distractions)
Witmer and Singer [28]	Presence	is increased by **immersion**
Witmer and Singer [28]	Presence	is increased by the ability to have **control**
Hoffman et al [5]	Presence	is increased by the ability to **control** the environment
Hoffman et al. [5]	Presence	increases **cognitive or sensorimotor performance** in virtual environments
Hoffman et al. [5]	Presence	increases **efficiency and planning** in virtual environments
Hoffman et al. [5]	Presence	increases **the ability to transfer a training to the real world**
Hoffman et al. [5]	Presence	improves **learning**
Witmer and Singer [28]	Presence	is increased by **sensory factors**
Mueller et al. [6]	Social play	is increased by **visual sensory factors**
Mueller et al. [6]	Social play	is increased by **anticipation**
Mueller et al. [12]	Social play	is increased by **anticipation**
Mueller et al. [3]	Social interaction/play	is increased by **anticipation**
Heidicker et al. [22]	Co-presence and behavioral interdependence	are increased by **avatars** with a complete body and movements which are plotted from the user's movement
Mueller et al. [3]	Social interaction/play	is increased by a good **translation of real life to the virtual environment**
Mueller et al. [3]	Social interaction/play and fun	are decreased by **delay**

D Information Brochure and Informed Consent Form

ROWING REIMAGINED

THE DESIGN, DEVELOPMENT AND EVALUATION OF A MULTI-PERSON MIXED REALITY ROWING PLATFORM

INFORMATION BROCHURE

The Rowing Reimagined project is a large-scale research project that focusses on the design, development, and evaluation of a multi-person, mixed reality, rowing platform. The project is carried out by a multidisciplinary team of researchers, working on different studies. You are reading this information brochure because you are asked to participate in one of these studies. This information brochure provides you with general information about the Rowing Reimagined project. More detailed information about this study will be provided orally by the researcher(s) involved. Feel free to ask any questions. Your participation in this research is voluntary and you are free to withdraw from participation at any time.

What is the purpose of this research?

The aim of the Rowing Reimagined project is to explore the potential of virtual reality (VR) for rowing. Can VR help rowers to *perform better*, *learn faster*, or train in a *more engaging* way? These are some of the questions that we set out to answer. Besides these rowing-specific questions, we are also focusing on the design of the system itself. How can we design the interaction between athlete and machine in a meaningful and effective manner?

What will participation entail?

To explore the potential of VR for rowing, you may be asked to participate in various research activities. Research activities include, but are not limited to:

1. Rowing in Virtual Reality. Many of the studies related to the Rowing Reimagined project involve rowing in VR. For this kind of research activity, you will be placed on a rowing ergometer (RP3) and you will be equipped with VR equipment (VR headset and trackers). The movements that you make on the ergometer will be translated to rowing movements in the virtual world. During the experiment, you may be presented with different experimental conditions. For example, to study 'social connectedness', we may ask you to row *with* and *without* an avatar present in your virtual boat.
2. Qualitative research methods. Many of the studies related to the Rowing Reimagined project involve the collection of *qualitative* data. These methods may be used to better understand rowing practice, but may also be used to study usability, user experience, or subjective experiences of rowing in VR. Qualitative research methods include: interviews, observations, surveys, diary studies, self-reports, and other qualitative data collection methods.
3. Quantitative research methods. Many of the studies related to the Rowing Reimagined project involve the collection of *quantitative* data. These methods may be used to better understand the biomechanics, biodynamics, and physiology of rowing. Quantitative research methods include: recording movement data through motion capture, computer vision, and VR trackers; recording physiological data through heartrate sensors and respiration sensors.

Are there any risks of adverse effects?

Virtual Reality is known to induce motion sickness in some people. Motion sickness arises when there is a perceptual mismatch between what we *see* and what we *feel* – as might be the case in a car or on a boat. We have designed our system to minimize the risk of getting motion sick. If, however, you feel nauseous, light-headed, dizzy, or generally unwell, alert the researcher immediately to halt the research. If you are aware that you are sensitive to motion sickness or have had bad experiences with Virtual Reality in the past, you may not participate in research activities that require you to enter virtual reality.

Figure 35: Information brochure and informed consent form

In rare cases, Virtual Reality might also induce a photosensitive epileptic attack in people who are sensitive to light and bright flashes. If you are aware of such sensitivity, you may *not* participate in research activities that require you to enter virtual reality. The researchers will always closely monitor your general well-being. The researcher may halt the experiment when there are signs that you are not feeling well.

May I withdraw from the research?
You may withdraw from the research at any time. You do not need to justify your decision to withdraw. If you wish to stop the experiment, simply notify the researcher. If you have concerns after completion of the experiment, you may ask for your data to be removed. This should be done within 24 hours of the experiment.

What will happen to the collected data?
The studies that are carried out in the context of the Rowing Reimagine project will involve the collection, use, and storage of research data. The data may be qualitative or quantitative in nature.

To protect your privacy, we will make sure to anonymize all data. In some cases, anonymization, however, might not be possible, as might be the case with video or audio data. We will only record video or audio data when necessary. If possible, we will blur out your face and make your voice unrecognizable so that none of the data can be traced back to you. To further protect your privacy, your data will be labeled – if applicable, any links to personally identifiable information will be removed. The researcher will indicate on the 'informed consent form' whether personally identifiable information will be collected in your case. Personally identifiable information will never be made public, any data that is used in scientific publications cannot be traced back to you. Anonymized data however, might be made part of a publicly available corpus.

The data from the Rowing Reimagined project will be safely stored. Data will be stored for 10 years on a GDPR-secure location, according to the GDPR guidelines. You may ask for your data to be removed within 24 hours upon completion of the experiment.

Will I be reimbursed for participation?
If not indicated otherwise, there will be no (monetary) compensation for your participation in this research.

What can I do if I have questions or complaints?
If you wish to seek independent advice or file a complaint, you can contact the secretary of the ethics committee of the University of Twente (ethicscommittee-cis@utwente.nl). For any additional questions regarding this research, please contact dr. D.B.W. Postma (d.b.w.postma@utwente.nl) or any of the other researchers involved in this research project.

What is next?
With this information brochure, you have been informed about the general scope of the Rowing Reimagined project. Next, the researcher that is involved in the current study will provide you with additional information on the specifics of their study. If you have been fully informed about the purpose of the research, the research procedure, and the relevant research methodology, both in writing and orally, you can sign the informed consent form.

Figure 36: Information brochure and informed consent form

INFORMED CONSENT

I hereby declare that I am fully informed about the purpose of the research, the research procedure, and the relevant research methodology. I have read and I understand the provided information and have had the opportunity to ask questions.

To the researcher: strikethrough which option is *not* applicable.

I give my consent for the collection of: anonymous / personally identifiable information data, the kind of which has been detailed in writing (in the information brochure) and orally.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without cost.

Date:

Name:

Signature:

…………………………………………………….

Figure 37: Information brochure and informed consent form

E Introduction Text of Experiment

E.1 English version

"Welcome to our study, and thank you for participating. In this study, you will engage in a Virtual Reality rowing exercise together. The procedure of this test is as follows: in a minute, I will divide you into two rooms. The study consists of two sessions with an intermission for questions in between. During the sessions, I will switch between both rooms. You can hear and see each other in the virtual environment. I will ask you to use the rowing machine and wear the virtual reality headset. You will receive instructions about the rowing exercise within this environment. If you do not hear instructions for a while, you can keep rowing, as this is part of the exercise. After each session, you will be asked to complete a questionnaire. After the second session, there will also be a collaborative discussion about the rowing exercise.

Before we start, I will record audio and video to observe the conducted test again. I will be the only person watching and listening to these recordings. Lastly, I would like to emphasize that as a participant, you can stop at any point without consequences, and if requested, all previously provided answers and collected data can be deleted. I hope I have provided you with sufficient information, do you have any questions? I will now start the recording."

E.2 Dutch version

"Welkom bij mijn onderzoek en bedankt voor je deelname. Tijdens het onderzoek zullen jullie samen deelnemen in een Virtual Reality roeitraining. De procedure van het onderzoek is als volgt: straks zal ik jullie verdelen over twee kamers. Het onderzoek bestaat uit twee sessies met een pauze voor vragen ertussen. Tijdens beide sessies zal ik wisselen tussen jullie kamers. Je zult straks elkaar kunnen horen en zien in de virtuele omgeving. Ik zal je vragen om de roeimachine te gebruiken en de virtual reality headset op te zetten. Je zal instructies ontvangen in de virtuele omgeving. Als je een tijdje geen instructies hoort, kan je gewoon doorgaan met roeien, aangezien dit onderdeel is van de training. Na elke sessie, zal ik je vragen om een vragenlijst in te vullen. Na de tweede sessie, zal er ook een gezamenlijke discussie zijn over de roeitraining.

Voordat we beginnen, ik zal de audio en video opnemen van dit onderzoek zodat ik dit later kan terug kijken en observeren. Ik zal de enige persoon zijn die deze opnames zal bekijken en beluisteren. Tot slot wil ik benadrukken dat jij als deelnemer mag stoppen op elk moment zonder consequenties, en op aanvraag zouden de gegeven antwoorden en verzamelde data kunnen worden verwijderd. Ik hoop dat ik je voldoende informatie heb gegeven, heb je nog vragen? Ik zal nu beginnen met opnemen."

F Questionnaires and Post-Experiment Discussion

F.1 Questions before first condition

Three questions are posed to each participant before starting with the first experimental condition. The first question is: *"Have you used virtual reality before?"* and requires a yes or no response. The second question, *"Have you rowed before?"*, is answered on a scale that ranges from 'never', 'a few times', 'beginner', 'intermediate', or 'expert rower'. The third question, *"How close are you to the other participant?"*, is answered using the IOS scale (see Figure 30).

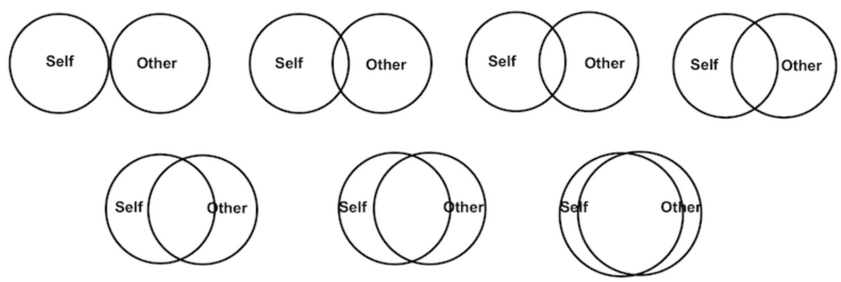


Figure 38: IOS Scale by Aron et al. [41]

F.2 The Networked Minds Measure questionnaire

The Networked Minds Measure questionnaire of Harms and Biocca [23].

Co-presence

1. I noticed (my partner).
2. (My partner) noticed me.
3. (My partner's) presence was obvious to me.
4. My presence was obvious to (my partner).
5. (My partner) caught my attention.
6. I caught (my partner's) attention.

Attentional Allocation

1. I was easily distracted from (my partner) when other things were going on.
2. (My partner) was easily distracted from me when other things were going on.

3. I remained focused on (my partner) throughout our interaction.
4. (My partner) remained focused on me throughout our interaction.
5. (My partner) did not receive my full attention.
6. I did not receive (my partner's) full attention.

Perceived Message Understanding

1. My thoughts were clear to (my partner).
2. (My partner's) thoughts were clear to me.
3. It was easy to understand (my partner).
4. (My partner) found it easy to understand me.
5. Understanding (my partner) was difficult.
6. (My partner) had difficulty understanding me.

Perceived Affective Understanding

1. I could tell how (my partner) felt.
2. (My partner) could tell how I felt.
3. (My partner's) emotions were not clear to me.
4. My emotions were not clear to (my partner).
5. I could describe (my partner's) feelings accurately.
6. (My partner) could describe my feelings accurately.

Perceived Emotional Interdependence

1. I was sometimes influenced by (my partner's) moods.
2. (My partner) was sometimes influenced by my moods.
3. (My partner's) feelings influenced the mood of our interaction.
4. My feelings influenced the mood of our interaction.
5. (My partner's) attitudes influenced how I felt.
6. My attitudes influenced how (my partner) felt.

Perceived Behavioral Interdependence

1. My behavior was often in direct response to (my partner's) behavior.
2. The behavior of (my partner) was often in direct response to my behavior.
3. I reciprocated (my partner's) actions.
4. (My partner) reciprocated my actions.
5. (My partner's) behavior was closely tied to my behavior.
6. My behavior was closely tied to (my partner's) behavior.

F.3 Anthropomorphism of the agent

This questionnaire combines the Rapport Scale of Acosta and Ward [39] and the ASA questionnaire of Fitrianie et al. [40]. The participants are asked to rate the following statements on a Likert scale from one to seven, with one being "strongly disagree" and seven being "strongly agree".

1. (The agent) has the appearance of a human
2. (The agent) has a human-like manner
3. (The agent) seems natural from its outward appearance
4. (The agent's) appearance is appropriate
5. I like (the agent)
6. (The agent) has a distinctive character
7. (The agent) is boring
8. The interaction captured my attention
9. I can rely on (the agent)
10. (The agent) is attentive
11. (The agent's) behavior does not make sense
12. (The agent) has no clue of what it is doing
13. I see the interaction with (the agent) as something positive
14. (The agent) is a social entity
15. (The agent) is emotionless
16. The emotions I feel during the interaction are caused by (the agent)
17. (The agent) is persuasive
18. I would recommend (the agent) to others

F.4 Post-experiment discussion

The following questions are asked for both conditions: *"Which picture fits best with the agent? And why?"* and *"Which picture fits least with the agent? And why?"* Figure 39 shows the pictures that are presented to the participants.

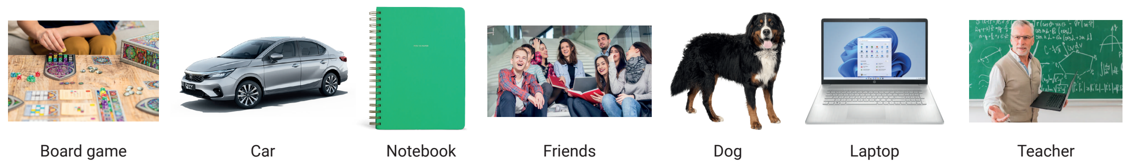


Figure 39: Pictures used in the post-experiment discussion that are adapted from Escobar-Planas et al. [42]. They are adjusted from a pediatric to an adult audience

The pictures of Figure 39 can be interpreted as follows, the car serves as a technological tool that humans can use; the notebook represents a non-technological tool; the laptop represents a digital tool; the board game represents a toy or game; the dog represents a pet, something alive but not the same as a human; friends represent people; the teacher represents someone who instructs.

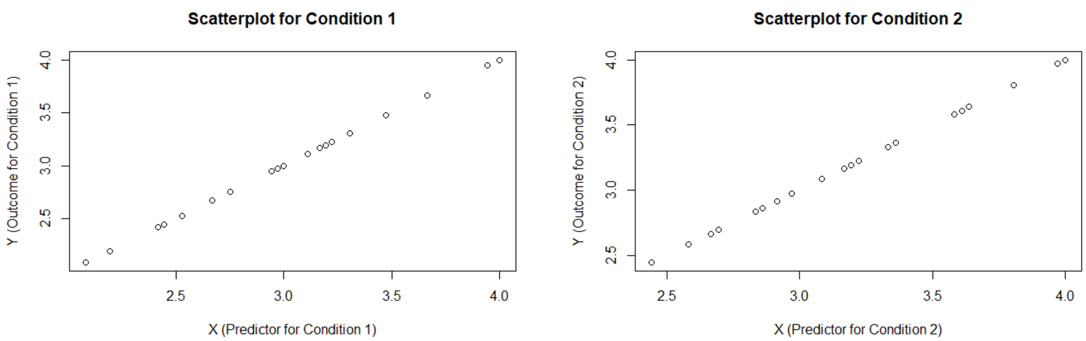
Next, a few questions will be asked about the study:

- What did you like about rowing exercise one?
- What did you dislike about rowing exercise one?
- What would you change about rowing exercise one?
- What did you like about rowing exercise two?
- What did you dislike about rowing exercise two?
- What would you change about rowing exercise two?
- Which condition would you prefer?

G Statistical Model Assumptions

G.1 LMER model assumptions Networked Minds Measure questionnaire

The assumptions of linear mixed effects regression posed by Winter [44] are verified for this dataset. First, the linearity of the data is examined by plotting the outcome variable against the predictor variable. The plots should reveal an approximately linear pattern, which is the case as can be seen in Figure 40.



(a) (b)

Figure 40: The Figure on the left shows a scatterplot of condition one, which is the condition with the non-embodied coxswain, and the Figure on the right shows a scatterplot of condition two, which is the condition with the embodied coxswain. The calculations can be found in Appendix H.2, Listing 5

Next, Winter [44] states that the predictors should not be correlated. Given that the LMER model only includes one predictor, condition, there is no concern for collinearity. As such, this assumption is not relevant for this model. Moreover, there should be a homoskedasticity or homogeneity of variance. As shown in Figure 41, the residuals are randomly scattered, and therefore this assumption is satisfied. Moreover, Levene's test is conducted to assess the homogeneity of variance. The outcome shows that a homogeneity of variance can be assumed ($p = 0.9535$; for calculations see Appendix H.2, Listing 6).

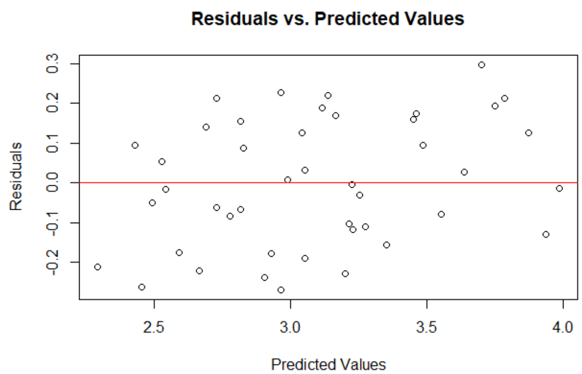
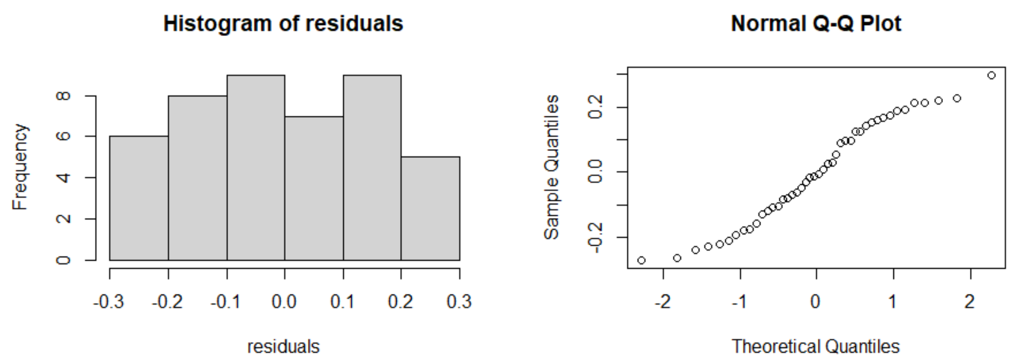


Figure 41: The residuals are plotted against the predictor values, and no clear pattern is visible. The red line is the zero line at $y = 0$. The calculations can be found in Appendix H.2, Listing 7

In addition, the residuals should be normally distributed. To verify this, a histogram and a Q-Q plot of the residuals are plotted (see Figure 42), and both show an approximate normal distribution.



(a)

(b)

Figure 42: The histogram of the residuals (left) shows an approximately bell-shaped curve, which indicates that the residuals are normally distributed. The Q-Q plot of the residuals (right) demonstrates that the data follows approximately a straight line, which suggests normality. The calculations can be found in Appendix H.2, Listing 8

Lastly, the observations should be independent of each other. This experiment has a within-subject design, which means that the observations are correlated as participants test both conditions. However, LMER models can account for the within-subject correlation. Moreover, including the participant number as a random effect reduces individual variability and correlations. Besides, it should be noted that the order of testing the conditions is randomized, and there are no evident clusters in the scatterplots (see Figure 40). Hence, it is assumed that this assumption is fulfilled.

G.2 LMER model assumptions agent questionnaire

The assumptions of Winter [44] are verified for the agent dataset. Firstly, linearity should be analyzed, and as can be seen in Figure 43, the plots reveal an approximately linear pattern. Therefore, linearity can be assumed.

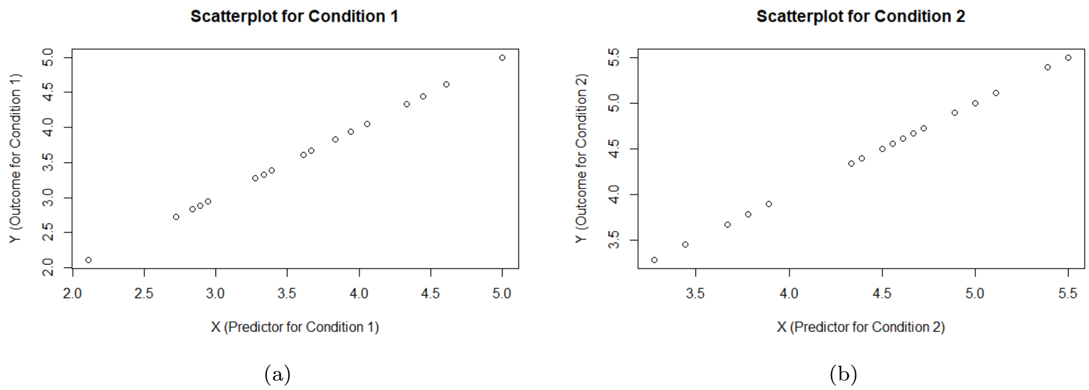


Figure 43: The Figure on the left displays a scatterplot of condition one, which is the condition with the non-embodied coxswain, and the Figure on the right shows a scatterplot of condition two, which is the condition with the embodied coxswain. The calculations can be found in Appendix H.5, Listing 14

Moreover, the predictors in the LMER model should not be correlated. Similar to the Networked Minds Measure questionnaire, the LMER model only contains one predictor, condition, so there is no concern for collinearity. Additionally, LMER models assume a homogeneity of variance. Figure 44 shows that the residuals are randomly scattered, and Levene's test is conducted ($p = 0.5862$; for calculations see Appendix H.5, Listing 15). Both show that the assumption of homogeneity of variance can be confirmed.

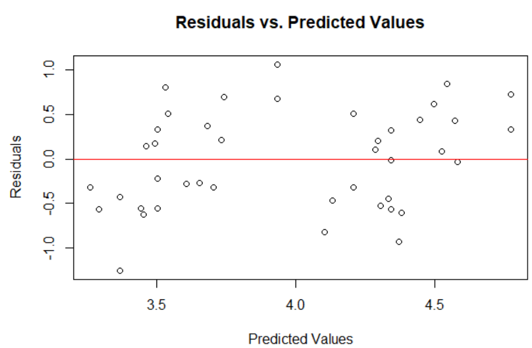


Figure 44: Residuals are plotted against the predictor values, and no clear pattern is visible. The red line is the zero line at $y = 0$, for calculations see Appendix H.5, Listing 16

Furthermore, the residuals should be normally distributed. The histogram and Q-Q plot of the residuals show approximately a normal distribution (see Figure 45).

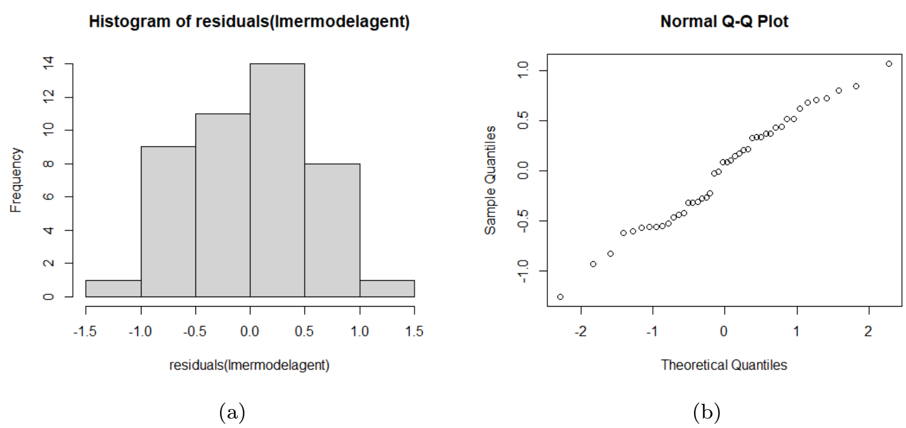


Figure 45: The histogram of the residuals (left) displays an approximate bell-shaped curve, hence they are approximately normally distributed. The Q-Q plot of the residuals (right) demonstrates that the residuals follow a nearly straight line, and therefore normality can be assumed. For calculations see Appendix H.5, Listing 17

Finally, one of the assumptions of LMER entails that the observations should be independent of each other. Given that this experiment has a within-subject design, both observations of the same participant are correlated. Nonetheless, LMER models can account for the within-subject correlation and individual variability, and correlation is decreased by including the participant number as a random effect. Additionally, the order of testing the conditions is randomized, and there are no visible clusters in the scatterplots (see Figure 43). Therefore, we assume that this assumption is satisfied.

H R-script Code

This Appendix includes the code in R that is used for inspecting the datasets and for analyzing the assumptions of LMER.

H.1 Inspecting the dataset of the Networked Minds Measure questionnaire

The dataset needs to be prepared for testing, and therefore the variables are organized. Some variables should be treated as nominal or ordinal variables instead of numeric variables. Listing 1 demonstrates the process of conversion.

Listing 1: Converting numeric variables to ordinal and nominal variables

```
# Converting numeric variables to nominal variables
DATA$Participant <- factor(DATA$Participant)
DATA$Condition <- factor(DATA$Condition)
DATA$Category <- factor(DATA$Category)
DATA$Question <- factor(DATA$Question)
DATA$BQ1 <- factor(DATA$BQ1)
DATA$Position <- factor(DATA$Position)
DATA$Order <- factor(DATA$Order)

# Converting numeric variables to ordinal variables
DATA$BQ2 <- ordered(DATA$BQ2)
DATA$BQ3 <- ordered(DATA$BQ3)
```

In addition, the dataset is inspected, and several normality tests are applied [23]. Listing 2 demonstrates the execution of the Shapiro Wilk's test in R. Listing 3 shows the R code for creating a Q-Q plot, and Listing 4 illustrates the R code for generating a histogram.

Listing 2: Testing for normality using Shapiro Wilk's test

```
# Shapiro Wilk's test to check normality
shapiro.test(new_dataset$Mean_outcome)

       Shapiro-Wilk normality test

data: new_dataset$Mean_outcome
W = 0.97, p-value = 0.27
```

Listing 3: Testing for normality using a Q-Q plot

```
# Create a Q-Q plot to check normality
qqnorm(new_dataset$Mean_outcome, xlab = "Theoretical Quantiles", ylab = "Sample
    Quantiles from Variable Outcome")
qqline(new_dataset$Mean_outcome)
```

Listing 4: Testing for normality using histograms

```
# Create a histogram to check normality
new_dataset$ConditionLabel <- ifelse(new_dataset$Condition == 1, "Condition Non-
    Embodied Agent", "Condition Embodied Agent")
library(ggplot2)
ggplot(new_dataset, aes(x = Mean_outcome)) +
  geom_histogram(binwidth = 1, fill = "white", color = "black") +
  facet_grid(. ~ ConditionLabel) +
  labs(
    title = "Histograms of Outcome by Condition",
    x = "Outcome",
    y = "Frequency"
  )
```

H.2 Assumptions of LMER model of the Networked Minds Measure questionnaire

A linear mixed effects regression analysis is performed to see whether there is a significant effect of condition on the outcome in the Networked Minds Measure questionnaire. The assumptions of a LMER model are verified in Appendix G.1, and the code is provided in this Appendix. Listing 5 presents the R code for analyzing linearity using scatterplots. Next, Listing 6 performs Levene's test for homogeneity of variance. Moreover, Listing 7 checks the homogeneity of variance by inspecting the randomness of the residuals. Lastly, Listing 8 examines the normality of the residuals.

Listing 5: Testing linearity of the dataset by scatterplots

```
# Scatterplot for condition non-embodied agent
plot(new_dataset$Mean_outcome[new_dataset$Condition == 1],
    new_dataset$Mean_outcome[new_dataset$Condition == 1],
     main="Scatterplot for Condition 1", xlab="X (Predictor for Condition 1)",
         ylab="Y (Outcome for Condition 1)")

# Scatterplot for condition embodied agent
plot(new_dataset$Mean_outcome[new_dataset$Condition == 2],
    new_dataset$Mean_outcome[new_dataset$Condition == 2],
     main="Scatterplot for Condition 2", xlab="X (Predictor for Condition 2)",
         ylab="Y (Outcome for Condition 2)")
```

Listing 6: Testing for homogeneity of variance by with Levene's test

```
# Install and load packages
install.packages("car")
library(car)

# Conduct Levene's test
levene_test <- leveneTest(residuen, group = DATA$Outcome)
print(levene_test)

Levene's Test for Homogeneity of Variance (center = median)
      Df F value Pr(>F)
group 1 <0.01 0.95
      42
```

Listing 7: Testing for homogeneity of variance by plotting the residuals

```
# Mean zero residuals assumption
# Calculate residuals and predicted values
residuals <- residuals(lmermodel)
predicted_values <- fitted(lmermodel)

# Create scatterplot of residuals vs. predicted values
plot(predicted_values, residuals, main = "Residuals vs. Predicted Values",
     xlab = "Predicted Values", ylab = "Residuals")

# Add a horizontal line for reference
abline(h = 0, col = "red")
```

Listing 8: Testing the normality of the residuals by means of a histogram and Q-Q plot

```
# Test the normality of residuals by creating a histogram and Q-Q plot
hist(residuals(lmermodel))
qqnorm(residuals(lmermodel))
```

H.3 Code LMER Networked Minds Measure questionnaire

The code provided in Listing 9 shows the results of the LMER model for the Networked Minds Measure questionnaire.

Listing 9: Linear mixed effects regression analysis on the Networked Minds Measure questionnaire

```
# Load the lmerTest package and carry out the LMER test
library(lmerTest)
lmermodel <- lmer(Mean_outcome ~ Condition + (1|Participant), data = new_dataset)
summary(lmermodel)

Linear mixed model fit by REML. t-tests use Satterthwaite's method ['
    lmerModLmerTest']
Formula: Mean_outcome ~ Condition + (1 | Participant)
   Data: new_dataset

REML criterion at convergence: 44.7

Scaled residuals:
     Min 1Q Median 3Q Max
-1.25 -0.55 -0.04 0.67 1.37
Random effects:
 Groups Name Variance Std.Dev.
 Participant (Intercept) 0.20 0.45
 Residual 0.05 0.22
Number of obs: 44, groups: Participant, 22

Fixed effects:
           Estimate Std. Error df t value Pr(>|t|)
(Intercept) 2.98 0.11 25.32 27.86 < 0.01 ***
Condition2 0.23 0.07 21.00 3.58 < 0.01 **
---
Signif. codes: 0 *** 0.001 ** 0.01 * 0.05 . 0.1   1

Correlation of Fixed Effects:
          (Intr)
Condition2 -0.30
```

H.4 Inspecting the dataset of the agent questionnaire

This dataset also needs to be prepared for testing and, therefore needs organizing. The variables 'participant', 'condition', and 'question' must be converted to nominal variables. Listing 10 demonstrates the process of conversion. Moreover, the normality of the dataset is inspected using Shapiro Wilk's test (see Listing 11), a Q-Q plot of the outcome values (see Listing 12) and a histogram of the outcome values (see Listing 13).

Listing 10: Converting numeric variables to nominal variables

```
# Convert numeric variables to nominal variables
DATA$Participant <- factor(DATA$Participant)
DATA$Condition <- factor(DATA$Condition)
DATA$Question <- factor(DATA$Question)
```

Listing 11: Testing for normality using Shapiro Wilk's test

```
# Shapiro Wilk's test to check normality
shapiro.test(agent_dataset$Mean_outcome)

       Shapiro-Wilk normality test

data: agent_dataset$Mean_outcome
W = 0.98, p-value = 0.77
```

Listing 12: Testing for normality using a Q-Q plot

```
# Create a Q-Q plot to check normality
qqnorm(agent_dataset$Mean_outcome, xlab = "Theoretical Quantiles", ylab = "Sample
     Quantiles from Variable Outcome")
qqline(agent_dataset$Mean_outcome)
```

Listing 13: Testing for normality using histograms

```
# Create a histogram to check normality
agent_dataset$ConditionLabel <- ifelse(agent_dataset$Condition == 1, "Condition
    Non-Embodied Agent", "Condition Embodied Agent")
library(ggplot2)
ggplot(agent_dataset, aes(x = Mean_outcome)) +
  geom_histogram(binwidth = 1, fill = "white", color = "black") +
  facet_grid(. ~ ConditionLabel) +
  labs(
    title = "Histograms of Outcome by Condition",
    x = "Outcome",
    y = "Frequency"
  )
```

H.5 Assumptions of LMER model of the agent questionnaire

The assumptions of LMER are verified in Appendix G.2, and the code is provided in this Appendix. Listing 14 gives the R code for analyzing linearity using scatterplots. In addition, Listing 15 performs Levene's test for homogeneity of variance. Furthermore, Listing 16 analyzes homogeneity of variance by examining the randomness of the residuals. Lastly, Listing 17 examines the normality of the residuals.

Listing 14: Testing linearity of the dataset by scatterplots

```
# Scatterplot for condition non-embodied agent
plot(agent_dataset$Mean_outcome[agent_dataset$Condition == 1],
    agent_dataset$Mean_outcome[agent_dataset$Condition == 1],
     main="Scatterplot for Condition 1", xlab="X (Predictor for Condition 1)",
         ylab="Y (Outcome for Condition 1)")

# Scatterplot for condition embodied agent
plot(agent_dataset$Mean_outcome[agent_dataset$Condition == 2],
    agent_dataset$Mean_outcome[agent_dataset$Condition == 2],
     main="Scatterplot for Condition 2", xlab="X (Predictor for Condition 2)",
         ylab="Y (Outcome for Condition 2)")
```

Listing 15: Testing for homogeneity of variance with Levene's test

```
# Install and open packages
install.packages("car")
library(car)

# Perform Levene's Test for homogeneity of variance
levene_test <- leveneTest(Mean_outcome ~ Condition, data = agent_dataset)
print(levene_test)

Levene's Test for Homogeneity of Variance (center = median)
     Df F value Pr(>F)
group 1 0.30 0.59
     42
```

Listing 16: Testing for homogeneity of variance by plotting the residuals

```
# Mean zero residuals assumption
# Calculate residuals and predicted values
residualsagent <- residuals(lmermodelagent)
predicted_valuesagent <- fitted(lmermodelagent)

# Create scatterplot of residuals vs predicted values
plot(predicted_valuesagent, residualsagent, main = "Residuals vs. Predicted
    Values",
     xlab = "Predicted Values", ylab = "Residuals")

# Add a horizontal line for reference
abline(h = 0, col = "red")
```

Listing 17: Testing the normality of the residuals by means of a histogram and Q-Q plot

```
# Test the normality of residuals by creating a histogram and Q-Q plot
hist(residuals(agentmodel))
qqnorm(residuals(agentmodel))
```

H.6 Code LMER agent questionnaire

The code provided in Listing 18 shows the results of the LMER model for the agent questionnaire.

Listing 18: Linear mixed effects regression analysis on the agent questionnaire

```
# Load the lmerTest package and carry out the LMER test
library(lmerTest)
lmermodelagent <- lmer(Mean_outcome ~ Condition + (1|Participant), data =
    agent_dataset)
summary(lmermodelagent)

Linear mixed model fit by REML. t-tests use Satterthwaite's method ['
    lmerModLmerTest']
Formula: Mean_outcome ~ Condition + (1 | Participant)
   Data: agent_dataset

REML criterion at convergence: 91.4

Scaled residuals:
    Min 1Q Median 3Q Max
-2.09 -0.75 0.14 0.64 1.78

Random effects:
 Groups Name Variance Std.Dev.
 Participant (Intercept) 0.09 0.31
 Residual 0.36 0.60
Number of obs: 44, groups: Participant, 22

Fixed effects:
           Estimate Std. Error df t value Pr(>|t|)
(Intercept) 3.56 0.14 40.25 24.76 < 0.01 ***
Condition2 0.84 0.18 21.00 4.64 < 0.01 ***
---
Signif. codes: 0 *** 0.001 ** 0.01 * 0.05 . 0.1   1

Correlation of Fixed Effects:
          (Intr)
Condition2 -0.63
```

H.7 R code variable position

Listing 19 provides the code for the exploratory research to analyze if there is a perceived difference in social presence between the front and the back rower.

Listing 19: Analysing if the variable position has a significant effect on the outcome

```
# Import the data and set the directory
library("readxl")
setwd("C:/Users/frevo/Downloads")
DATA = read_xlsx("Sheet for R.xlsx",sheet = "Sheet1")

# Install and open packages
install.packages("dplyr")
library(dplyr)

# Create a new dataset with mean outcome per condition for each participant
pos_dataset <- DATA %>%
  group_by(Participant, Condition, Position) %>%
  summarise(Mean_outcome = mean(Outcome))

# Change numeric variables to nominal variables
pos_dataset$Condition <- factor(pos_dataset$Condition)
pos_dataset$Participant <- factor(pos_dataset$Participant)
pos_dataset$Position <- factor(pos_dataset$Position)

# View new dataset
View(pos_dataset)

# Load the lmerTest package and carry out LMER test
library(lmerTest)
lm_position <- lmer(Mean_outcome ~ Position + (1|Participant), data = pos_dataset)

summary(lm_position)

Linear mixed model fit by REML. t-tests use Satterthwaite's method ['
    lmerModLmerTest']
Formula: Mean_outcome ~ Position + (1 | Participant)
   Data: pos_dataset

REML criterion at convergence: 52.8

Scaled residuals:
     Min 1Q Median 3Q Max
-1.49 -0.57 0.04 0.55 1.37
```

```
Random effects:
 Groups Name Variance Std.Dev.
 Participant (Intercept) 0.20 0.45
 Residual 0.07 0.27
Number of obs: 44, groups: Participant, 22

Fixed effects:
           Estimate Std. Error df t value Pr(>|t|)
(Intercept) 3.06 0.15 20.00 20.81 < 0.01***
Position2 0.08 0.21 20.00 0.37 0.72
---
Signif. codes: 0 *** 0.001 ** 0.01 * 0.05 . 0.1   1

Correlation of Fixed Effects:
         (Intr)
Position2 -0.71
```