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Exploring the Visualisation of Avatars to Support Remote Collaboration in Immersive Virtual Environments

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Declaration

This thesis presents work carried out by myself and does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university; to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text; and all substantive contributions by others to the work presented, including jointly authored publications, are clearly acknowledged.

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Glossary

2D 2-dimensional. 48, 54, 62, 67

3D 3-dimensional. 16–20, 48, 54, 59, 62, 67, 76

AR Augmented Reality. 24, 59

EEG Electroencephalogram. 75

FoV Field of View. 53

GB gigabyte. 58, 59

HMD head-mounted display. 22, 28–30, 32, 44, 48, 49, 55, 82

IAPS International Affective Picture System. 83

IVE Immersive Virtual Environment. 1, 8, 23, 24, 26, 45–50, 52, 54

LTS long-term support. 55

OASIS Open Affective Standardized Image Set. 83

PC Personal Computer. 29, 30, 38

RAM Random Access Memory. 58, 59

RGB RGB. 16, 17, 22, 32

RSME The Rating Scale on Mental Effort. 61

SDK Software Development Kit. 17, 32

SPQ Social Presence Questionnaire. 61

SUS System Usability Scale. 61

VE Virtual Environment. vi, 38, 45, 48, 53, 55, 57

VR Virtual Reality. v, 1–8, 11, 13, 14, 17–25, 28–38, 40, 42–55, 57–59, 62, 69, 70, 72–82

WebRTC Web Real-Time Communication. 55

Abstract

The primary objective of this thesis is to investigate the use of virtual avatars to support remote collaboration in a Virtual Reality (VR) environment. VR is a technology that creates a computer-generated simulation of a three-dimensional environment, providing users with an immersive and interactive experience through the use of specialized head mounted displays (HMDs) and input devices.

One of the most compelling application of VR technology is the creation of collaborative virtual spaces, where remote participants can interact and collaborate with each other using virtual avatars. This thesis explores the impact of avatar-mediated communication in VR on collaboration outcomes, including task performance, communication effectiveness, system usability, and user experience. The thesis analyses the effect of different avatar features, such as expression, position, and appearance, on social presence and collaboration outcomes.

This research presents the findings of a pilot study and a subsequent full user study that investigated the impact of avatar visualisation techniques on social presence, perceived user experience, and user preference in VR remote collaboration. The pilot study provided valuable insights and informed the design of the full study, which involved participants engaging in collaborative tasks while utilizing different avatar visualisation techniques.

The results of this research shows that avatar design and features significantly impact collaboration outcomes. For instance, avatars with more expressive features were found to be preferred over non-expressive avatars, even if they did not assist with social presence or collaboration outcomes. Furthermore, the results suggest that where the avatars are placed in the

virtual space can also impact these outcomes, while avatar appearance was mixed in these respects.

The research identified several areas for future work in this field. These include further exploration of the impact of avatar design and features on collaboration outcomes, as well as investigation into the use of VR technology to support remote collaboration in different contexts and scenarios. Overall, this research contributes to a better understanding of the use of virtual avatars to support remote collaboration in a Virtual Reality environment.

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List of Publications

The following publications were generated as a result of the thesis research, or while the author was a postgraduate student at the University of South Australia:

1. Hart, Jonathon Derek, Thammathip Piumsomboon, Gun A. Lee, Ross T. Smith, and Mark Billinghurst. 'Manipulating Avatars for Enhanced Communication in Extended Reality'. In 2021 IEEE International Conference on Intelligent Reality (ICIR), 9–16. Piscataway, NJ, USA: IEEE, 2021. https://doi.org/10.1109/ICIR51845.2021.00011.

2. Hart, J.D., Piumsomboon, T., Lawrence, L., Lee, G.A., Smith, R.T., Billinghurst, M., 2018a. Demonstrating Emotion Sharing and Augmentation in Cooperative Virtual Reality Games, in: Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts - CHI PLAY '18 Extended Abstracts. Presented at the the 2018 Annual Symposium, ACM Press, Melbourne, VIC, Australia, pp. 117–120. https://doi.org/10.1145/3270316.3270596

3. Hart, J.D., Piumsomboon, T., Lawrence, L., Lee, G.A., Smith, R.T., Billinghurst, M., 2018b. Emotion Sharing and Augmentation in Cooperative Virtual Reality Games, in: Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts - CHI PLAY '18 Extended Abstracts. Presented at the the 2018 Annual Symposium, ACM Press, Melbourne, VIC, Australia, pp. 453–460. https://doi.org/10.1145/3270316.3271543

4. Hart, J.D., Piumsomboon, T., Lee, G., Billinghurst, M., 2018c. Sharing and

Augmenting Emotion in Collaborative Mixed Reality, in: 2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct). Presented at the 2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct), IEEE, Munich, Germany, pp. 212–213. https://doi.org/10.1109/ISMAR-Adjunct.2018.00069

Chapter 1

Introduction

This thesis explores how avatars can support remote collaboration in an Immersive Virtual Environment (IVE). An avatar refers to a 3D virtual representation or embodiment of a user in an IVE, enabling them to interact, communicate, and collaborate with others in the virtual space[3]. Avatars serve as the visual and interactive representation of individuals, mimicking their movements, gestures, and expressions to create a sense of presence and facilitate effective remote collaboration in an IVE.

Individuals around the world are becoming increasingly connected virtually. The recent COVID-19 global pandemic accelerated the need for people to adapt to collaboration technology like Zoom or VR to maintain social bonds and work environments over a remote distance [4, 5, 6, 7]. Since then, virtual conferencing has continued to be an affordable alternative to long-distance travel and meeting in person.

A variety of collaborative technologies allow users to experience the presence of their remote friends, family, and workmates. For example, people can make

Facetime [8] calls on their tablets, use Zoom video conferencing [9], or even control tele-presence robots [10]. The use of immersive VR and virtual avatars for improving social presence is becoming increasingly popular [11]. There are also many ways we can now detect a user's emotion and facial expression, which can then be mapped onto realistic avatars.

Despite the various technology options, remote collaboration is often difficult. This is particularly true in a professional environment that is increasingly complex, and where communication needs to be effective [12]. One of the most popular current solutions used by professionals is desktop video conferencing, such as Skype [13] or Zoom [9]. However, these systems can have several limitations. First, they require a web camera, and the position of the camera is often not at a good angle to see the other person's face making it impossible to maintain eye contact. One user may see the top of the other user's head or random part of their face while they look at the screen. A close-up of the face or poor lighting can make it hard to see the users' environment, which makes contextual cues difficult or impossible to understand. Limited internet bandwidth may create a blocky, blurry and jittery 2D image, perhaps only good enough for standard definition at a low frame-rate [14]. Finally, natural gaze and gesture cues can be seen but cannot be clearly understood due to the lack of spatial cues that can be crucial in face-to-face communication [15].

Prolonged use of these tools can lead to physical, perceptual, and cognitive strain, resulting in what has become known as "zoom fatigue" [16]. The constant need to be present and engaged in a video conferencing environment can require high cognitive load which can make it difficult to maintain focus and productivity [16]. Cognitive, physical, and perceptual strains in the context of video

conferencing can be understood as the collective challenges faced by an individual. Cognitive load encompasses the mental processing capacity demanded when engaging in a task or assimilating information, reflecting the balance between task complexity and available cognitive resources [17]. Physical strain emerges from the extended static posture and repetitive actions [18], while perceptual strain results from the constraints of interpreting a limited, often 2D, sensory environment devoid of natural spatial cues and full-spectrum sensory feedback.

Using virtual avatars is one way of overcoming the limitations of desktop video conferencing [19]. For example, avatars can be used to display a wide range of emotions and expressions, using what can often be subtle social cues to show empathy [20]. They can also be used in mixed-modality environments where both avatar and video representations are possible, like in Microsoft Teams Together Mode [21] where people are shown together in the same virtual meeting room. Using avatars in VR can help to create a sense of presence and embodiment, allowing users to feel as if they are truly interacting with other people in the same 3D space [22].

Avatars can be used as an embodiment of a user shown to a remote user instead of using an image of the other person. Nevertheless, there are several challenges associated with using them. For example, the avatars' non-verbal cues (such as subtle facial expressions and body language) can be hard to convey. Junuzovic et al. [23] showed that cartoon-based avatars, may be less effective than video for conveying social presence. In contrast, Panda et al. [24] showed that realistic avatars could help bridge the gap between cartoon and video representations, creating a more engaging and immersive experience for users. Therefore, improving the fidelity and expressiveness of avatars, might create a more immersive commu-

nication experience for remote collaborators.

With the development of VR environments, there is an opportunity to explore the use of virtual avatars in more depth and investigate their potential to support remote collaboration. Therefore, this thesis aims to explore the use of virtual avatars in a VR environment to support remote collaboration and investigate the benefits and limitations of various approaches to how the avatar appears to the remote user.

1.1 Research Problems

This research explores the use of avatar technology for conveying information within the context of VR as compared to face-to-face interactions. Virtual Reality is an evolving technology that immerses users entirely in a computer-generated environment, enabling them to interact with virtual elements as if they were physical. These new avatars designed for VR must address the limitations present in current collaborative VR systems.

The exploration of how avatars can be used to convey the same (or enhanced) communication cues between remote participants compared to face-to-face conversation is an important problem, and addressing it could significantly enhance remote collaboration [25]. For example, when a person focuses on something not in the view of a collaborator, they cannot share gaze or gesture expressions. This restricts the communication channels available while performing a task[26]. However, in VR, virtual gaze or gesture cues could be used that are always in view, enhancing the communication [27].

The research problem that this thesis addresses is exploring the impact of

avatar visualisation techniques on various aspects of VR remote collaboration, such as social presence, user experience, and social preference. The research aims to explore whether different avatar visualisation techniques have a significant impact on the user's engagement and experience while collaborating remotely in VR. This research can provide valuable insights to VR developers and designers to enhance the user's experience and improve the overall effectiveness of remote collaboration.

We will address this problem by answering the following research questions:

The main research questions are:

- RQ1: How can virtual avatars facilitate remote collaboration in a VR environment.

  This research question explores the ways in which virtual avatars can effectively support remote collaboration in VR. It aims to investigate some of the specific functions and features of virtual avatars that contribute to enhanced communication, interaction, and collaboration among remote participants. The question focuses on understanding how virtual avatars can bridge the spatial and social gaps between remote collaborators, enabling them to effectively work together, share information, and engage in collaborative tasks within the VR environment.

- RQ2: What are the key components that impact their effectiveness?

  This research question aims to identify some of the critical elements that influence the effectiveness of virtual avatars in facilitating remote collaboration. It investigates various factors that contribute to the overall effectiveness of virtual avatars, such as avatar design, representation, communication cues, social presence, and user experience. The question seeks to uncover the key

components that significantly impact the success of virtual avatars in supporting remote collaboration, providing insights into how to optimize these components to maximize their effectiveness.

The research aims to address these research questions by designing a virtual reality prototype and testing various metrics: including the user preference of position, appearance and expression of avatars; social presence, system usability and mental effort. The pilot study explored modalities of avatar representation and its findings were detailed in "Emotion Sharing and Augmentation in Cooperative Virtual Reality Games" [28], emphasizing the role of emotion in VR interactions. Building on this, the main study, published as "Manipulating Avatars for Enhanced Communication in Extended Reality" [29], delved into avatar manipulation techniques, underscoring their significance in enhancing communication in virtual spaces. Together, these studies provide valuable insights into avatar-mediated communication in extended reality environments.

Example Scenario: Remote Maintenance

One application for this research could be to enhance remote collaboration on physical tasks. For example, imagine that there is an individual who is an expert, highly trained mechanic who is collaborating remotely with a new mechanic who has never worked on a particular model of car before.

John is a mechanic who runs his own garage in a small town. One day, he has a particularly challenging car repair job, and he needs assistance from a more experienced mechanic. He decides to use an VR remote collaboration platform to connect with his friend, Mike, who is a skilled mechanic but lives in a different

state. John wears a VR headset to get a better sense of the problem and to show Mike the details of the car by the real environment being captured and streamed to him. Mike joins the session from his computer and sees the same view as John through his own avatar in the virtual environment.

(R1) In this scenario, the research question is whether the choice of avatar visualisation techniques will affect social presence in VR remote collaboration. John and Mike use realistic avatars that resemble their actual appearance. This choice of avatar may enhance social presence, as they can see each other as they would in real life, which can increase their sense of connection and engagement with each other.

(R2) In the remote maintenance scenario, the role of avatar visualization techniques on user experience in VR remote collaboration becomes paramount. Beyond John and Mike's avatars reflecting their real-world likenesses, their avatars are equipped with movement synchronization, capturing and displaying real-time gestures such as pointing or illustrating. These gestures provide an added layer of non-verbal communication, crucial for tasks requiring precision. Ambient sounds, like the car's engine or tools, supplement the visual cues, offering context. With voice and chat features complementing the visualization, the research question delves into which avatar techniques most effectively bolster collaborative efforts in VR, paving the way for optimized avatar-centric design in such platforms.

1.2 Approach

The first user study focused on exploring the sharing and augmenting of facial expressions in cooperative VR games. It involved the development of a proto-

type system to capture facial expressions from a desktop user and display them on an avatar within the VR environment. Two cooperative VR games were created to evaluate the impact of the avatar's facial expressions on social interaction and gameplay. A pilot study was conducted that mainly focused on qualitative methodology, gathering feedback and observations from participants to inform further refinements and investigations.

The second user study aimed to formally investigate the impact of avatar elements on social presence, perceived user experience, and user preference in an IVE. It used an asymmetric remote collaboration system to simulate eye and face-tracking in VR, enabling the representation of a desktop user as an avatar in the VR environment. The study manipulated factors such as avatar expression (On/Off), representation (2D/3D), and position (screen-attached/in-scene). A full user study was conducted to assess the effects of these elements on participant experiences and perceptions of social presence and user preference.

By developing these prototypes and conducting these two studies, the research aimed to contribute to a deeper understanding of how virtual avatars can facilitate remote collaboration in VR environments. The approaches employed in each study provided valuable insights into the potential of avatar-based communication and interaction, paving the way for further investigations and advancements in this field.

1.3 Contributions

The thesis makes several notable contributions to the field of avatar design for enhancing remote collaboration in virtual reality. The key contributions are:

- **Proposing a novel approach to avatar design for enhancing remote collaboration in VR environments:** This work addresses the challenge of improving remote collaboration by introducing and evaluating the use of avatars that manipulate multiple modalities (e.g., position, facial expressions, appearance). This provides a new framework for understanding how avatars can be leveraged to improve interaction and communication in virtual spaces.

- **Conducting an empirical evaluation of avatar modalities and non-verbal cues:** The thesis includes comprehensive user studies that evaluate various approaches to avatar modalities in VR, particularly focusing on non-verbal communication cues. The results of these studies contribute to a deeper understanding of how different avatar modalities impact user experience and collaboration effectiveness.

- **Demonstrating the potential for real-world applications:** The findings reveal that the proposed approach can be applied to real-world scenarios such as remote training, virtual meetings, and other professional collaborations, showing a clear pathway for practical application in industry and education.

- **Contributing to the design guidelines for VR collaboration tools:** The thesis emphasizes the critical role of user experience (UX) in VR collaboration and provides actionable insights for designers and developers to create more effective and user-friendly VR collaboration tools. This contribution highlights the importance of tailoring avatar modalities to enhance user satisfaction and task performance.

1.4 Structure

The remainder of the thesis has the following structure:

- Chapter 2: Related Work

  Building upon the introduction, this chapter provides an extensive review of the existing literature related to virtual avatars, remote collaboration, and virtual reality technologies. It explores the current state of research in these areas, shedding light on the gaps and opportunities for further investigation. By examining the work of other researchers, this chapter establishes a foundation of knowledge and helps identify the key themes and challenges in the field. It clarifies the research gap that is being addressed by the thesis research.

- Chapter 3: Pilot Study

  The research study was divided into two phases, namely a pilot study and main study. In the pilot study, different combinations of modalities for avatar representation such as position, appearance, expression, and study task were tested. The focus was on identifying the modalities that contribute to the usability of the system, social presence, and task performance. This involved using both subjective and objective measures to evaluate the effectiveness of the avatar modalities.

- Chapter 4: Main Study

  Following the pilot study, the main study was conducted where the modalities identified from the first study were incorporated into the avatar technology. The main study aimed to evaluate the effectiveness of the avatar technology

in supporting remote collaboration in a VR environment. This was achieved by testing the position, appearance and expression of the avatar modalities, and measuring the system usability, social presence, and task performance using both subjective and objective measures. The novel contribution of this research is the identification of the most effective modalities for avatar representation in a VR environment, which can enhance the overall effectiveness of remote collaboration.

- Chapter 5: Discussion

  Drawing upon the findings from the previous chapters, this chapter presents a detailed discussion of the results obtained from the experiment conducted during the main study. It explores the implications of these findings for the field of remote collaboration, highlighting the strengths and limitations of virtual avatars in supporting remote collaboration in a VR environment. The chapter also explores the practical applications of virtual avatars and discusses potential future developments in this area.

- Chapter 6: Conclusion and Future Work

  The conclusion and future work chapter provides a concise summary of the key findings presented throughout the thesis. It reflects upon the research objectives and highlights the contributions made by the two studies. This chapter reinforces the significance of virtual avatars for remote collaboration and emphasizes the potential impact of this research. Furthermore, it proposes recommendations for further research avenues to continue exploring and advancing the field of virtual avatars in remote collaboration.

The chapter also outlines potential areas for future research and development. It identifies research gaps and suggests directions for further investigation, considering technological advancements and emerging trends in virtual avatars and remote collaboration. This chapter encourages continued exploration and improvement in the field, offering insights for researchers and practitioners interested in expanding upon the findings presented in the thesis.

Chapter 2

Related Work

The previous chapter provided an overview of the research goals and aims, focusing on how virtual avatars can enhance remote collaboration in a VR environment. This chapter provides an in-depth review of the related work in the field, exploring various aspects relevant to the study of enhancing remote collaboration through virtual avatars in a VR environment. It begins by discussing the video conferencing, then concept of avatars, examining different types of avatars and their role in mediating communication and interaction. The chapter then delves into the use of virtual environments in shared VR settings, highlighting the benefits and challenges of creating collaborative spaces for remote participants.

The chapter also explores the role of video conferencing as a common tool for remote communication and collaboration, discussing its limitations and the potential of virtual avatars to address these shortcomings. It further investigates the importance of sharing and augmenting emotions in VR and examines techniques for using multi-modal avatar parameters (expressions, position and appearance) in virtual environments. The significance of avatar facial expressions in convey-

ing emotions and social cues is explored, along with the challenges and design considerations involved. Lastly, the chapter discusses the use of avatars in cooperative games in VR, examining their impact on communication, teamwork, and collaboration.

Overall, this chapter establishes the current state of knowledge in the field, providing valuable insights into the potential of virtual avatars and their role in enhancing remote collaboration in a VR environment. It establishes the need for the research described in more depth in the remainder of the thesis.

2.1 Video Conferencing

Video conferencing is one of the most popular methods for remote collaboration. Tools such as Skype[13], Google Hangouts[30], Zoom[9] and Webex Meetings [31] enable remote people to establish a video link and easily talk together. However, there are some limitations that make speaking over video conferencing very different from face-to-face collaboration. For example, the lack of spatial cues in video conferencing can make it challenging for participants to understand each other's relative positions or to point and refer to shared objects within a physical space[32]. When there are several people speaking, it can be difficult to differentiate between speakers, although some researchers have explored the use of spatial audio cues to address this [33]. Video conferencing can make it difficult to see non-verbal communication cues such as gesture or gaze, and can make eye contact challenging due to the camera placement relative to the screen of each user [34].

Some researchers have explored how to overcome these limitations using depth sensing with video conferencing. For example, [1] presents a research prototype

which allows for remote symmetrical telepresence with two local users and two remote users in realistic avatars using kinetic displays (see Figure 2.1). User 1 and User 2 sit across from Avatar 3 and Avatar 4 and vice versa. The avatars can show head gaze and gestures by always looking towards the person the owner of the avatar is looking at to improve eye-contact and gaze-awareness. Actuators drive the kinetic display, which allows it to move in six degrees of freedom, mirroring the movement of the remote user's head. In a user study with the system, they found that users preferred the kinetic display avatars over static displays.

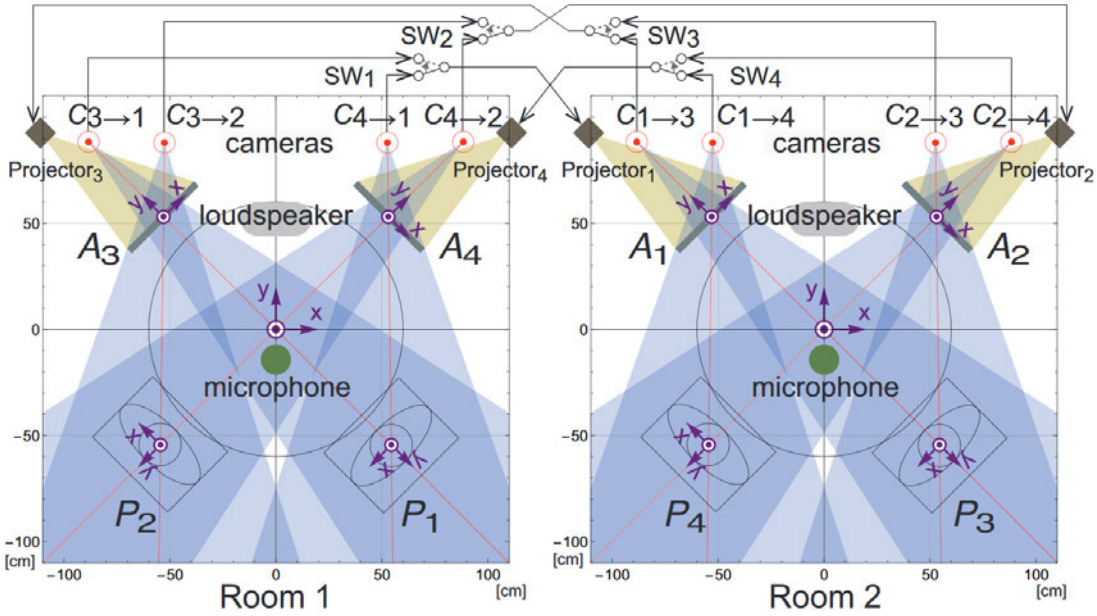

Figure 2: Spatial configuration. Conversation participants (P_1, P_2, P_3, and P_4) and their avatars (A_1, A_2, A_3, and A_4) are seated around a table. $C_{i\to j}$ denotes the camera at avatar A_i that is pointed at person P_j.

Figure 2.1: A screenshot from [1] that shows a diagram of the setup used for their system.

Similarly, [35], presented a system called ImmerseBoard which allows for re-

mote collaboration using only a digital whiteboard and a Kinect (RGB (RGB)-D Camera) on each side. The Kinect is placed perpendicular from the whiteboard and creates a 3-dimensional (3D) model of the remote user that is shown on the local user's digital whiteboard on the opposite side of the local user. The digital input of the users is shared either side-by-side or mirrored as a default function of the whiteboards. They conclude that when compared with baselines of standard video conferencing, it is easier to determine the remote user's gaze, gesture, aim, and level of agreement. In addition, the users agreed that working together using this method is more enjoyable. However, there are also some limitations to ImmerseBoard that could be addressed through the user of avatars, including:

- Lack of personalisation: The system does not allow users to personalise their visual representation when interacting with the board. The use of avatars could allow users to change their visual representation by allowing them to customise their avatar's appearance. This could also increase the immersion and the sense of being together (social presence) [36].

- Limited non-verbal cues: The system allows users to estimate their remote partners gaze direction, while avatars could provide additional non-verbal cues such as subtle expressions and body language. Additional non-realistic cues could also be added such as a gaze ray from the avatars forehead.

- Accessibility: Some users may have limitations that prevent them from fully using the system, such as physical disabilities that prevent them from standing or reaching. By using avatars, participants could still interact with the system and collaborate remotely, regardless of their physical limitations.

2.2 Avatars

Many of the limitations mentioned in the previous sections can be overcome through the use of 3D virtual avatars to represent the real users. For example, virtual avatars can provide richer spatial cues in remote collaboration, realistic gestures and gaze patterns. This is especially true when the avatars are presented in VR collaborative systems.

Platforms like High Fidelity[37] and Spatial[38] makes it easy for people to join virtual worlds as lifelike virtual humans. In numerous instances, the virtual avatar mimics the actions of a real person[39], or can be controlled by a variety of input devices, or even driven by artificial intelligence. The Virtual Human Toolkit[40] integrates many technologies together to create a realistic avatar system. There are also developer assets which allow for easy creation of these systems[41] as well as embodying the avatars with an artificial intelligence [42].

However, until recently most avatars were incapable of automatically generating realistic face expressions, and so collaborating in VR was very different from face-to-face conversation [21]. Some software such as Second Life [43] allowed users to manually trigger face expressions, but this was unnatural compared to more natural expression formation.

There are some tools now available that can be used for automatically representing a users' face expression and applying it to a virtual avatar. For example, the "Affectiva" Software Development Kit (SDK) uses an RGB camera for real-time face detection and can determine the emotional or expressive state of the user [44]. Similarly, the openFace library is open-source code that can recognise face expression [45]. The software "4dface" morphs and fits a 3D model using the RGB

camera to create a 3D virtual face that looks like the real user [46]. Other recent hardware such as the Quest Pro[47] or Vive's Facial Tracker[48] also provide these features.

This research shows that virtual avatars are important for representing real users [49][50] and that it is now possible to generate avatars that have realistic face expression and body movement[51][52]. Some shortcoming of current avatars are limited expression or expressions that are not visible to the user, an inability to effectively convey non-verbal cues, and limited interaction capabilities, such as always being in one location or having a single appearance. In the next section, we review the use of virtual avatars in remote communication.

2.3 Virtual Avatars in Shared VR Environments

Avatars provide a way for real people to represent themselves in virtual spaces, and previous research has shown that they can improve remote communication and collaboration in shared AR and VR environments. For example, [53] found that remote teams that had avatars completed tasks far more quickly with fewer actions than teams without avatars. Users also felt communication was a lot better with these avatars. In this case, the virtual avatars were capable of providing relevant gestural cues inside of virtual environments.

Horizon Workrooms provides a good example of a VR space with shared virtual avatars [54] as shown below in Figure 2.2. Using a VR head-mounted display[55], the user can communicate remotely with their avatars and play games together. Some technologies this system provides are:

- Using your profile images to create your matching 3D avatar to make it look

like you. This can help users feel more immersed in the experience and create a sense of ownership over their avatars.

- Allow the avatars' owner to go "live" which allows other users to join in allowing other users find each other that have similar interests.

- The avatars show expressions, gestures and emotions which makes the avatars feel more natural and engaging to create a more immersive experience.

- Allow a user to connect via video-link for desktop computer users, which allow VR and non-VR individuals to communicate to make the platform more accessible.

- Create virtual billboards that can show photos or videos of the user's choice, so all users can chat about themselves in the VR space.

- Draw 3D objects in real-time, allowing the user to create any prop they want for the avatars.

- Create avatar "selfies" which can be a fun way for users to express themselves while giving a sense of community.

- Play virtual games such as poker with other avatars and their owners to help create a social atmosphere.

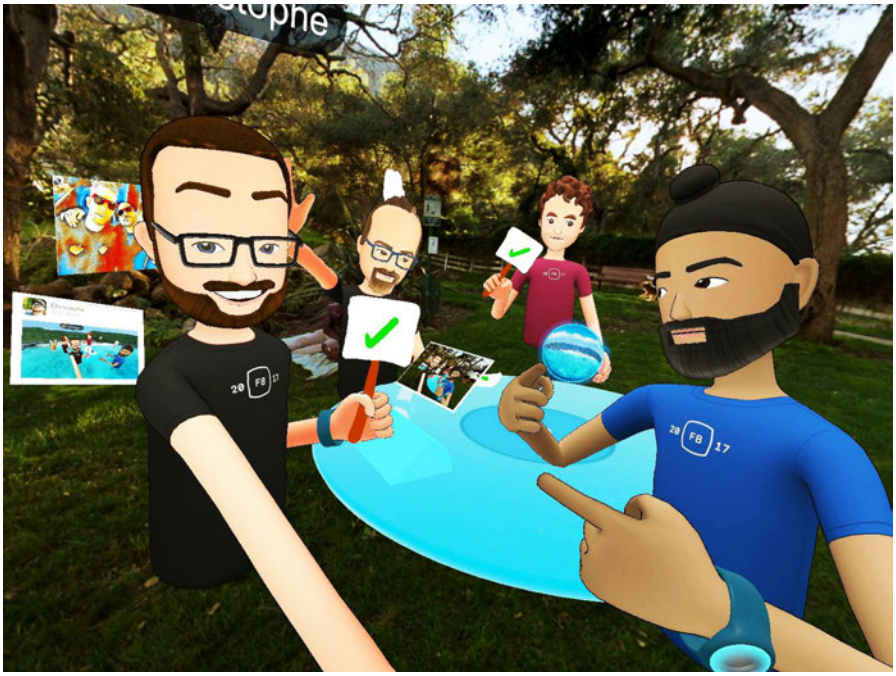

Figure 2.2: Communication with others remotely with Facebook Spaces in VR Credit:[2].

The avatars in Facebook Spaces are simple and cartoon like, even the latest Meta Horizon [56] are using these types of avatars. However, more realistic avatars can be created. Wang and Khoo [57] describes a remote telepresence system in two identical empty virtual reality rooms. Each room contains three Kinect sensors that create a realistic 3D avatar of the local user as a virtual image displayed to the remote user. The Vicon tracking system[58] detects the user's head via markers which track their orientation, and the system can also track gaze when combined with the Dikablis Eye Tracker [59]. The VR system allows the remote user to be positioned and orientated that is appropriate to the scenario, and not necessary exactly where the remote user is, as a being-there experience. In other words, the avatar's position and orientation are determined based on the context of the virtual scenario, allowing the remote user to feel as if they are physically present

in that environment, even though their actual physical location may be different.

Previous research has shown that people respond similarly to virtual avatars in VR as they do to people in face-to-face situations in the real world, including maintaining personal space [60] and using gesture and gaze to communicate [61]. Avatars have also been observed to enhance cooperation on tasks when compared to face-to-face situations [62]. Moreover, representing remote collaborators as virtual avatars increases the sense of social presence in immersive VR environments [63].

However, while avatars in VR can mimic visual and auditory cues, they often lack the ability to fully convey or detect users' emotions, thereby limiting their potential for deep emotional communication. The absence of physical senses such as touch or smell further disconnects the virtual experience from reality, making emotional sharing and understanding more challenging [64]. Additionally, there are technical constraints like the need to construct a virtual world for the avatar, which may be intricate for an end-user. Furthermore, users must become familiar with navigating these virtual worlds, which can be a source of frustration [65]. As we transition into the next section, we will explore the significance of sharing and augmenting emotions in VR, given these current limitations.

2.4 Sharing and Augmenting Emotion in VR

There has been earlier research exploring techniques for conveying emotions in VR, using various inputs. This section describes some of the most relevant research.

Capturing Facial Expression in VR

Early research suggests that facial expression of an avatar is crucial for eliciting an emotional response from the observer [66, 67] and even basic facial animation can convey emotion [68]. With today's advances in computer vision, face tracking with a single camera is a trivial problem [69][70]. However, when the player is wearing an head-mounted display (HMD), their face is largely occluded. In VR games, an avatar's facial expression is typically controlled by certain actions and situations due to the lack of facial expression input. For example, as players speak, their avatar's mouth movement can be modulated by the intensity of the microphone input [71]. Previously, Li et al. [72] combined embedded sensors with a head-mounted RGB-D camera for real-time face capture and animation. Masai et al. [73] used proximity sensors to detect facial deformation around player's eyes region to recognise facial expression. More recently, The HP Omnicept G2 Reverb [74] and Quest Pro [47] are examples of commercial HMD that have real-time integrated face-tracking technology which is capable of driving the expressions of avatars such as in Meta Horizon Workrooms[54]. This is more realistic than using other methods, such as the intensity of the microphone input to control the avatars mouth.

Mapping facial expressions to an avatar can elicit emotional responses from an observer [75] inside of a collaborative VR. However, Oh et al. [52] showed that manipulating the expression of an avatar in VR by adding smiling expressions did not increase the perceived social presence.

Cooperative Games in VR

In the realm of collaborative systems, cooperative games, especially within virtual reality (VR), offer a unique platform to study and understand user interactions, emotions, and collaboration mechanisms. Such games are particularly valuable as they inherently necessitate cooperation, often simulating challenges that can be analogous to real-world collaborative tasks. Our research leverages this potential by focusing on cooperative games for either co-located or remote players, both immersed in an IVE. We intend to use these games as tools in our user studies to elicit genuine interactions and emotions, enabling us to explore the nuances of sharing emotions for social VR games. This approach will, in turn, provide insights that can support both co-located and remote collaboration. Given the above, there are lessons that can be drawn from past research on cooperative VR games that will inform and shape our studies.

There are several noteworthy examples from previous research that can provide valuable insights for our work.

Arnold et al. [76] developed a two-player VR game wherein players had to consume real food for survival while attempting to escape an island. The key takeaways from this game include:

- **Integration of Real-World Elements:** Introducing tangible elements, such as real food, into a virtual game environment can enhance the feeling of presence. This underscores the potential of bridging the gap between the real and virtual worlds to create more immersive experiences.

- **Trust Dynamics:** The game's survival aspect, heightened by the consumption of real food, emphasized the importance of trust between players. This

suggests that introducing real-world stakes can significantly influence collaborative dynamics in virtual environments.

- **Enhanced Believably:** Authentic tasks or challenges, like eating for survival, can increase the believably of virtual scenarios, making participants more invested in the outcomes.

Gaze and Place [27] is a cooperative game combining both Augmented Reality (AR) and VR, where players work collaboratively to find and correctly position a virtual object. The lessons from this game encompass:

- **Cross-Platform Collaboration:** The integration of both AR and VR showcases the potential for diverse platforms to work in tandem, suggesting that multi-platform games can offer rich cooperative experiences.

- **Importance of Communication:** The search-and-place nature of the game highlights the crucial role communication plays in achieving a shared goal within a virtual space.

Lastly, Urban Planner [71] presents a logic puzzle where local AR and remote VR players cooperate to arrange buildings based on given clues. The primary insights drawn from this game are:

- **Cognitive Collaboration:** Logic puzzles stimulate players' cognitive faculties, suggesting that games requiring intellectual cooperation can be a rich avenue for studying collaborative problem-solving in virtual environments.

- **Shared Virtual Tasks:** The game emphasizes the importance of sharing a common goal, teaching us that clear objectives can anchor and guide collaborative efforts in IVEs.

In synthesizing lessons from these games, our work aims to harness the demonstrated benefits and potential of virtual cooperative gaming for understanding and enhancing collaborative experiences.

For co-located social experience, Invisible Walls [77] investigated the effects of avatars and verbal communication on co-presence in an asymmetrical cooperative game where VR players and spectators could interact through visualization. The VR player saw virtual spectators in VR and the spectators in the real world could see the avatar projected on the wall behind the player. Similarly, SharedVR [78] support interaction between a VR player and spectators in a living room setting. They projected the VR environment on the floor as well as displaying the VR player's view on an external display monitor.

2.5 Summary

In summary, previous research has shown that virtual avatars can provide a benefit in VR environments and there are several technologies that can be used to capture and share body motion and face expressions. However, there are some limitations with these systems for effectively sharing communication cues. For example, avatar face expressions are only visible when a user is looking at the avatar, and even then, it may be difficult to see due to the low fidelity of avatar capture or representation. Not facing the user or having a low fidelity avatar can also allow the user to miss useful social cues which are important for communication.

The focus of a lot of this previous research has been on using virtual avatars to reproduce face-to-face conversations. This has led to life-sized virtual avatars with a high degree of visual realism. However, in our research we are focused first on

how to share communication cues, going beyond reproducing realistic face-to-face behaviours. For example, we will explore how we can make face expressions always visible, even when the user is not looking at the remote users' avatar, or how to make gesture cues more visible [71]. By emphasising sharing of communication cues over reproducing face-to-face behaviour, we should be able to make avatar interfaces that provide a better collaborative experience. In the next section, we describe our research focus in more detail and the expected novel contribution. We will perform pilot (chapter 3) and full user studies (chapter 4), which will focus on testing various combinations of modalities for avatar representation, including position, appearance, expression and study tasks. We aim to determine which of these modalities contribute to system usability, social presence, task performance, using subjective and objective measures to provide our novel contribution.

By reviewing the related work in these areas, this chapter sets the stage for the subsequent pilot study. It establishes the current knowledge and understanding in the field, identifying gaps and opportunities for further exploration. This review shows that there has been little previous research on multi-modal avatar representations [79] (avatars that incorporate multiple modes of representation such as appearance, voice, gesture, and facial expressions simultaneously) as comparisons are between one type of representation e.g. male avatar vs female avatar. The review [79] cites "Lack of a cohesive definition" of avatar representations. Our thesis addresses this gap by studying these multi-modal avatar representations to assist in allowing researchers to come up with consistent definitions for different avatar representations. The insights gained from this review informs the design and implementation of the pilot study, contributing to a deeper understanding of sharing and augmenting avatars in IVEs.

The pilot study serves as a crucial stepping stone in our research journey, as it allows us to investigate and evaluate the effectiveness of different avatar representation modalities and their impact on system usability, social presence, and task performance in interactive virtual environments. By conducting this preliminary study, we aim to gain practical insights and identify potential challenges and opportunities that will inform the design and execution of the full user study.

The findings from the main study will contribute to a deeper understanding of how avatar interfaces can be optimized to facilitate effective communication and collaboration in virtual environments. We anticipate that the study will provide valuable empirical data, highlighting the strengths and weaknesses of different avatar modalities, and shedding light on the potential trade-offs that need to be considered in their implementation.

Chapter 3

Pilot Study

3.1 Overview

To explore how virtual avatars in a VR environment can be enhanced to improve collaboration, this chapter presents a pilot study focused on sharing and augmenting facial expressions in cooperative VR games, addressing both RQ1 and RQ2. One of the challenges encountered in capturing facial expressions within a VR HMD is occlusion, which hinders the accurate representation of facial cues. However, recent advancements in research have shown promising techniques for capturing facial expressions within HMDs. In line with RQ1, this study aims to understand how the manipulation of avatar facial expressions can bridge the spatial and social gaps between remote collaborators in a VR setting, fostering enhanced communication and interaction. Concurrently, addressing RQ2, the research seeks to identify key components, such as the representation of facial cues, that significantly impact the effectiveness of these avatars in remote collaboration scenarios. To overcome the limitations of capturing facial expressions within an

HMD, a prototype system was developed that captures the player's facial expressions from a laptop Personal Computer (PC) and displays them to the VR player within the HMD.

This system was pilot tested in two cooperative VR games designed to emphasize distinct roles in social interaction. These games serve as the context for evaluating the impact of shared and augmented emotions on the players' experiences. Preliminary findings from the pilot study are presented, providing initial insights into the effectiveness of the prototype system and the potential implications for social VR games.

By conducting this pilot study, the research aims to shed light on the implications of sharing and augmenting emotions in VR, exploring the potential benefits and identifying the types of social VR games that can leverage such systems. The findings from this study informed the subsequent main study (Chapter 4) and contributed to the overall understanding of enhancing remote collaboration through virtual avatars in a VR environment.

Our research interest, as captured in core RQ1, is to investigate how sharing and augmenting emotion, through the manipulation of the avatar's facial expression, can impact social VR experiences and what sort of social VR games might benefit from such systems. By exploring the effectiveness of conveying emotions through avatars, we aim to understand how this augmentation influences the social presence, engagement, and overall user experience in virtual reality environments. Furthermore, our study, guided by core RQ2, seeks to identify the key components that contribute to the effectiveness of avatar-based emotion sharing and augmentation. By examining factors such as the fidelity of facial expressions, the realism of avatar representation, and the contextual integration of emotions within

social VR games, we can uncover the critical elements that enhance the impact of avatar-driven emotional communication. This research endeavor will provide valuable insights into designing social VR systems that use the power of emotion to create immersive and socially engaging experiences in remote collaboration and interactive virtual environments.

To circumvent capturing facial expression from within an HMD, we created a prototype for capturing the player's facial expression from a laptop PC and displaying it to the VR player in a HMD. We created two cooperative VR games that emphasise the user's distinct roles in their social interaction. In the next section, we present our prototype system overview, descriptions of our two games, and preliminary findings from our pilot study.

3.2 Research Questions

Drawing from the core research questions in the Introduction, the research in this chapter will address three research questions, as follows:

- **RQ3.1: Does the choice of scenario and avatar visualisation techniques influence social presence in VR remote collaboration?**

  This research question aligns with RQ1 of the thesis: “”How can virtual avatars facilitate remote collaboration in a Virtual Reality environment?” By exploring how the choice of scenario and avatar visualization techniques impact social presence, we are investigating one aspect of how virtual avatars can enhance collaboration in a VR environment.

  Social presence is the degree to which a person feels present in a mediated

environment and the degree to which others perceive that person as being present [80]. In the context of VR remote collaboration, social presence refers to the extent to which participants feel connected and engaged with each other in a virtual environment.

- **RQ3.2: Does the choice of scenario and avatar positioning (fixed vs adaptive) influence user experience in VR remote collaboration?**

  This research question is related to RQ2 of the thesis: “”What are the key components that impact the effectiveness of virtual avatars?”. By examining how the choice of scenario and avatar positioning affects the user experience, we are exploring a key component that can influence the effectiveness of virtual avatars in remote collaboration.

  Avatar positioning refers to the placement of the avatar in a virtual environment. In the context of VR remote collaboration, avatar positioning can be fixed or adaptive. In this case, fixed avatar positioning means that the avatar is placed behind a virtual table in the virtual environment. Adaptive avatar positioning means that the avatar is placed behind the virtual table if it is in view, and attached in front of the user's face if it is not.

- **RQ3.3: Does the choice of scenario and avatar visualisation techniques influence avatar noticeability and usefulness in VR remote collaboration?**

  This research question also relates to RQ2 of the thesis: “”What are the key components that impact the effectiveness of virtual avatars?”. By investigating how the choice of scenario and avatar visualization techniques impact

avatar noticeability and usefulness, we are examining another key component that can affect the effectiveness of virtual avatars in remote collaboration.

Avatar noticeability refers to the extent to which an avatar is visible and noticeable in a virtual environment. Avatar usefulness refers to the extent to which an avatar is helpful and effective in facilitating communication and collaboration in a virtual environment.

3.3 System Overview

Our ultimate goal is to create a multimodal VR system that uses facial expression, eye-gaze, tone of voice, and physiological data to understand a player's emotional state. In turn, the system could augment and share the emotion to the uses partner, creating better understanding between the players or enhancing their social experience. Previous work had produced the necessary components for the integration of this system e.g. facial recognition in eyewear [73], eye-gaze tracking in VR [81, 82], capturing and sharing physiological input in VR [83]. However, the current prototype does not support input from the proximity sensors. Therefore, we had to simulate the process of facial recognition and face tracking on a laptop using an RGB camera instead of capturing from within the HMD.

Figure 1 illustrates an overview of the system. We developed our software on the Unity game engine [84](version 2018.1.1). WebRTC Video Chat was used for streaming and data transfer. For facial motion capture, we used F-Clone [85] (see Figure 3). The facial motion data is mapped to facial BlendShape on the avatar in Unity. Our software also supports the Affectiva SDK for emotion detection [86]. On the VR side, we used SteamVR for Unity [87] to interface with the VR devices.

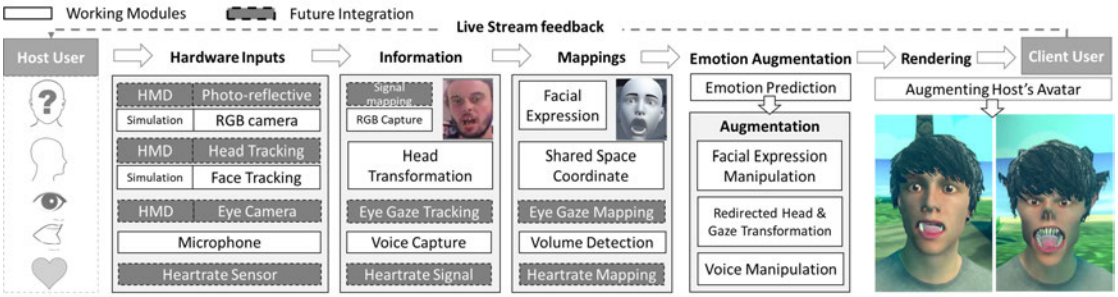

Figure 3.1: Prototype system overview for sharing and augmenting emotion in VR. On the far right, two augmented faces expressing a fearful face and a monster face for extreme anger.

In terms of emotion augmentation, different facial expressions input from the player can trigger different expression on the virtual avatar. For example, the player can express a surprised face, which can trigger a pre-defined expression of the avatar that looks more suitable and natural. Furthermore, having systems that can recognise and map a particular expression to express extreme emotions or acting out as part of the play might enhance the experience (Figure 3.1).

3.4 Cooperative VR Games

We implemented two cooperative VR games to evaluate the system. The first game involves tasks that requires the player to perform with asymmetric roles and the second is a negotiation task that has players in equal roles. Both games required constant communication, which promoted a high level of social engagement. We believed that these types of games might benefit the most from facial expression sharing.

Game 1: Bomb Defusal

This game was inspired by a popular VR game, "Keep Talking and Nobody Explodes" [88]. In our version, we place three virtual bombs for the players to defuse, which are counting down from different random starting times. The local VR player takes on the task of a bomb defuser and the remote player, on a laptop, is an instructor who has access to the bomb defusing manual. The instructor can see the VR player's view but cannot interact with the bomb in any way. A manual provides a series of steps that must be followed correctly to defuse the bomb. If the VR player does not follow the steps correctly, this will lead to the bomb exploding.

To defuse each bomb, there are a number of details that the players must exchange. The instructor and defuser may also see different information on the bomb. For example, a keypad on the bomb might show a set of letters to the instructor and a set of numbers to the defuser, making constant communication necessary. The players win the game when they can successfully defuse all three bombs before the time is up. Figure 3.2 shows screenshots captured from the game.

Game 2: Island Survivor

This game takes place on a virtual remote island which the players are trying to escape on a raft. There are a number of items with the player on the island, however, the players can only take with them three out of five items presented. They must discuss about the items and then the VR player must arrange the items in order of importance. Each item has a unique point depending on its significance to the survival of the players. The remote player sees the VR player's view but has



Figure 3.2: Cooperative Bomb Defusal game: the VR player picks up a bomb (top), cutting a cyan wire (middle), and the remote player is surprised by the explosion.



Figure 3.3: F-Clone, facial motion capture software was used to simulate avatar's facial expression rendered for the VR player.

no additional information or knowledge regarding the items. Only the VR player can interact with the objects. Figure 3.3 shows screenshots from the game.

3.5 Study Overview

We conducted a preliminary study to evaluate our system usability, and determine preferences for different avatar's positioning in each game. All participants experienced both games, and we collected general feedback for improving our VR games, and observed social interaction between the players. We recruited 4 participants (all male) among the staff and students in our school with an average age of 27 (SD=3.94). They have reasonably high level of experience with VR (3 participants use VR several times a month and one several times a week). They are also active computer/video gamers (2 participants play several times a month, one plays several times a week, and another plays every day).

In the study, the participants took on the role of a VR player, and our actor, also a male, played on the laptop PC side. Our actor could see the VR player's view. One of our researchers took notes and observed the interaction for every session. Our actor and every participant knew each other prior to the study, and so they were relaxed and comfortable in their social interaction. For our experimental measures, we used the SUS questionnaire [89] to measure our system usability, follow by preference questionnaires (in Section 7) of the avatar's position for the two games, and the overall experience questions regarding the avatars and our games. We briefly held an unstructured interview for any other feedback from the participants.

3.5.1 System Setup

Our system setup used a desktop PC (Intel 7700k with Nvidia GTX 1080) with a Samsung Odyssey Mixed Reality Headset for the VR player and a laptop PC (Intel 7700hq with Nvidia 1060 MAX-Q) for the laptop player. The study was conducted in a single room where the two users were separated by a red partition as shown in (Figure 3.4) (top). Although our system supports spatial audio, we did not use a microphone input in the study because the players shared the same room and could easily hear one another.

For the avatar's augmented facial expression, we included two predefined expressions, a fearful face and a monster face (Figure 3.1). To ensure that the expressions were reliably expressed at the right moment, we mapped keyboard keys to override the expression for these two predefined faces, so they did not rely solely on facial recognition for triggering emotions.

Avatar Positioning Techniques

Apart from sharing emotion, we were also interested in the best location to place the avatar in the game to take advantage of sharing the facial expression. We demonstrated three positioning techniques to the participants, an On-Screen avatar always shown within the player's view (Figure 3.5 (top)), an In-Place avatar shows the avatar at a fixed location in the VE, which is a normal scenario (Figure 3.5 (middle)), and an Adaptive avatar which mixes both techniques, showing the avatar In-Place when it is within the player's view and On-Screen when it is out of view (Figure 3.5 (bottom)). We did not formally conduct the study for each condition but rather let the participants experience each technique to provide qualitative



Figure 3.4: Island Survivor game: players choose 3 items out of five (top), players discuss if they should bring a map (bottom).



Figure 3.5: Pilot study setup: Both players are co-located in the same room (top), the remote player (an actor) is seated in front of a laptop PC (middle), and the VR player is seated in an open space.

feedback.

Results

Usability – We found the average system usability score to be 73.75 (SD=5.15), after trying both experiences, which was taken to be a positive result considering that this was our first usability test. The highest score was 80 and the lowest was 67.5. Anything over 68 for the SUS test is considered above average [90]. The system was best rated for being highly consistent but rated lowest for their confidence using the system.

Positioning Preferences - In term of the preferences of the avatar's position, in the Bomb Defusal game, all participants preferred the *In-Place* avatar. For the Island Survivor game, three participants preferred the *In-Place* avatar and one preferred the *On-Screen* avatar. After the experiment, Subject P1 mentioned that *"I dislike the On-Screen one as it affects my view"*, while P3 stated that *"I found having the avatar in one place made them feel more real, like they were actually there with me and not just an instructor"*.

Avatar Noticeability and Usefulness - We also asked the participants in which game they noticed the avatar more; three participants voted for *Island Survivor* and one for *Bomb Defusal*. However, when we asked what game that they thought the facial expressions was more useful, three voted for *Bomb Defusal* and one for *Island Survivor*. We expected that this was the case because the participant could look at the avatar in the bomb defusal game in order to try to clarify what the remote user was saying as it is a more intense game with a instant lose condition.

Discussion

We observed that the Island Survivor game, a task heavily reliant on negotiation and with diminished emphasis on spatial objectives, showcased the avatar's facial expressions more prominently. This heightened prominence perhaps offers insight into the 3 to 1 votes favoring avatar noticeability within the Island Survivor context. The participants' interpretation of the game's objectives varied, with some concentrating on enduring until rescue, while others strategized on escaping the island. Their exploration of the environment, coupled with their interactions with available items, underlined the dynamic nature of the game. Each player pair introduced a distinct balance of problem-solving and negotiation, indicating the malleability of the game's core mechanics based on player approach.

In the contrasting dynamics of the Bomb Defusal game, the instructor's dominant role in directing and the VR player's reactionary role ensured a largely unidirectional communication. The exceptions were the sporadic inquiries from the instructor, leading to pockets of negotiation. The intriguing facet here was the VR player's reliance on the instructor's facial cues, using them almost as a compass to determine which wire to sever. As one participant aptly noted, the avatar in the Bomb scenario felt more like a real-time gauge of the consequence of their choices. Such a sentiment likely clarifies why a significant portion of participants deemed the avatar's role more crucial in the Bomb Defusal context.

The misinterpretation of one participant, who credited the avatar's expressions to sophisticated animations rather than actual mirroring of a remote player's face, presents a captivating dimension to our findings. This could be suggestive of two things: firstly, the high quality and realism of the VR environment that makes dis-

cerning real from virtual challenging; and secondly, it underscores the potential of real-time facial expression sharing. This mechanism not only augments gameplay but may also pave the way for more enriched, genuine social interactions within the VR sphere.

The variability in how players approached the Island Survivor game versus the Bomb Defusal game underscores the vast potential of VR in catering to diverse cognitive and strategic styles. Some players might gravitate towards open-ended scenarios where imagination and interpersonal negotiation drive outcomes, as seen in the Island Survivor game. In contrast, others might find satisfaction in more structured tasks where cues, like facial expressions, become instrumental in decision-making, as evidenced in the Bomb Defusal game. This duality suggests that future VR applications might benefit from offering a range of experiences, from the freeform to the directed, to cater to a broader audience spectrum.

Another pivotal takeaway revolves around the role of avatars in VR experiences. Avatars are not just placeholders or representations of players but can become instrumental tools in gameplay or communication. The fact that participants responded so keenly to facial cues, and even mistook real-time mirroring for animation, implies a depth of immersion that's ripe for exploration. As VR technology advances, designers and developers might consider further harnessing the emotive capabilities of avatars. Beyond gaming, this could extend to virtual meetings, therapy sessions, or educational settings, where nuanced non-verbal cues can significantly enrich virtual interactions.

Summary

In this pilot study we explored sharing and augmenting emotion in social VR games. We described our current prototype and how it could be integrated into our ultimate system. We conducted a pilot study to evaluate our prototype with two VR games. We plan to integrate facial motion capture in the HMD. Beyond sharing facial expression, we would like to capture physiological data, to support emotion detection and sharing for VR players. We will also refine one of the VR games following user feedbacks and will conduct a formal study on the game experience for the next study. Some of the lessons learned that we can use for the main study are as follows:

- Avatar Noticeability and Effectiveness: The pilot study demonstrated that the design of the cooperative VR games and the specific tasks involved can influence the noticeability and effectiveness of avatars in conveying emotions. Understanding the impact of game design on avatar perception can inform the selection and development of tasks in the main study to ensure that the avatars are appropriately utilized and their impact is accurately measured.

- Participant Feedback and Preferences: The pilot study provided valuable participant feedback on the avatar visualizations and their impact on the social VR experience. Taking into account participant preferences and perceptions from the pilot study, the main study can refine and optimize the avatar visualizations to enhance social presence and user engagement. Incorporating participant feedback can lead to more effective and user-centered avatar designs.

- Problem Interpretation and Task Variations: The pilot study revealed variations in how participants interpreted the problem to be solved in the cooperative VR games. Understanding these variations can inform the main study's task design, ensuring that the tasks are clear, engaging, and promote collaboration. Considering different problem interpretations can help in evaluating the impact of avatar visualizations on communication and teamwork in various task scenarios.

- Facilitating Emotional Communication: The pilot study's findings emphasized the potential of sharing and augmenting facial expressions in social VR environments to enhance emotional communication. Building on this insight, the main study can further investigate the impact of different avatar visualizations on emotional expression and communication cues. This understanding can guide the development of avatar designs that effectively convey emotions and foster more immersive and engaging social interactions.

By incorporating these lessons learned from the pilot study, the main study can refine the research methodology, task design, and avatar visualizations to deepen the investigation into the impact of avatar visualizations on social presence, perceived user experience, and user preferences in a VE.

Justification

Based on the findings and conclusions of the pilot study, the main study will aim to further investigate the impact of avatar visualisation techniques on social presence, perceived user experience, and user preference in IVEs. The pilot study provided valuable insights as mentioned previously into the effectiveness of different avatar

visualisation techniques in two specific VR games, highlighting the importance of negotiation tasks and the role of facial expressions in enhancing social VR experiences.

In the main study, the focus will be on refining and expanding the avatar visualisation techniques based on the pilot study feedback. The study will explore the integration of facial motion capture within the VR headset to improve the fidelity of facial expressions. Additionally, physiological data capture will be considered to enhance emotion detection and sharing among VR players. The study will also refine one of the VR games based on the pilot study feedback and conduct a formal evaluation of the game experience.

The main study is contextualized within the broader trends of increasing social VR adoption and the rise of remote collaboration through VR, especially given the shift towards more remote work. It highlights the potential of advanced consumer VR hardware, such as the HP Omnicept, and the need for research on combining multiple visualisation techniques for avatar expressiveness within IVEs. The main study aims to address this research gap by investigating non-verbal facial cues and exploring different avatar representation and placement factors. The asymmetric remote collaboration system, simulating eye and face-tracking using a desktop setup, will enable real-time capture and presentation of features on the avatar, enhancing the collaborative experience in the VR environment.

Overall, the pilot study findings and the identified research gaps lay the foundation for the main study, which will further explore and refine the avatar visualisation techniques in the context of social presence, perceived user experience, and user preference in interactive virtual environments.

Chapter 4

Main Study

The pilot study conducted in Chapter 3 provided valuable insights into the effectiveness of avatar visualisation techniques in social VR games. The study found that in the Island Survivor game, which involved more negotiation and less spatial tasks, the avatar was more noticeable and conveyed emotions effectively. On the other hand, in the Bomb Defusal game, where the instructor gave instructions and the VR player relied on the instructor's facial expressions for guidance, the majority of participants found the avatar to be more useful. These findings indicate the potential of sharing and augmenting facial expressions in enhancing social VR experiences. Additionally, participants positively perceived the well-animated avatar expressions, suggesting that this approach can contribute to a more immersive social VR experience.

Building upon the insights gained from the pilot study, the main study aimed to explore the impact of avatar visualisation techniques on social presence, perceived user experience, and user preference in an IVE. The main study investigated three specific visualisation techniques: (1) manipulating the avatar's expression,

(2) comparing between 2-dimensional (2D) and 3D representations, and (3) exploring different avatar locations within the scene. By investigating these specific visualisation techniques, the main study aimed to provide insights into how virtual avatars can facilitate remote collaboration in a VE (RQ1). Additionally, the study aimed to identify the key components that impact the effectiveness of avatar visualisations, such as facial expression, representation type, and avatar location (RQ2). Through a comprehensive analysis of these techniques, the study aimed to contribute to a deeper understanding of the role of avatars in enhancing remote collaboration and informing the design of future social VR systems.

This research endeavor is motivated by the surge in remote work and the increasing adoption of social VR and remote collaboration in the VR domain. While next-generation consumer VR HMDs offer features like eye-tracking and face-tracking, the effects of combining multiple visualisation techniques and representation/placement factors on avatar expressiveness within an IVE remain unexplored.

To address this research gap, the main study focused on non-verbal facial cues to enhance virtual avatar expressions, position, and representation within an IVE. This included techniques such as exaggerating facial expressions to strengthen their communicative impact. The avatar was presented as a 2D video inset attached to the user's view or as a 3D talking-head avatar representing a remote collaborator. An asymmetric remote collaboration system, utilizing a desktop setup to capture real-time eye and face-tracking features of the desktop user, was be employed to simulate these visual cues on the avatar in the VR environment. The study used an island survival scenario where pairs of participants collaborated to create a survival item list.

Overall, the main study aimed to extend the understanding of avatar visualisation techniques in social VR experiences. By investigating non-verbal facial cues, representation, and placement factors, the research sought to enhance social presence, perceived user experience, and user preference within IVEs. The insights from the pilot study and the identified research gaps provided a strong foundation for this investigation, highlighting the potential of sharing and augmenting facial expressions to enrich social interactions in VR environments.

4.1 Overview

This chapter explores the impact of avatar visualisation techniques on social presence, perceived user experience, and user preference in an IVE. We examined three visualisation techniques by manipulating the avatar's expression, comparing between 2D or 3D representation, and displaying the avatar in two different locations, either attached to the user's view or embedded within the scene.

The surge of remote work in the pandemic era fuelled a rapid adoption of social VR and remote collaboration in VR [91]. People flocked to IVE for various purposes, whether it was for professional or leisure activities, using a variety of popular IVE platforms [92, 93]. Next generation consumer HMD, such as the HP Omnicept [74], have hardware features that enable eye- [94] and face-tracking [95] that could improve avatar expressiveness within an IVE [96]. However, we are not aware of any research investigating the effects of combining multiple visualisations of avatar's rich expressiveness in conjunction with various representation and placement factors [91].

To address this gap we investigated non-verbal facial cues to augment the

virtual avatar expressions, position, and representation in an IVE. This included aspects such as exaggerating the facial expression of the avatar to strengthen the commiunication cues. For the representation and position, the avatar could be presented as a 2D video inset anchored to the user's view, or displayed as a remote collaborator's 3D talking-head avatar.

To investigate these factors, we have created an asymmetric remote collaboration system to simulate eye and face-tracking using a desktop setup to capture those features of the desktop-user in real-time and present them on the avatar to a VR user. The VR user could then see the desktop-user as an avatar in the VR environment as if they are also a VR user. For our study, we used the island survival scenario where a pair of participants must collaborate and create a list of items that they would need to survive the deserted island.

This research makes several contributions, as follows:

1. **Asymmetric VR system:** We developed a system that allows two remote collaborators to communicate simulating eye- and face-tracking in VR through a desktop and VR setup.

2. **Exploration of the avatar design space in an IVE:** We proposed three factors in avatar visualisation techniques in terms of facial expression (on/off), position (screen-attached/in-scene), and representation (2D/3D).

3. **A study comparing the avatar visualisation:** We conducted a user study with twelve pairs of participants (n=24) comparing eight combinations of expression, position, and representation that may influence the perceived social presence, mental effort, and user preference.

4.2 Research Questions

Informed by the main research questions from the introduction, and the pilot study research questions, we explored the followingthree research questions:

- **RQ4.1: Does the choice of avatar visualisation techniques influence social presence in VR remote collaboration? (RQ1)**

  This research question aligns with RQ1, which explores how virtual avatars can facilitate remote collaboration in a VR environment. By investigating the influence of avatar visualisation techniques on social presence, the study explores the extent to which different visualisation techniques impact users' feelings of connection and engagement in VR remote collaboration.

  Social presence refers to the degree to which individuals feel connected to and engaged with others in a virtual environment [80]. In this research question, the aim is to investigate whether the choice of avatar visualisation techniques has an impact on how socially present users feel in VR remote collaboration.

- **RQ4.2: Does the choice of avatar visualisation techniques influence the perceived user experience in mental effort and communication assistance in VR remote collaboration? (RQ2)**

  This research question addresses RQ2, which focuses on understanding the key components that impact the effectiveness of virtual avatars in remote collaboration. By examining the influence of avatar visualisation techniques on perceived user experience, specifically in terms of mental effort and communication assistance, the study explores how different visualisation techniques affect the users' cognitive load and the effectiveness of their communication

in VR remote collaboration.

User experience refers to the overall experience of using a product or system; in this case, the VR remote collaboration platform. Mental effort refers to the cognitive load required to complete a task, while communication assistance refers to the support provided to users in communicating with others in the virtual environment. This research question aims to explore whether the choice of avatar visualisation techniques affects users' perceived user experience in terms of mental effort and communication assistance.

- **RQ4.3: Does the choice of avatar visualisation techniques influence user preference in VR remote collaboration? (RQ2)**

  This research question also addresses RQ2. By investigating users' preference for different avatar visualisation techniques, the study explores users' preferences and inclinations towards specific visualisation approaches in VR remote collaboration.

  Understanding user preference contributes to the comprehensive evaluation of avatar visualisation techniques and their potential effectiveness in enhancing remote collaboration experiences. This insight can inform the design and implementation of remote collaboration platforms by aligning them with users' preferences, ultimately contributing to more user-centered and effective collaboration in IVEs.

In summary, the main study research questions (RQ4.1, RQ4.2, and RQ4.3) directly address the main thesis research questions (RQ1 and RQ2) by examining the impact of avatar visualisation techniques on social presence, perceived user

experience, and social preference in VR remote collaboration. The findings contribute to a deeper understanding of how virtual avatars can effectively facilitate remote collaboration in a VR environment and shed light on the key components that influence their effectiveness.

The research questions (RQ4.1, RQ4.2, and RQ4.3) are mutually reinforcing, as each question contributes something to the potential enhancements of having an avatar facilitate collaboration in a unique and interesting way. For example, if avatar visualisation technique A is found to increase social presence but decreases perceived user experience in mental effort, while avatar visualisation technique B has the opposite effect, the choice of avatar visualisation technique may depend on the specific goals of the remote collaborative task, such as emphasising social interaction versus optimising task efficiency.

4.3 Avatar Design Consideration and System Implementation

We aimed to understand the effects of various avatar visualization techniques in VR remote collaboration. There are many forms of possible enhancement, but based on our previous research [96, 28, 97], we have identified three interesting dimensions in the avatar design space in VR. Firstly, we were interested in, *Avatar's Expression (On vs Off)*, and how well the avatar conveys emotion through the support of facial expression. Secondly, we wanted to learn the difference in, *Avatar's Position (In-scene vs Screen-attached)*, between fixing the avatar onto the screen within the user's Field of View (FoV) or positioning it in the VE. Finally, we desire to

compare, *Avatar's Representation (2D vs 3D)*, to explore if the appearance of the avatar in 2D or 3D has any influence on the user's perception. Fig. 4.3 illustrates the eight resulting conditions in our study. Ultimately, this research would help inform designers of the suitability of different avatar visualisation in the chosen context so as to improve the overall experience in VR remote collaboration and mitigate any potential pitfall in making collaboration more challenging.

Experimental Scenario and Virtual Environment Design

In our IVE, we supported a pair of users who needed to work together to complete an island survival scenario [28] having to decide on the order of items for survival on a desert island, randomly chosen from a larger pool of items. There were 56 items in total, of which 7 were randomly chosen and presented to each pair. These items included useful objects from scenarios created by a lifeguard [98] and [99], such as first aid supplies and items that may seem pointless, like a stone statue or a guitar. A time-constraint in the activity was enforced, and a virtual clock was placed on the table to notify the time remaining.

The VR user could use a handheld controller to manipulate the objects and a physics simulation was enabled to ensure realistic object motion. The users had to negotiate the order of an items' importance for survival and place the most important item on the left-hand side of a table in front of the VR user. The desktop user could not interact with the virtual objects. The desktop user shared the VR user's perspective in the screen-attached conditions and saw through the eyes of an avatar fixed in the scene in the in-scene condition. These configurations were chosen to reflect the two common types of VR collaboration where the remote



Figure 4.1: A screenshot of the VE that shows the final selection of a condition.

user's view is provided by the camera either attached to the local user's head or placed in the task space [97]. A screenshot of the VE is shown in Fig 4.1.

System Design

We designed and implemented an asymmetric remote collaboration system, consisting of two components (Fig. 4.2): (1) a VR front end and (2) a desktop back end. Both components were created in separate projects in Unity 2017.4.24 long-term support (LTS) [100]. The two sides were connected with a remote Web Real-Time Communication (WebRTC) server using the WebRTC Video Chat Unity Asset [101]. The front end for the local user had a Dell Windows Mixed Reality HMD and controllers for viewing and interacting with the VE, while the back

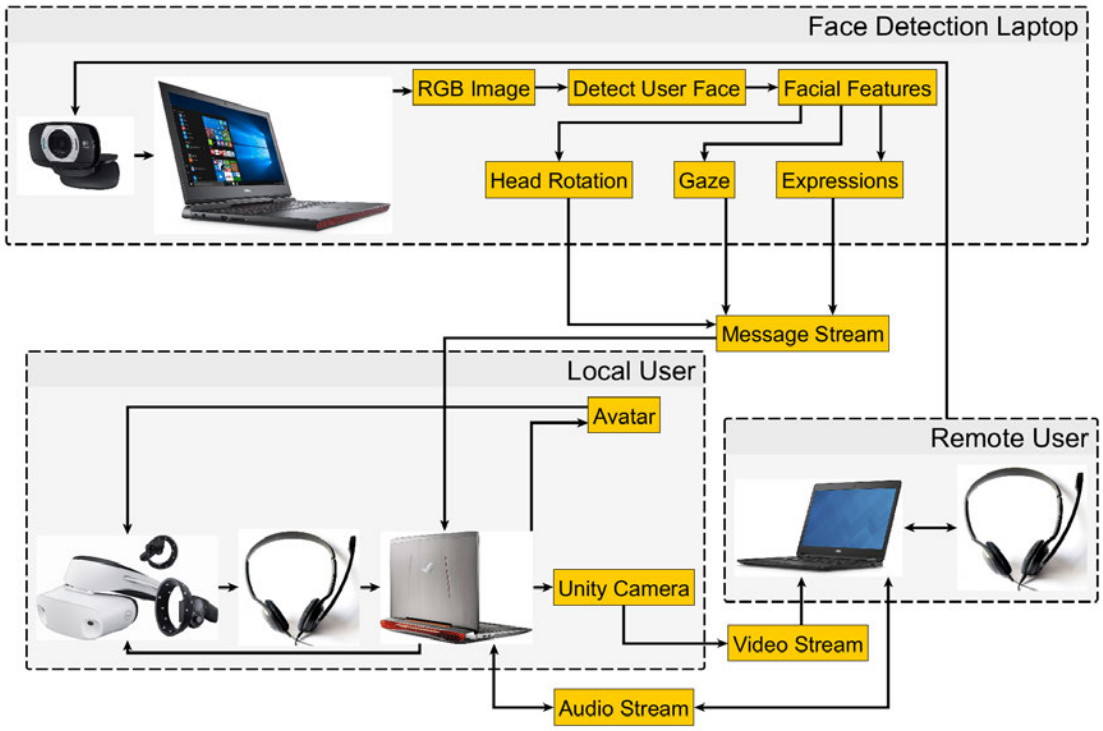

Figure 4.2: An overview of the system developed for user study. The face detection laptop processes the users face, then sends the facial expression data to the local user which is then mapped to the avatar on the local users laptop.

end for the remote user was a laptop computer. Using the camera on the laptop, the system captured a video of the desktop user's face to detect and track facial features and recognise facial expressions. Detected facial expressions, gaze and head orientation data were then streamed to the front end system to control the expression of avatar of the remote user for the local user to see. On the other side, a virtual camera, either attached to the local user's view or on the avatar's head, captured the rendered image of the VE, and streamed the video of the virtual scene to the front end for the remote user to view on the laptop screen.

User Interface

The VR user could pick up virtual items by using the left or right VR controller and holding the grip button on the side. A virtual ray pointer was activated by holding down the trigger button, and could be used for pointing for communicating or picking up an object. When the pointer ray collided with the targeted object, a semi-transparent blue ball then appeared surrounding the target object to indicate a selection. Once the trigger was held down, the item was picked up and the blue ball turned yellow to let the user know that they were holding that item. The VE included a physics simulation, and each object had a convex collider, so it was possible to knock items into each other and around the table. In addition, there were invisible colliders on the walls, floor and the ceiling around the table to prevent objects from falling off. Trying to force an object outside this invisible box forced the item back in once the user let go of it. The VR user could place or drop selected items by releasing the grip button.

The desktop user's avatar was only visible to the VR user. The desktop user could see through the eyes of their avatar in the *In Scene* condition and saw the

virtual headset representing the VR user. In the *Screen Attached* condition, they saw through the eyes of the VR user but would not see their own avatar.

Avatars and Facial Expression Tracking

We used the iClone Character Creator 3 to create our avatars [102], which supports facial expression mapping from Faceware LiveServer [103], facial tracking software. In addition to facial expression tracking, the software also handled head rotation and eye gaze. The Faceware LiveServer was integrated into the desktop end component to provide facial expression tracking. It outputs data to the avatar Blendshape input data. The head rotation, gaze rotation, eye blinking and mouth opening and closing was always be active regardless of the emotion condition. Any face expressions that helped to convey an emotion was only turned on when the *Emotion On* condition was active. We calibrated the system, by making sure the participants face is in the same position, looking at the center of the monitor. This is done to ensure acceptable accuracy during the software implementation so that the avatar looked at the same object that the desktop user does.

Hardware Setup

We used three laptops to distribute the processing power of our system to maintain stability. The remote expert user used a Dell 7500U with 16 gigabyte (GB) of Random Access Memory (RAM); integrated Intel graphics with Windows 10 installed. The VR user used a 6700HQ with GTX 1070 Nvidia graphics card. The VR headset used was the Samsung Odyssey Windows Mixed Reality headset with a resolution of 1440x1600 per eye, a field of view of 110 degrees, and a 90Hz refresh rate. Finally, to process face-tracking for the VR user to observe, we used

a Dell 7700HQ with 16 GB of RAM and a dedicated GTX Nvidia 1060 graphics card that was used to run the backend facial expressing tracking and server software. A Logitech C615 webcam was plugged into this laptop for face tracking and streaming the user's face image to the Faceware Live server.

4.4 Experimental Design

We investigated the effect of an avatar's expression, position and representation, on social presence, mental effort, and user preference. These design dimensions were chosen due to their potential to influence remote collaboration. Expression helps convey the user's emotion, which is a crucial factor in effective communication. Representation affects the perceived appearance as people are familiar with communicating through 2D video-conferencing, but the face-to-face experience was in 3D, and finally, position dictated people's social behaviour.

Participants

Twenty four participants in pairs (16 males and 8 females in 12 pairs) participated in the study, aged between 20 and 58 years ($SD = 8.32$; $M = 27.17$). All participants were recruited from staff and students (and their friends) of the university. Their experience with VR/AR is as follows: (*Everyday* = 1; *Several times a week* = 7; *Several times a month* = 2; *Several times a year* = 4; *More rarely* = 8; *Never* = 4).

Table 4.1: The avatar's representation that make up the 8 conditions. The numbers are the condition numbers.

Condition Parameter	Numbers	Description
Expressions: On	1,3,5,7	The avatar is displaying all expression the remote user is showing on their face.
Expressions: Off	2,4,6,8	The avatar is only displaying a subset of expressions (eyes open/closing, mouth opening, head and eye rotations).
Appearance: 3D	1,2,3,4	The avatar is displayed as if they were a normal person in the scenario.
Appearance: 2D	5,6,7,8	The avatar is displayed as if they were a person inside a HoloLens Skype video-call window.
Position: In Scene	1,2,5,6	The avatar is located behind the table of items.
Position: Screen Attached	3,4,7,8	The avatar is attached to the VR user's view at the bottom centre and is placed just in front of any objects.

Experiment Conditions

The experiment was a within-group design with three independent variables (expressions, appearance and position) forming 8 conditions, and the order of the condition for each participant pair was counterbalanced in a balanced Latin Square design. We used a within-group design to reduce participant variability and to compare perceived preferences between each of the modalities. An outline of the conditions is shown in Table. 4.1.

Each condition involved carrying out the island evacuation scenario within 3 minutes. If the participants completed it in less than 3 minutes, for the remainder of the time they were encouraged to discuss anything they may have missed in order to properly get used to each condition.

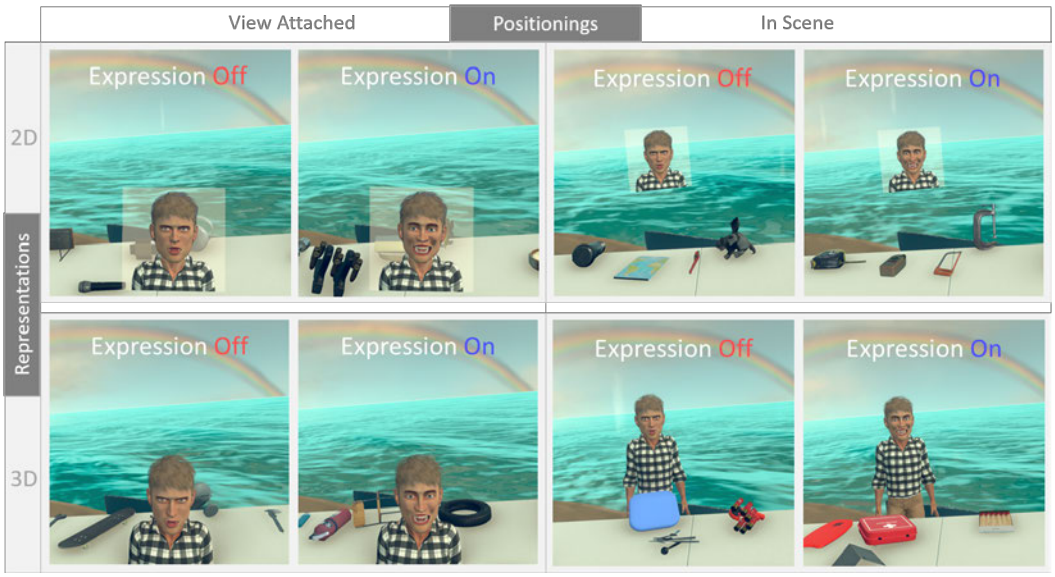

Figure 4.3: All 8 conditions of the study which includes all 3 visualisation techniques (Expression, Position,and Representation).

Measures

We used several different measures after each condition, including the Social Presence Questionnaire (SPQ) survey [104] for social presence, and The Rating Scale on Mental Effort (RSME) survey [105] to measure cognitive load. In addition, some custom rating questions measured on a 1-7 (Strongly Disagree-Strongly Agree) Likert scale included: *I noticed the avatars expressions a lot.*, *I thought the avatars expressions matched the desktop user's voice and tone.*, *The avatar assisted the communication with the other person.*. After completing all of the conditions, the System Usability Scale (SUS) survey was also answered by the participants. The participants were then asked to indicate their preference between the two contrasting modes in each independent variable. Users also provided written comments after each condition and also at the end of the experiment. We had also recorded the audio of each participant, the final result of the negotiation task, the position

of the avatar related to the local user camera, and the rotation of the VR users head.

Experimental Procedure

An experiment session started with a pair of participants signing the consent form. Then participants completed a questionnaire that collected demographic information such as: age, gender, experience in VR/Video Games/Remote Collaboration. Faceware Live required a calibration process, so we required the remote user to have a completely neutral face. We instructed them to keep their eyes open, mouth closed and look at the centre of the laptop screen while the camera captured a video of their face for calibration.

The study was conducted across two rooms with participants talking to one another through the system headphones and microphones. The two participants decided who would be on the VR side and who would be the desktop user.

After each of the eight conditions, the participants completed a post-condition survey that measured Social Presence, mental effort, and other aspects of perceived user experience of the condition. There was also an optional space to write in other comments.

After completing all eight conditions, the participants completed the System Usability Scale survey and a preference questionnaire about which avatar conditions they preferred. The questions were broken up into their preference of one specific factor (*2D* vs (*3D*, (*In Scene* vs (*Screen Attached*, (*Expressions On* vs (*Expressions Off*). Participants were given a sheet of the eight different conditions, so they did not have to remember what each condition looked like (Fig. 4.3).

Data Analysis

We performed a factorial analysis on the rating results using a Repeated Measures ANOVA with Aligned Rank Transform [106]. The questions of the relevant Social Presence scores were averaged for each factor, across all the conditions that share a property. For example, to compare between *In Scene* vs. *Screen Attached*, all of the users' Social Presence responses of the four conditions that shared the avatar property of *In Scene* was placed together in one group.

The means of each element category *Expressions On* vs. *Expressions Off* were also displayed to show which categories scored the highest social presence. For the calculation of the mean, for example, with Expressions, we took all the responses that were *Expressions On* and averaged them, then we did the same with *Expressions Off*, and then compared them.

For analysing the results of user preference, we used a Chi-squared test with alpha = 0.05. Preference questions were asked after the experiment with multiple categories as shown in (Fig 4.5). Each preference question had three options (the two levels of the factor being compared, and a third option of no preference), hence the frequency distribution of the chosen options was compared to the expected category responses of a random choice (4 votes per category, $n = 12$).

4.5 Results

In this section we present the experiment results.

Social Presence

According to the factorial analysis of the subjective rating results using Repeated Measures ANOVA with Aligned Rank Transform, there were limited significant effects of each independent variable. All Social Presence measures showed no statistically significant effect of all the factors, nor any interaction effect ($p > 0.05$). However, there was a trend towards *Representation* affecting Co-Presence ($p < 0.078$; $F_{1,77} = 3.180$; $M_{\text{2D}} = 6.181$, $SD_{\text{2D}} = 0.758$; $M_{\text{3D}} = 6.264$, $SD_{\text{3D}} = 0.932$).

Perceived User Experience

For the Mental Effort measure, participants considered the *screen attached* avatar to significantly increase the work load ($p < 0.001$; $F_{1,77} = 17.355$; $M_{\text{In Scene}} = 11.771$, $SD_{\text{In Scene}} = 14.639$; $M_{\text{Screen Attached}} = 16.042$, $SD_{\text{Screen Attached}} = 14.624$). No other factors nor interactions had significant effect. Figure 4.4(a) summarises the results of Mental effort measure.

Amongst the custom rating questions, two of the rating items showed significant effect of the *Facial Expression*. Figure 4.4(b) shows the rating results of the item "*I thought the avatars expressions matched the remote users voice and tone.*" The results showed that participants reported that having facial expressions significantly increased the sense that the voice and tone matched the avatar ($p = 0.011$; $F_{1,77} = 6.871$; $M_{\text{Expressions Off}} = 4.354$, $SD_{\text{Expressions Off}} = 1.828$; $M_{\text{Expressions On}} = 5$, $SD_{\text{Expressions On}} = 1.726$).

For the rating item "*The avatar assisted the communication with the other person.*" (see Figure 4.4(c)), the results indicated participants perceived that the avatar assisted the communication significantly more when the facial expressions

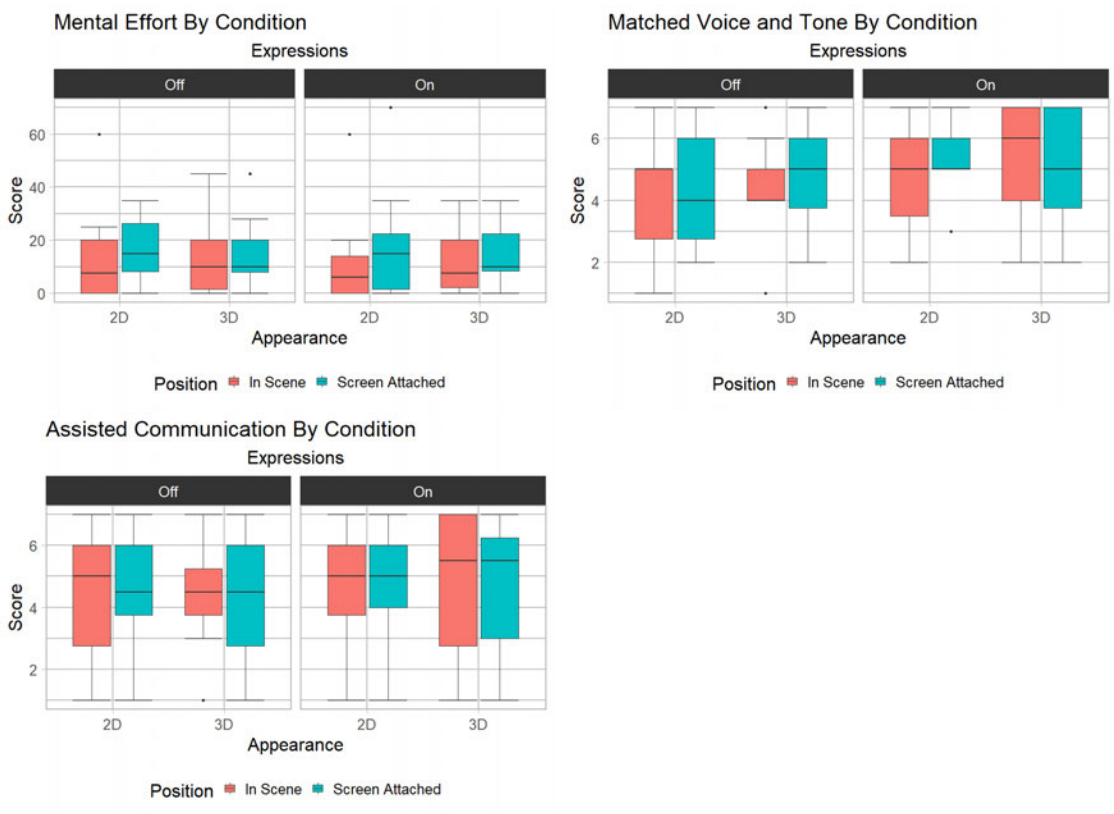

Figure 4.4: Participant responses for the questions that produced significant results. (Position is significant for Mental Effort, Emotion is significant for Matched Voice and Tone and Assisted Communication).



Figure 4.5: Graph showing participant response to 12 avatar related questions related to the 3 avatar elements. NS: $p > 0.05$, *: $p < 0.05$, **: $p < 0.01$. The questions were; **All Q:** Which element category did you **Q1:** enjoy more? **Q2:** think would be most useful? **Q3:** think is most noticeable? **Q4:** feel like you communicated the best with the other person?

were on ($p = 0.012$; $F_{1,77} = 6.602$; $M_{\text{Expressions Off}} = 4.438$, $SD_{\text{Expressions Off}} = 1.901$; $M_{\text{Expressions On}} = 4.708$, $SD_{\text{Expressions On}} = 1.978$).

Other rating items "*I was paying attention to the avatar.*" and "*I noticed the avatars expressions a lot.*" did not show any significant effect. However, there was a trend towards noticing the avatars expressions more in the Screen Attached conditions ($p = 0.083$; $F_{1,77} = 3.086$; $M_{\text{In Scene}} = 4.167$, $SD_{\text{In Scene}} = 1.950$; $M_{\text{Screen Attached}} = 4.708$, $SD_{\text{Screen Attached}} = 1.833$).

User Preference

Overall, participants reported that they felt the *3D*, *In-Scene* avatar with *Expression On* was more preferable than the *2D*, *Screen Attached* avatar with *Expression Off* (Fig. 4.5).

In terms of avatar position, participants significantly preferred *In Scene* over

Screen Attached. Chi-square tests indicated that with the *In Screen* conditions participants enjoyed it more ($p < 0.01$), thought it was more useful ($p < 0.01$), and felt they communicated better with their partner ($p < 0.05$).

In terms of facial expression, overall, users reported that they preferred the avatars *Expressions On* than *Expressions Off* (Fig. 4.5). The results indicated that having facial expression on is significantly more preferable as it's more enjoyable ($p < 0.01$), more useful ($p < 0.01$), more noticeable ($p < 0.05$), and users felt that they could better communicate with their partner ($p < 0.01$). However, there were also negative comments such that the expressions were too exaggerated to be taken seriously in general usage.

Most participants preferred the *3D* avatar over the *2D* avatar (Fig. 4.5), however, some also liked the *2D* avatar (4.5). One participant noted after the experiment, *"I prefer 3D avatar to 2D. It felt more easier to understand and communicate.""* Overall, results on participants' preferences indicated the *3D* avatar was more preferable as it was perceived as being more enjoyable ($p < 0.01$), more useful ($p < 0.05$), and users felt that they could better communicate with their partner ($p < 0.05$).

4.5.1 Experimenter Observations

During the course of the experiment, several observations were made by the experimenters which could provide supplementary insights:

- While all measures of Social Presence showed no statistically significant effect, the trend towards *Representation* affecting Co-Presence suggests potential areas for deeper investigation in future studies.

- Participants reported a higher workload with the *screen attached* avatar. This subjective feedback was corroborated by their actions and behaviors during the experiment, hinting at the potential ergonomic or cognitive challenges posed by this configuration.

- The significant effect of *Facial Expression* in custom rating questions showed that avatar facial cues play an important role in remote communication. Observationally, participants displayed a higher engagement and more synchronized interactions when the avatars had expressions on.

- Interestingly, while most participants preferred the *3D* avatar, there were still some who gravitated towards the *2D* representation. Observational nuances showed that individual preferences might stem from personal experiences or familiarity with virtual platforms.

- Some feedback on the exaggerated facial expressions of the avatars was noted. During the sessions, a few participants seemed to be momentarily distracted or amused by these expressions, suggesting that while facial cues are important, their design and implementation require careful calibration to avoid unintended effects.

It's worth noting that these observations, while valuable, are qualitative in nature and should be considered as supplementary insights that can guide future investigations.

Chapter 5

Discussion

The core research questions of this thesis revolve around understanding how virtual avatars can facilitate remote collaboration in a VR environment and identifying the key components that influence their effectiveness. In the introduction, we established the growing significance of remote work and the increasing adoption of social VR and remote collaboration in the VR domain. However, there is a lack of research exploring the potential of virtual avatars and their impact on collaborative experiences in VR. By addressing this research gap, we aim to contribute to the understanding of avatar-mediated remote collaboration and shed light on the crucial components that influence their effectiveness.

Before diving into the main study, a pilot study was conducted to refine the experimental design and gather preliminary insights. The findings from the pilot study played an instrumental role in shaping the main experiment. It provided valuable feedback on the selected avatar visualization techniques, ensuring their viability for the primary study. Moreover, the pilot allowed us to iron out any logistical or technical issues, ensuring a smoother experience for participants in

the main study. These preliminary findings reinforced our belief in the potential of virtual avatars in VR and set the stage for a more detailed exploration in the main user study.

From the findings of the main user study, we could partially answer our research questions on whether or not the choice of avatar visualization techniques influences a collaborative task in VR remote collaboration. In terms of i) social presence (RQ1), we could not find any significant difference between different combinations of the visualization techniques. On ii) perceived user experience (RQ2) in terms of mental effort and communication assistance, we found that using a *Screen Attached* avatar significantly increased the user's mental effort, while having *Expression On* improved the user experience. Finally, in iii) user preference (RQ2), it was found that participants preferred having *Expression On* over *Expression Off*, *3D* over *2D*, and *In scene* over *Screen attached*. In this section, we further discuss specific findings from the study.

5.1 Mental Effort

Screen Attached vs In Scene

Mental effort was greatly affected by the avatar's position, with the results indicating participants perceived the *Screen Attached* avatar requiring significantly higher mental effort. Participants stated that it was distracting to have an avatar constantly in their view and they did not like the screen attached conditions. For example, participants' comments on the *Screen Attached* condition were *"P4 Local: Too close, and I was more trying to avoid him"*, *"P3 Local: Was in the way,*

had to look around to get at some of the items easier" and *"P2 Local: I felt that this condition's avatar setup was a slight hindrance to task completion as the scale and position of the avatar was very close to the centre of my field of view."*. Some comments in support of *In Scene avatar* conditions were: *"P2 Local: ... this avatar was positioned in a more comfortable and natural position (in relation to a real life 2-way face-to-face communication scenario)"* and *"P1 Local: although view attached is noticeable but is it not very good"*.

From a user experience perspective, having a screen-attached avatar can be likened to someone constantly hovering over your shoulder or being too close for comfort. In real-world scenarios, such proximities are usually uncomfortable and can be perceived as invasive. This perpetual presence might have inhibited participants' sense of spatial freedom, making them feel constricted and constantly watched. The *In Scene* avatar, on the other hand, respects personal space and allows for a more natural interaction, akin to how individuals interact in physical settings.

Verbal Cues

Many participants opted to use verbal cues for communication. For example, one participant reported, *"P2 Local: ... found myself reverting to verbal communication as a primary communication source as the avatar's facial expressions seemed too subtle to focus on them often."* Many other participants also made similar comments e.g. *"P7 Local: I think avatar didn't synchronized with remote user, so I didn't pay attention to the avatar so much."*. The use of verbal cues likely helped reduce the perceived mental load. Even though mental effort was reported on a

scale between 0 and 150, the highest mental effort reported was 70 and the average was close to 10 as shown in (Fig 4.4(a)).

5.2 Expressions

Facial Expressions

The results indicated that participants significantly preferred having facial expressions on as they perceived that it improved the avatar to better match the voice and tone as well as better assisting the communication.

Participants tended to notice the expressions of the avatar more when the position was Screen Attached, which makes sense given that they were also paying more attention to the avatar. Participants said that the expressions assisted communication while the appearance definitely did not. Position was very mixed, which agreed with the mixed response to their avatar position preferences in (Fig 4.5).

Expressions may not be as relevant as first thought. This may be because the focus of the VR user was on the task at hand and the emotional state of their partner was not a major aspect of the chosen task. We were surprised by the results that expressions have no measurable effect on affective understanding or emotional interdependence sub-scales of social presence, which are related to understanding the affect and the other persons emotional state, respectively.

There are several possible reasons why expressions may not have had a significant impact on affective understanding or emotional interdependence in our study. One possibility is that the chosen desert island task in our VR environment placed

more emphasis on the task itself rather than on emotional cues from the partner. Participants may have been more focused on completing the task successfully, leading to a reduced attentional focus on their partner's expressions. In addition, it is possible that the task did not require a high level of emotional understanding, or that participants relied on other non-verbal cues or verbal communication to interpret their partner's emotional state. These unexpected results highlight the complex nature of social presence and the multifaceted factors that contribute to the perception of emotions in VR environments. Further research could be performed to explore the specific contexts and tasks in which expressions may have a more significant impact on affective understanding and emotional interdependence.

VR users observed that the avatar's expressions aligned well with the voice and tone when expressions were turned On. This observation held true even during an instance where a male avatar was mistakenly used to represent a female participant. Such a correlation suggests that an individual's voice and tone are intrinsically linked to their facial expressions. Interestingly, users did not significantly notice the expressions more in any given condition. This lack of attention to expressions might be due to the users' primary focus on the visual task. However, it's noteworthy that they could still discern the voice and tone of the avatar and recall its appearance. This is likely because detecting voice and tone doesn't require constant visual attention to the avatar, allowing users to notice these auditory cues while concurrently concentrating on the task workspace.

The quality of the expressiveness of the avatar and the accuracy of the mapping was commented on. For instance, one participant reported that they noticed their partner yawning e.g. *"... The avatar was really accurate in this condition. My partner yawned and I could see that. Pretty cool! :)"* The implications were that

users were overloaded visually, but yet, not mentally overloaded.

Understanding the desktop user's attention was easier when the avatar was closer to the VR user's viewpoint when compared to expressions and appearance of the avatar due to the eye gaze, even though audio was still the primary communication method for most people. This might be attributed to the facing direction and eye gaze that assisted the VR user to determine the object that the remote user was referring to in their discussions.

The avatar could be useful in a number of scenarios, such as computer-mediated communication where the avatar could provide more cues than a zoom call. If the remote user was able to select the context they want the local user to pay attention to, the avatar could float over and look towards it, in order to get the local user to look at an object, without spending the time to say it. Any scenario that uses face-to-face communication, but in a low bandwidth environment where this is not possible, could use an avatar instead of a video stream of the other user in order to provide a good visual experience.

5.3 Limitations

We identified several limitations with our experiment and propose future work that could address them:

- The task used in our study did not encourage enough active discussion and interaction between participants. A task which requires unique knowledge or information between people, such as having each user have a subset of the task instructions, would encourage the users to collaborate more.

- The tasks were relatively short, only three minutes long. It might be possible that another task length will provide more significant results.

- Many users complained about the location of the avatar in the Screen Attached conditions. Although the position was decided based on the pilot test results, the chosen position in the Screen Attached condition may still not have been ideal. Therefore further investigation would be necessary to determine the most suitable location for it.

- With eight conditions, the questionnaires took a significant amount of time to complete. To reduce participants' fatigue, we should have divided the experimental session across a number of days.

Other limitations could be that the avatar didn't look like the real person, there was no use of additional physiological cues to convey emotion, the characters still looked cartoon-like, there were only two people in the experiment (and so doesn't related to larger social VR applications), etc]

We also did not measure Electroencephalogram (EEG) for the mental effort, and using this we could have had a different set of mental effort results. EEG is a non-invasive technique used to measure electrical activity in the brain. It provides valuable insights into cognitive processes and mental states, making it a useful tool for assessing mental effort. By analyzing EEG signals, we would be able to identify specific patterns associated with different levels of cognitive load and mental engagement. In the context of our study, EEG could have been be employed to measure participants' mental effort during VR remote collaboration tasks. This objective measurement of mental effort would then be compared to participants' the self-reported mental effort. By comparing objective EEG data

with self-reported mental effort, we could gain a comprehensive understanding of the cognitive demands of the tasks and explore the relationship between subjective experiences and neurophysiological responses. This combined approach should enhance the validity and reliability of our findings, providing a deeper understanding of the impact of avatar visualisation techniques on mental effort in VR remote collaboration.

Overall, the main study results showed a strong preference of the participants for 3D, In Scene avatars with facial expressions on. Although no significant effect on Social Presence was found, the facial expressions matching the tone and voice of the desktop user helped improve the collaborative experience. Replicating how people typically use non-verbal cues to assist in their communication in the real world, even if people can communicate their point with verbal-only cues, they often like to use non-verbal cues to emphasise a point they are making. On the other hand, certain visualisations could create undesirable side effects. For example, some participants seemed tired, fatigued or annoyed by the avatars. The presence of the avatar created a secondary task that was redundant to the original problem-solving task, and the unnecessary addition may have impeded cognitively.

Challenges and Future Directions

As the domain of virtual avatars in VR collaboration continues to grow, several challenges and opportunities lie ahead.

From a technical standpoint, achieving perfection in avatar representation remains elusive. While advancements have been made, there's still a noticeable disparity between virtual avatars and their real-world counterparts. Perfecting

lip-syncing, capturing subtle facial expressions, and ensuring real-time, accurate avatar movements are all pivotal for enhancing the authenticity of virtual collaborations. Furthermore, the overall stability and robustness of the VR platforms, especially in scenarios with limited bandwidth, are vital for a smooth collaborative experience.

Avatar design and representation bring forth social challenges. The choices made in the design of avatars—whether regarding gender, ethnicity, or age—can have unintended implications. It's essential to approach avatar design with an inclusive mindset, ensuring diverse representation and avoiding unintentional biases.

Ethical considerations also come into play, particularly as avatars become more personalized. The collection and storage of personal data for avatar customization raise concerns about user privacy and data protection. Clearly defined policies regarding data ownership and its use will become increasingly important as VR technologies mature.

Looking ahead, there's significant potential for deeper research into the role of avatars in VR collaboration. Areas such as the influence of avatars on collaborative problem-solving, the dynamics of team interactions, or the impact of avatars on creative brainstorming sessions are all worthy of exploration. Additionally, understanding how avatars with varying features—like dynamic emotional displays or adaptive behaviors based on user feedback—affect collaboration can provide valuable insights.

In the broader context, the psychological and social dynamics of avatar-mediated collaboration deserve attention. Questions about how avatars influence an individual's self-perception, team dynamics, or even leadership roles within collaborative VR environments can provide a richer understanding of virtual collaborations.

In conclusion, while virtual avatars present exciting prospects for the future of remote collaboration in VR, it's imperative to address the existing challenges and continually push the boundaries of what's possible.

5.4 Conclusion of the Discussion

The core research questions are: (RQ1:) How can virtual avatars facilitate remote collaboration in a VR environment and (RQ2:) what are the key components that impact their effectiveness?

Based on the current web page context, the choice of avatar visualization techniques does influence a collaborative task in VR remote collaboration. In terms of social presence, there was no significant difference found between different combinations of visualization techniques. However, having the avatar's expression on improved the user experience while having the avatar screen attached significantly increased the mental effort. In terms of user preference, participants preferred having expression on over expression off, 3D over 2D, and in scene over screen attached.

Mental effort was greatly affected by the avatar's position, with participants perceiving the screen attached avatar as requiring significantly higher mental effort. Many participants found it distracting to have an avatar constantly in their view and did not like the screen attached conditions. Some participants opted to use verbal cues for communication which likely helped reduce the perceived mental load.

The results indicated that participants significantly preferred having facial expressions on as they perceived that it improved the avatar to better match the

voice and tone as well as better assisting communication. Participants trended towards noticing the expressions of the avatar more when the position was screen attached. However, for these tasks expressions may not be as relevant as first thought, since the focus of the VR user was on the task at hand and the emotional state of their partner was not a major aspect of the chosen task.

The quality of the expressiveness of the avatar and the accuracy of the mapping was commended by participants. The implications were that users were overloaded visually, but not mentally overloaded. Understanding the desktop user's attention was easier when the avatar is closer to the VR user's viewpoint due to the eye gaze, even though audio was still the primary communication method for most people.

The avatar could be useful in a number of scenarios, such as computer-mediated communication where it could provide more cues than a zoom call. If the remote user is able to select the context they want the local user to pay attention to, the avatar could float over and look towards it in order to get the local user to look at an object without spending time to say it. Any scenario that uses face-to-face communication but in a low bandwidth environment where this is not possible, could use an avatar instead of a video stream of the other user in order to provide a good visual experience.

In summary, for the tasks tested we have found that virtual avatars could facilitate remote collaboration in a virtual reality environment by providing a shared virtual space for users to interact and communicate efficiently. The key components that impact their effectiveness include avatar fidelity, nonverbal expressiveness.

Chapter 6

Conclusion and Future Work

The primary objective of this thesis was to investigate the use of virtual avatars to support remote collaboration in a VR environment. The research examined the impact of avatar-mediated communication on collaboration outcomes, including task performance, communication effectiveness, system usability, and user experience. A pilot study and then full study was conducted where the user's partner was shown as a virtual avatar in two communication tasks. The study showed that avatar design and features significantly impact collaboration outcomes. For instance, avatars with more expressive features were found to be preferred over non-expressive avatars, even if the feature did not assist with social presence or collaboration outcomes. Furthermore, the results suggest that the location of avatars in the virtual space can impact these outcomes, while appearance was mixed in these respects.

The research explored the answer to the research questions: (RQ1:) How can virtual avatars facilitate remote collaboration in a VR environment and (RQ2:) what are the key components that impact their effectiveness? The problem that

these research questions address is the impact of avatar visualisation techniques on various aspects of VR remote collaboration, such as social presence, perceived user experience, and social preference.

In conclusion, this thesis presents a comprehensive investigation into the use of virtual avatars in a Virtual Reality environment to support remote collaboration. The results demonstrate that avatar design and features play a significant role in shaping collaboration outcomes. The study also highlights the importance of considering avatar location in the virtual space when designing for remote collaboration. These findings provide valuable insights for VR developers and designers to enhance user engagement and improve the overall effectiveness of remote collaboration in VR environments. Further research is needed to explore the impact of other avatar visualization techniques on user experience and engagement in remote collaboration.

As part of the research from the main study, data was collected on participants' interaction with the avatar. The findings revealed that participants were less likely to focus on the avatar if its expression, face, or appearance was not relevant to the task. In the future, the next study could address this issue further by having the participants solely focus on the avatar, which will be embodied by another participant who will perform a task that will capture and transfer their emotions to the avatar.

Another finding from the data collection was that participants found it unsettling when the avatar was too close to their face. The reason for this could be because it is not normal for a person to be directly in front of one's face. The next study will remove this condition to ensure that participants are comfortable during the interaction with the avatar. These findings highlight the importance of

considering participants' comfort and the relevance of the avatar's appearance to the task in designing virtual avatars for remote collaboration.

Several future research directions spring to mind based on our current exploration. Notably, the potential of face tracking within VR HMDs catches our interest. As VR technology continues to evolve, there's an apparent push towards integrating advanced sensors in HMDs. These sensors, capable of capturing nuanced facial movements, can bring a level of realism and authenticity to avatars that we've not seen before. By mirroring real-time facial expressions, we can imagine a scenario where virtual interactions feel almost as genuine as face-to-face ones. It's a fascinating intersection of the physical and virtual worlds, ensuring that the subtleties of human communication aren't lost in the VR environment.

Pair this with the capabilities of tools like the OpenBCI Galea [107], and we're looking at an incredibly detailed portrayal of a user's emotional state. Beyond just facial expressions, leveraging physiological cues could give us deeper insights into emotions that might not always be outwardly visible. Such a rich dataset could guide us in designing visualisations that resonate best with VR users.

Building on previous work, like the findings from Oh et al. [52], it's worth investigating how amplifying avatar expressions could play out in VR. If cartoon avatars with exaggerated features can enhance social presence, what might this mean for more realistic avatars? It's an avenue definitely worth exploring, given the implications it could have for our understanding of avatar interactions in VR.

We could also study the ability of people to understand the emotions of others through their verbal communication. This could be done through a task that involves a remote user being presented with an image that has either a negative, natural, or positive valence arousal rating, while a local user is shown an avatar that

embodies the expressions of the remote user and cannot see the image. The remote user would then be required to create a story or talk about the object in the image in about 10 seconds before clicking on the finish button. After this, a survey would appear on-screen for both users to gauge their understanding of the emotions in the image. The images used could be taken from the Open Affective Standardized Image Set (OASIS) or International Affective Picture System (IAPS) dataset, a structured set of images commonly used in psychological studies to study emotion and attention. The images are categorised based on their valence and arousal values, and a subset of happy, sad, and neutral images are selected for the task.

This task allows us to examine the perception and interpretation of emotions conveyed solely through verbal communication, without visual cues from the images. By manipulating the emotional valence and arousal of the images, the task could provide insights into how well individuals can understand and empathize with others' emotions. It also enables the investigation of the effectiveness of remote communication in conveying emotional information, comparing the impact of embodied expressions (local user) versus verbal communication alone (remote user). Utilizing a standardized dataset ensures consistency in the emotional content and facilitates comparisons with existing psychological studies. Overall, this task contributes to our understanding of emotion perception, empathy, and the dynamics of remote communication in emotional contexts.

Chapter 7

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Appendix

Pilot Study

Local/Remote User Pre-Questionnaire

- Participant ID Number (given by us)
- Age
- Gender
  - Female
  - Male
  - Other
- Experience in VR
  - Everyday
  - Several Times A Week
  - Several Times A Month
  - Several Times A Year

  - More Rarely/Never

- Experience playing Video/Computer Games
  - Everyday
  - Several Times A Week
  - Several Times A Month
  - Several Times A Year
  - More Rarely/Never
- What games do you current play?

Local/Remote User Post Trial

- Task ID
- Group ID (given by us)
- Participant ID (given by us)
- Condition
- Considering the AVATAR shown in this condition, please rate on how much you agree on each statement.
  - Overall, the task was - Likert Scale from 1-7 (Strongly Disagree-Strongly Agree)
- Please explain WHY the task was easy or difficult.

- Based on the scale provided on Mental Effort, please type in a number (0-150).

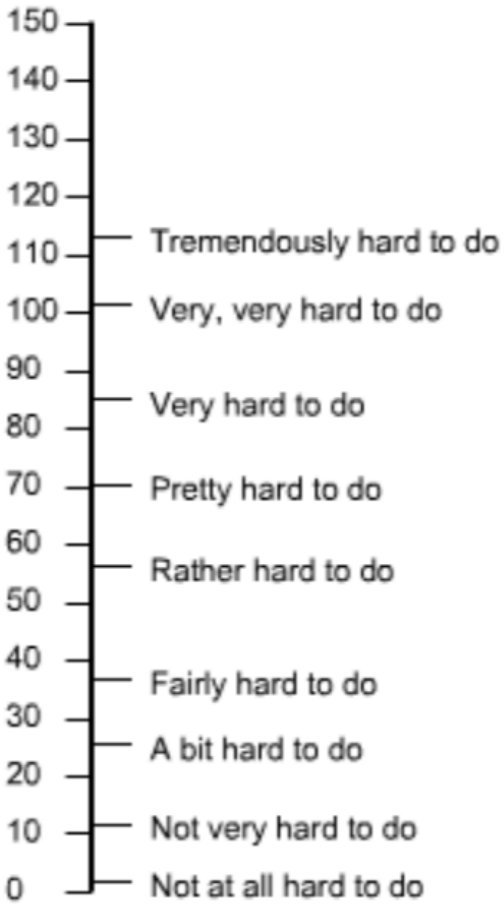

Figure 8.1: Mental effort image from the Subjective mental effort questionnaire

- The follow questions were given as a Likert Scale from 1-7 (Strongly Disagree-Strongly Agree)
  - I enjoyed the experience.
  - I was about to focus on the task activities.
  - I understood where my partner's focus was on.

  - I noticed my partner.
  - My partner's presence was obvious to me.
  - My partner caught my attention.
  - I was easily distracted from my partner when other things were going on.
  - I remained focused on my partner throughout our interaction.
  - My partner did not receive my full attention.
  - My partner's thoughts were clear to me.
  - It was easy to understand my partner.
  - Understanding my partner was difficult.

- How would you describe your collaboration with the partner? (Given as likert scale from 1-7, the prefix and suffix of the scale given in each subquestion.
  - Cold - Warm
  - Small - Large
  - Hard - Soft
  - Erratic - Periodic
  - Constricted - Spacious
  - Boring - Interesting
  - Ugly - Beautiful
  - Impersonal - Personal
  - Colourless - Colourful

  - Unsociable - Sociable
  - Closed - Open
  - Passive - Active
  - Insensitive - Sensitive
  - Dehumanizing - Humanizing
- Considering the collaboration in this condition, please describe ...
  - What did you like?
  - What did you dislike?
- Any other comments?

Local/Remote User Post Experiment

- Participant ID number (given by us)
- System Usability - Likert Scale from 1-5 (Strongly Disagree-Strongly Agree)
  - I think that I would like to use this system frequently
  - I found the system unnecessarily complex
  - I thought the system was easy to use
  - I think that I would need the support of a technical person to be able to use this system
  - I found the various functions in this system well integrated
  - I thought there was too much inconsistency in this system

  - I would imagine most people would learn to use this system very quickly
  - I found the system very cumbersome to use
  - I felt very confident using the system
  - I needed to learn a lot of things before I could get going with this system
- What game did you notice the expressions of the avatar more?
  - Island Survivor
  - Bomb Game
- What game did you think would the expressions of the avatar was more useful?
  - Island Survivor
  - Bomb Game
- What is your preference on the position of the avatar? - On-Screen, In-Place or Adaptive for each row
  - Island Survivor
  - Bomb Game
- What do you think about the different positions of the avatar?
- What do you think about the facial expressions and its impact on the game?
- What did you think of the Monster face on the avatar?
- Do you feel it is natural to be communicating with this avatar in the game?

- What did you think of the games?
- What did you think of the controls of the games?
- How can the games be improved?
- What type of facial expression/representation would be useful to manipulate/support in future iterations?
- What is your suggestion of games that would be fun to play with this system?
- What is your suggestion for non-game applications that would benefit from this system?
- Any other thoughts?

Main Study

Local/Remote User Pre-Questionnaire

- Group ID Number (given by us)
- Age
- Gender
  - Female
  - Male
  - Prefer not to say
  - Other

- Experience in VR
  - Everyday
  - Several Times A Week
  - Several Times A Month
  - Several Times A Year
  - More Rarely
  - Never
- Experience playing Video Games
  - Everyday
  - Several Times A Week
  - Several Times A Month
  - Several Times A Year
  - More Rarely
  - Never
- Experience remote collaborating. (e.g. Skype call, Cooperative Games, etc)
  - Everyday
  - Several Times A Week
  - Several Times A Month
  - Several Times A Year
  - More Rarely

  - Never

- What is the relationship with your partner?
  - Never met before
  - Acquaintance
  - Friends
  - Family

Local/Remote User Post Trial

- Group ID Number (given by us)
- Condition (given by us) 1,2,3,4,5,6,7 or 8
- Social Presence Questionnaire - Likert Scale from 1-7 (Strongly Disagree-Strongly Agree)
  - I noticed my partner
  - My partner noticed me
  - My partner's presence was obvious to me
  - My presence was obvious to my partner
  - My partner caught my attention
  - I caught my partner's attention
  - My thoughts were clear to my partner
  - My partner's thoughts were clear to me

  - It was easy to understand my partner
  - My partner found it easy to understand me
  - Understanding my partner was difficult
  - My partner had difficulty understanding me
  - I could tell how my partner felt
  - My partner could tell how I felt
  - My partner's emotions were not clear to me
  - My emotions were not clear to my partner
  - I could describe my partner's feeling accurately
  - My partner could describe my feelings accurately
  - I was sometimes influenced by my partner's moods
  - My partner was sometimes influenced by my moods
  - My partner's feelings influenced the mood of our interaction
  - My feelings influenced the mood of our interaction
  - My partner's attitudes influenced how I felt
  - My attitudes influenced how my partner felt

- Please rate the amount of effort this task took based on the following image:

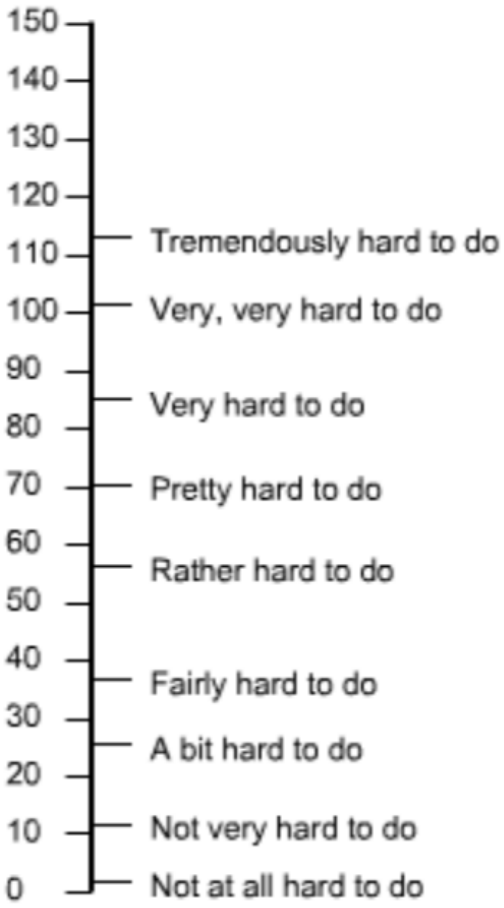

Figure 8.2: Mental effort image from the Subjective mental effort questionnaire

- (LOCAL USER ONLY) Other Questions - Likert Scale from 1-7 (Strongly Disagree-Strongly Agree)
  - I was paying attention to the avatar
  - I noticed the avatars expression a lot
  - I thought the avatars expressions matched the remote users voice and tone
  - The avatar assisted with the communication with the other person.

- Any other comments?

Local/Remote User Post Experiment

- Group ID Number (given by us)
- System Usability - Likert Scale from 1-5 (Strongly Disagree-Strongly Agree)
  - I think that I would like to use this system frequently
  - I found the system unnecessarily complex
  - I thought the system was easy to use
  - I think that I would need the support of a technical person to be able to use this system
  - I found the various functions in this system well integrated
  - I thought there was too much inconsistency in this system
  - I would imagine most people would learn to use this system very quickly
  - I found the system very cumbersome to use
  - I felt very confident using the system
  - I needed to learn a lot of things before I could get going with this system
- (LOCAL USER ONLY) Which Avatar appearance did you enjoy more? (2D, 3D, No Preference)
- (LOCAL USER ONLY) Which Avatar appearance did you think would be most useful? (2D, 3D, No Preference)

- (LOCAL USER ONLY) Which Avatar appearance did you think is most noticeable? (2D, 3D, No Preference)
- (LOCAL USER ONLY) Which Avatar appearance made you feel like you communicated the best with the other person? (2D, 3D, No Preference)
- (LOCAL USER ONLY) Which Avatar expressions did you enjoy more? (No Expression, Normal Expression, No Preference)
- (LOCAL USER ONLY) Which Avatar expressions did you think would be most useful? (No Expression, Normal Expression, No Preference)
- (LOCAL USER ONLY) Which Avatar expressions did you think is most noticeable? (No Expression, Normal Expression, No Preference)
- (LOCAL USER ONLY) Which Avatar expressions made you feel like you communicated the best with the other person? (No Expression, Normal Expression, No Preference)
- (LOCAL USER ONLY) Which Avatar position did you think would be most useful? (In Scene, Screen Attached, No Preference)
- (LOCAL USER ONLY) Which Avatar position did you enjoy more? (In Scene, Screen Attached, No Preference)
- (LOCAL USER ONLY) Which Avatar position did you think would be most noticeable? (In Scene, Screen Attached, No Preference)
- (LOCAL USER ONLY) Which Avatar position made you feel like you communicated the best with the other person? (In Scene, Screen Attached, No Preference)

- Any Other Comments?

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Statement of Authorship

Title of Paper	Emotion Sharing and Augmentation in Cooperative Virtual Reality Games
Publication Status	■ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
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PRINCIPAL AUTHOR	
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Contribution to the Paper Brief description of your work in this publication	"For this publication, I took the lead role in all phases of the research and writing process. I was responsible for the conceptualization and design of the study. I executed the research methodology, conducted data collection, and carried out the subsequent data analysis. Following the analysis, I authored the entirety of the paper, including drafting, revising, and finalizing all sections. While I took the primary lead in these tasks, I regularly consulted with and incorporated feedback from
Overall Percentage (%)	65
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CO-AUTHOR CONTRIBUTIONS	

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Contribution to the Paper Brief description of your work in this publication	"For this publication, I took the lead role in all phases of the research and writing process. I was responsible for the conceptualization and design of the study. I executed the research methodology, conducted data collection, and carried out the subsequent data analysis. Following the analysis, I authored the entirety of the paper, including drafting, revising, and finalizing all sections. While I took the primary lead in these tasks, I regularly consulted with and incorporated feedback from
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