Utrecht University

Department of Information and Computing Sciences

Game and Media Technology - Master Thesis

Presence and Embodiment in Augmented Reality

Author:
Jean-Paul van Bommel
ICA-3741508

Supervisors:
Dr. Wolfgang Hürst
Prof. Dr. Peter Werkhoven

Daily supervisor:
Nina Rosa, MSc.

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Abstract

Today's world is filled with mediated environments, and a lot of these have become increasingly immersive. Some even allow us to replace or augment the visual representations of our own bodies. This provides us with a completely new viewpoint and begs the question how do we experience our self in such environments? Two very relevant concepts to how we experience our self in immersive mediated environments are the concepts of Self-presence and the Sense of Embodiment (SoE). A lot of research on these concepts has been done in Virtual Reality, however, the same can not be said for Augmented Reality (AR). This is due to the fact that these concepts are often ignored in AR because they are considered inherent to the visual presence of the real body. This logic is flawed, as scenarios exist in which both the real body and a virtual self-representation are visually present. In this study, we investigated the possible levels of Self-presence and the SoE in such an AR scenario, alternating the virtual body's movement congruency and anthropomorphism. We also investigated the relationship between Self-presence and the SoE, to provide empirical proof that a relation between the two exists. In particular, we focused on the relation between Self-presence and body ownership, a sub-class of the SoE, because this relation has been speculated upon often in literature. To investigate these concepts we implemented an AR environment using two different system designs. The first system made use of a commercial optical see-through display, but this system was deemed unsuitable for this study after preliminary testing. For the second system, a custom video see-through AR Head-Mounted Display was designed and built, to avoid the limitations of the first system. This second system was deemed suitable and used in the experiment. The results of our experiment show that the SoE was induced to a certain extent for the disconnected avatar using congruent avatar movements, irrespective of avatar anthropomorphism. We can also argue that our results indicate some measure of Self-presence for the disconnected avatar occurred in the congruent movement cases, partially based on anecdotal evidence. Furthermore, our results show a strong correlation between subjective body ownership and Self-presence, which empirically proves the existence of a relationship between both concepts. These results demonstrate that both Self-presence and the SoE are difficult but viable concepts in AR, and definitely merit further research.

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Contents

Preface

This thesis was written as part of the graduation requirements for the Master's programme in Game and Media Technology at Utrecht University. The title of the thesis is *Presence and Embodiment in Augmented Reality*, and it investigates the concepts of Presence and the Sense of Embodiment in an Augmented Reality environment and empirically proves the relation between these two concepts. The culmination of this thesis is a scientific paper summarizing the major research outcomes of this project. Including this paper, this document contains the following deliverables:

- A detailed introductory literature study on presence and embodiment in Augmented Reality, in particular, body ownership and Self-presence as the relation between these two concepts has often been speculated upon but not been proven. In the study methods for inducing Self-presence and body ownership over disconnected avatars are investigated and a concrete relation between Self-presence and body ownership is hypothesized. This literature study can be found in Chapter I.
- A proposal for research on presence and the Sense of Embodiment in Augmented Reality based on the findings from the introductory literature study, which can be found in Chapter II.
- A detailed description of the implementations of the two Augmented Reality systems, that were used during this thesis project, one using a commercial optical see-through HMD and one using a custom built video see-through HMD. This can be found in Chapter III.
- The scientific paper that outlines the most important results and findings of this research, which can be found in Chapter IV.
- A set of reflections on the used methodologies for processing and analyzing the data results from the experiments. These can be found in Chapter V.

Further deliverables that were not included in this written thesis are:

- The source code, executables, and assets used in this study, with a written explanation of their main functionalities and instructions for use. Information on their implementation can be found in Chapter III.
- A video displaying the experiment and its results, targeted at a broad audience: `http://www.bommelvan.com/thesisvideo`
- All data that was acquired during the experiment.

Chapter I

Introductory Literature Study on Presence and Body Ownership in AR

1 Introduction

In today's world mediated environments are everywhere and some of these environments are becoming increasingly immersive and convincing, especially with the advent of sophisticated Virtual Reality (VR) and Augmented Reality (AR) displays. An important concept relevant to the experience of these mediated environments is the concept of presence. Presence in virtual environments has been studied for several decades and it has seen a variety of definitions and operationalizations. It is often described as the feeling of *being there*, however, this describes but a single aspect of presence. A more general definition of presence is the perceptual illusion of non-mediation [21].

Presence is an important topic in VR research because it concerns the experienced authenticity of the VR environment. Feeling presence implies we have forgotten the virtual environment is not real and one of the main goals of virtual reality is to make a virtual environment feel real. Similarly, in AR the feeling that the virtual objects which are integrated into reality feel authentic should be a major concern. However, the research on presence in AR is unfortunately sorely lacking. Unsurprisingly, it has been shown that a high level of presence has a variety of benefits in virtual environments. For example, it was found that presence in a VR museum caused a significantly higher enjoyment for the user [37]. In another study, specifically on Self-presence, one the subtypes of presence, it was shown that Self-presence promotes exercise and increases perceived exercise achievement in exercise games [36].

A related concept, which is often mentioned together with presence, is the concept of body ownership. Body ownership refers to one's self-attribution of a body. Traditionally this concept is researched in the real world using an illusion with a rubber hand, hence the name Rubber Hand Illusion (RHI) [16]. In more recent years, it has also received a virtual counterpart, aptly named the Virtual Hand Illusion (VHI). Using VR it has become easier to test new versions of this illusion which are difficult to test in the real world. The illusion has been shown to be able to be extended to include the entire body, this is known as a Body Transfer Illusion [35, 25].

Informally one could imagine that having the feeling of owning the virtual body that one sees in the environment should also increase one's sense of presence in that environment. However, very little is known about the concrete relation of these concepts. What we do find is that body ownership is often mentioned as being related to the higher level concept Self-presence. For example in [18] the authors mention body ownership being related to a higher level concept of Self-presence. Another example can be found in a study on RHI and VHI [13], where the authors mention having only focused on a small aspect of Self-presence, a third example can be found in a study on Self-presence [28] they mention the VHI as an example of body level Self-presence. All these examples indicate body ownership being a lower-level concept in relation to the higher level concept of Self-presence.

Self-presence concerns our connection to a virtual self-representation or avatar and can be defined as a psychological state in which virtual selves are experienced as the actual self [19]. Self-presence is but one of the three subtypes of presence, the other two being physical presence, the experience that virtual objects or environments are real, and social presence, the experience that virtual social actors are real [14, 3, 19]. Although the relations between body ownership and all three subtypes of presence seem worthy of research, to date no clear indications in literature exist for the relationships between body ownership and physical or social presence. Furthermore, both Self-presence and body ownership directly involve the perception of one's self and not the environment or a different individual.

Like with Self-presence, AR is often ignored in body ownership research. The probable reason for this is that in most current AR applications one can see one's real hand or body and not a virtual representation or extension. There are, however, scenarios in which such virtual representations or extensions are applicable and arguably essential. This provides an opportunity to not only investigate the relation between two important concepts but to do this in an environment in which they are usually considered non-existent.

The purpose of this literature study is to determine how Self-presence and body ownership over a virtual body can be induced in an AR environment, and whether and how body ownership could fit into a framework for Self-presence. In the following section, we will elaborate on a scenario in which the real body and a disconnected virtual avatar are visible and how Self-presence and body ownership could be induced over the virtual avatar in this scenario. Next, we look at a framework for Self-presence found in literature and how body ownership could fit into this framework. Fitting body ownership into Self-presence could be very valuable to research in presence because it could indicate that body ownership is a form of Self-presence.

2 The Self in Augmented Reality

2.1 Self-presence in AR

In the introduction in Section 1, we have mentioned some of the benefits of presence. Some of these benefits could also be translatable to the appropriate AR environments if one can induce a form of presence in them. However, little is known about presence in AR environments, and the little that is known concerns mostly physical presence and social presence [37, 15, 26]. Self-presence is considered completely ignorable and intrinsic to the fact that one can see one's real body [10]. However, this logic is flawed in the sense that one can feel Self-presence for a virtual avatar viewed on a computer screen while the real body is still very much visible. For example, in [36, 17, 30, 33] the authors showed that Self-presence was felt for a Wii avatar seen on a screen. In [2, 28] similar results showed participants feeling Self-presence while playing online video games.

Therefore, we argue that an AR scenario in which the real body is simultaneously visible with a disconnected virtual avatar should still induce a level of Self-presence for the virtual avatar. This scenario will inevitably be applied for a variety of purposes. For example, the disconnected avatar will surely be used to perform tasks outside of the user's reachable space. Another more concrete example would be a training application for learning martial arts such as Tai Chi. In this application, the user would simultaneously see their real body and a virtual body performing the exact same movements. The application would first show a second avatar performing the move to learn, then the user attempts to mimic the move, and while the user is moving the application provides pointers both on the real body and the virtual body for posture and movement corrections. Such an application could be very popular, seeing as there are hundreds if not thousands of training videos available for learning Tai Chi. Furthermore, in such an application Self-presence could play a critical role in promoting exercise and increasing exercise achievement.

To experience proto Self-presence, the bodily level of Self-presence (see Section 3.1), one has to use a virtual object as if it is an extension of one's real body. This requires a substantial level of comfort or experience with the method of controlling the virtual object [29]. Logically, the method of control that humans are almost unanimously most comfortable and experienced with is controlling their own real bodies.

Controlling a virtual body by directly using our real body's movements should in turn still be a method of control humans are comfortable with. Thus, in the previously described AR scenario, in which both a real and virtual body are visible, controlling the virtual body using movements of the real body should be sufficient to induce a high level of proto Self-presence if the virtual body copies these movements synchronously.

2.2 Body Ownership in AR

The question of body ownership in a similar AR scenario to the one described in the previous section, in which the real body and a virtual body are simultaneously visible, is a little less straightforward. As can be seen in one of the only studies on ownership to include an AR scenario, the real hand was hidden from view [16]. It has been shown however that it is possible to induce ownership over a third arm while the real arms are visible [12]. The same should be possible for an extra hand in an AR environment, or even an extra body. We see that in [20] the authors experimented with a VR environment in which a virtual self-representation was placed in front of the participant facing away. The authors found that body ownership can be felt for a disconnected virtual version of one's own body or a virtual fake body using synchronous visual-tactile stimulus. The illusion is broken when a non-corporeal object is used.

Similarly, in [11], the authors found that synchronous active visual-motor feedback could be used to induce ownership over a mirrored disconnected virtual body. Incongruent visual-motor feedback, however, broke the illusion. This indicates that body ownership over a disconnected virtual avatar in AR should also be possible using either synchronous visual-tactile or visual-motor feedback. An example application of such a scenario would be a player versus player fighting game, in which two players stand opposite each other, on elevated surfaces, while their avatars do battle between them using their actual movements. Such an application would allow people to fight without actually doing or receiving any harm. Furthermore, it would allow people to fight not just as themselves but as all sorts of anthropomorphized avatars. The influence of body ownership in such an application could be two-fold. First, having the feeling that the avatar you are fighting with is actually your body should make the fight more vivid and the responses you have to attacks by the opponent more real. Second, if body ownership is truly an instance of Self-presence it could significantly improve your enjoyment of the whole experience. Based on the popularity of dueling TV shows and video games, such as Pokémon or Medabots, such an application could be insanely popular.

3 Body Ownership and Self-presence

3.1 Framework for Self-presence

Self-presence has been interpreted in a variety of ways, some in a more physical sense [17, 2], others more in the sense of identity [33]. In [31], Ratan and Hasler give a more holistic definition of Self-presence: the extent to which some aspect of a person's media use is relevant to the user's proto (body-schema) self, core (emotion-driven) self, and/or extended (identity-relevant) self. To establish this inclusive definition of Self-presence, Ratan et al. designed a framework for Self-presence that describes three distinct but interrelated levels of Self-presence, namely proto Self-presence, core Self-presence and extended Self-presence [31], see Table I.1. They base these levels of Self-presence on a neuroscientific framework of consciousness and self by Damasio, which defines three distinct levels of self: proto self (bodily), core self (emotional), and extended self (identity) [5].

Multiple studies were done to test the validity of the framework and the reliability of the accompanying questionnaire [31, 28, 32, 30, 29]. These studies found that the three levels are moderately positively interrelated and that the questionnaire items verified three distinct factors corresponding to the three levels of Self-presence. Ratan et al. furthermore found that gender consistency of user and avatar influenced the perceived level of proto Self-presence, this influence however only occurred in the case where the user was allowed to customize their virtual self-representation and not in the case where the user was allowed no

Table I.1: Levels of Self-presence in the framework by Ratan [28]

	Proto Self-presence	Core Self-presence	Extended Self-presence
Definition	The extent to which a mediated self-representation is integrated into the body schema	The extent to which mediated interactions between a self-representation and mediated objects cause emotional responses	The extent to which some aspect of a self-representation is related to some aspect of personal identity
It occurs when	A user uses a virtual tool or body in a mediated environment as if it is an extension of the real body without thinking about the mediation involved	An interaction of the virtual self-representation with the virtual environment causes emotional responses in the user	A characteristic of the user's identity is represented through the user's virtual self-representation

customization. This should be taken into account in studies on Self-presence when designing the avatar and its customization options.

3.2 Fitting Ownership into the Framework

To find the relation between body ownership and Self-presence it needs to be investigated how body ownership would fit into the aforementioned Self-presence framework. Looking at the definitions of the three levels the most logical fit would be the proto Self-presence level since that concerns the integration of a virtual representation into the body schema, and body ownership *is* the integration of a faux body part into the body schema. We see that the example cases of proto Self-presence include research on the RHI, the prime methodology of researching body ownership [28]. The authors also drew from questionnaires used in this research when designing their own questionnaire, which means that further research should include some other objective confirmation of either body ownership or Self-presence being induced. Although the other two levels of Self-presence (core and extended) are positively related to proto Self-presence, they do not concern the bodily level of the self, but look at higher levels of consciousness concerning one's emotions and identity.

This all suggests body ownership fits into proto Self-presence, so the question then becomes whether body ownership is simply the same as proto Self-presence or a special instance of proto Self-presence. The first case cannot be true because there are instances of proto Self-presence that involve no body ownership. Tools, for example, are also integrated into the body schema during use [24], and proto Self-presence should thus also occur when using virtual tools [32]. However, the use of virtual tools should incur no body ownership, since the tool is not of an anthropomorphic shape [38]. Although this is contested by some results [23], these cases are special and, generally, a non-anthropomorphic tool should not incur body ownership [6]. A virtual non-anthropomorphic tool instead of an anthropomorphic avatar should thus also be a valid scenario for having proto Self-presence but no body ownership. Thus if body ownership is not the same as proto Self-presence, the second case must be true: it is a special instance of proto Self-presence.

4 Conclusion

As we have seen, both Self-presence and body ownership are important concepts in VR and AR. They concern an individual's connection to their self-representation. The relation between these two concepts has been mentioned often, but it has never been made concrete. Research into both concepts usually completely ignores AR, for reasons that are not entirely sound. This presents us with an opportunity to investigate these concepts and their relation in an environment in which they are usually considered trivial.

It was argued that the reasoning behind Self-presence and body ownership being considered ignorable in AR research is flawed as there is the inevitable scenario of a real and a virtual body being visible at the same time. Such a scenario could be applied for a variety of purposes. Next, it was argued that body ownership is a lower level concept in relation to the higher level concept of Self-presence. To find where body ownership fits into Self-presence, a framework was found that subdivides Self-presence into three levels: proto, core and extended Self-presence. Using this subdivision, it was argued that body ownership most logically fits into proto Self-presence, the bodily level. Furthermore, it was argued that body ownership is not the same as proto Self-presence, but a special instance of it. Body ownership and Self-presence could play critical roles in the experience of a user in the aforementioned scenario, especially if body ownership is a special instance of Self-presence.

Based on these findings an experiment is designed to verify the validity of the aforementioned scenario and to prove that body ownership is a special instance of proto Self-presence. In the following chapter, Chapter II, a research proposal is formulated to investigate the possible levels of Self-presence and body ownership's overarching concept of the Sense of Embodiment in an AR scenario and to test the hypothesized relation between Self-presence and body ownership in this scenario. In the subsequent chapter, Chapter III, two implementations of the AR systems and environments designed and applied for this experiment are described in detail, including their limitations. Following this, in Chapter IV, a scientific paper is presented, which details the most important findings of the executed experiment.

Chapter II

Research Proposal

1 Topic

Presence is generally defined as *the perceptual illusion of non-mediation* [21]. Self-presence, a subtype of presence [14, 3], is defined as *the extent to which the self is relevant during (and only during) media use* [32]. Presence is important in Virtual Reality (VR) research because it concerns the experienced authenticity of the environment. Furthermore, it was shown that presence can raise the enjoyment in entertainment media [37] and Self-presence can promote exercise in exercise games [36]. A concept suggested to be related is embodiment. The Sense of Embodiment (SoE) is said to occur when a body's properties are processed as if they were the properties of one's own biological body [18]. This concept consists of three sub-classes: a sense of body ownership, a sense of agency and a sense of self-location. SoE toward a body occurs if and only if one experiences at least one of the three senses at least in a minimal intensity. Full SoE toward a body requires one to experiences all of the three senses at the maximum intensity. As observed in the Chapter I, the concepts of presence and SoE are often speculated to be related. In particular, the SoE's sub-class body ownership is mentioned in literature to be a part of the higher level concept of Self-presence. Body ownership refers to one's self-attribution of a body [7, 18]. Traditionally, this concept was researched using only a hand [16]. It has, however, been shown that it can be applied to an entire body [35, 25]. Self-presence and embodiment should be important in Augmented Reality (AR). They are, however, routinely ignored in AR because they are considered trivial. The reasoning behind this is flawed, as will be explained in the next section. The topic of this research will be to study Self-presence and the SoE, and their relation to each other, in an AR environment.

2 Problem

Both the concept of Self-presence and embodiment have been researched thoroughly in VR, however their relation to each other is only assumed, and little is known about their actual relation. Looking at a conceptual framework for Self-presence, which subdivides Self-presence into three interrelated levels, as theorized and tested in [31, 32], we see that body ownership would fit into the lowest (proto) level of Self-presence. Proto Self-presence is defined as *the extent to which a mediated self-representation is integrated into body schema*, and body ownership *is* the integration of a faux body part into the body schema. We see that they refer to literature on body ownership illusions as cases of proto Self-presence and even use these in their questionnaire development. However, proto Self-presence is not the same as body ownership because there are cases in which proto Self-presence occurs but not body ownership.

As mentioned before, in AR research embodiment and Self-presence are often considered trivial, as they are believed to be an integral part of the real component of an AR environment [10]. This, however, is not necessarily the case, as this logic does not take into consideration that additions can be made to the real body in AR. There are multiple inevitable scenarios wherein the real body will be visible and a virtual avatar or extra virtual body parts will be shown as well. In these scenarios, Self-presence and the SoE is likely to be induced for the virtual avatar or virtual body parts if the correct stimuli are used. This presents an opportunity to investigate these two concepts and their relation to each other in AR.

3 Purpose

The purpose of this research is to investigate the possible levels of Self-presence and the SoE in AR and the relation between Self-presence and the SoE's sub-class body ownership. We hypothesize that body ownership can be fit into the framework of Self-presence as described in [32] as a special instance of proto Self-presence. We expect that by proving this we will confirm that the methods used to induce body ownership are also valid to induce a high level of Self-presence. We want to investigate this in AR specifically to prove that Self-presence can actually occur in an AR environment, which would also mean that some possible benefits of Self-presence could be translated into future AR applications.

4 Research Questions

Our main research interests are to verify the validity of Self-presence and the SoE in AR and to specify the relation between Self-presence and the SoE. To do this, we will be investigating the following research questions:

- Can some level of the Sense of Embodiment and Self-presence be induced for a virtual body while the real body is also visible in an AR environment?
- When both the real body and a virtual body are visible in an AR environment, is body ownership a special instance of proto Self-presence?

5 Objective & Hypotheses

We will test a variant of the Body Transfer Illusion for a disconnected avatar outside of the peripersonal space in an AR environment. The following dependent variables will be measured:

- Sense of Embodiment
  - Body Ownership (measured by questionnaire and skin conductance response)
  - Agency (measured by questionnaire)
  - Self-Location (measured by questionnaire)
- (Proto) Self-presence (measured by questionnaire)

These will be evaluated with respect to the following alternated levels of the independent variables:

- Congruent/incongruent avatar movement (Congruent movement should produce Self-presence and body ownership, whereas incongruent movement should not produce either)
- Anthropomorphic/non-anthropomorphic avatar type (An anthropomorphic avatar should not hinder Self-presence or body ownership, whereas a non-anthropomorphic avatar should hinder body ownership but not Self-presence

We expect alternation of the independent variables will have the effect on the dependent variables as shown in Table II.1 We have formulated the following hypotheses based on the literature study and the expected results:

Table II.1: Expected effects of avatar anthropomorphism and movement congruency on body ownership and Self-presence

	Anthropomorphic		**Non-anthropomorphic**	
	Body Ownership	*Self-presence*	*Body Ownership*	*Self-presence*
Congruent	High	High	None	High
Incongruent	None	None	None	None

- Hypothesis 1 (H1): It is possible to induce the Sense of Embodiment over a disconnected virtual body in an AR environment, while the real body is visible, using congruent movements and an anthropomorphic body.
- Hypothesis 2 (H2): It is possible to induce Self-presence over a disconnected virtual body in an AR environment, while the real body is visible, using congruent movements.
- Hypothesis 3 (H3): Body ownership is a special instance of proto Self-presence.

Chapter III

Implementation and technical setup

1 Introduction

To execute the experiment proposed in the research proposal, we required an Augmented Reality (AR) environment to be implemented. In this environment, the participant had to be able to see the real world and the real body, but at the same time also an anthropomorphic or non-anthropomorphic virtual avatar displayed in front of them. Furthermore, they had to be able to control this avatar using their own direct bodily movements, in order to provide congruent movement control. Prerecorded movements also had to be made for the incongruent movement conditions. To implement this environment we designed two systems. The first system used a commercial optical see-through Head-Mounted Display (HMD), but the system was deemed unsuitable after a pilot experiment exposed the inherent limitations of the used HMD. Its implementation and system's design description is found in Section 2. Since the first system was not suitable for the experiment, a new system had to be constructed, one which did not have the same limitations. For this, a custom video see-through HMD was designed and built. The second setup's implementation and system's construction are described in Section 3.

2 First Setup - Optical See-through HMD

This section describes the first implementation of the AR environment, which made use of a commercial optical see-through HMD. This implementation presented a major issue, due to very limited FOV of current optical see-through AR technology, which caused it to be unusable for the experiment in this study.

2.1 Hardware

To simulate the AR environment we used a Meta 1 Developer Kit. The Meta 1 is a commercial HMD that provides an optical see-through AR experience. This HMD provides stereoscopic vision, has a resolution of 480x540 per eye, a 35° nominal FOV (using the expander lens), a Soft-Kinetic DepthSense time-of-flight depth camera with 320x240 depth resolution (10cm to 2m), and 360° head tracking. The screen size of the Meta 1 is very limited and as such the cause of this implementation not being suitable for our study. To record the movement of the participants we used a Kinect v2 for Windows. This package includes a special adapter which allows the Kinect to be used with a Windows computer. The Kinect provides relatively accurate motion tracking of a whole body up to a distance of 4.5 meters, using a 1080p color camera and a 512x424 resolution depth camera. A large physical marker was used to place the avatar in the world. The whole environment was run on a Lenovo Y-50 laptop in all preliminary tests.

2.2 Software

The AR environment was implemented in Unity 5.3, an engine for making 2D and 3D virtual environments and games. Microsoft Visual Studio 2013 was used for writing the C# scripts in the project. The Meta 1 was implemented using the Meta 1 SDK 1.3.4, and the accompanying package was imported into the Unity project. Marker tracking for the placement of the virtual avatar on the large marker in front of the user was implemented using the functions provided by the Meta 1 SDK. The model for the neutral anthropomorphic avatar was made and rigged using Makehuman 1.1.1, an open source tool for making 3D characters, see Figure III.1(a). The model was made with no discernible personal features such as gender, hair or clothes. The model for the non-anthropomorphic avatar was made and rigged using Blender 2.78c, an open source 3D creation suite, see Figure III.1(b). The model was made with blocks to look abstract and not have any human-like features. Initially, a male and a female human model were made but after discussion, these were deemed inappropriate for our research, due to the influence that personal features might have on the participant's experience, see Figure III.1(c), III.1(d).

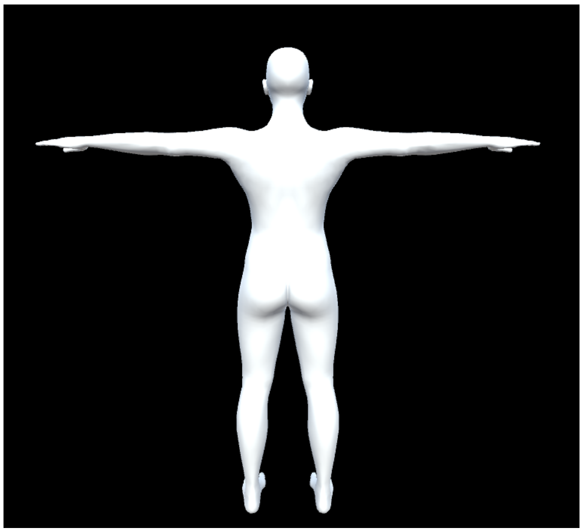
Movement capture using the Kinect v2 was initially implemented using the standard Unity asset package made by Microsoft. This implementation was successfully tested using a virtually drawn skeleton that followed the user's movements. Multiple attempts, however, were made at implementing the same movement control over the virtual avatar models, using the standard package, but these implementation attempts were unsuccessful. Finally, movement recording using the Kinect v2 was successfully implemented using a unity asset package called Kinect v2 with MS-SDK, made by Rumen Filkov [9]. This package used the Kinect for Windows SDK 2.0 instead of the standard Microsoft Unity asset package. The Kinect v2 with MS-SDK package was received free of cost from the author with the consent to use it in this academic project, on the condition that the package not be shared with third parties in its source form unless express permission was given by him. The author did not consider Utrecht University a third party and allowed the package to be shared with the University accompanied with the same license terms.

The avatar controller in the Kinect v2 with MS SDK package included two versions, one which controlled a whole virtual model and one which controlled only specifically assigned joints of the model. The latter one was chosen and implemented in this environment assigning only parts of the upper body of the model because the experiment in the current thesis project was designed so that the participant would only move their arms and not their lower body. The various skeleton rigs available in Makehuman were tested in the AR environment using the implemented movement control. They all provided the same visual results, thus the skeleton that was optimized for motion capture data was chosen to be used for the avatar.

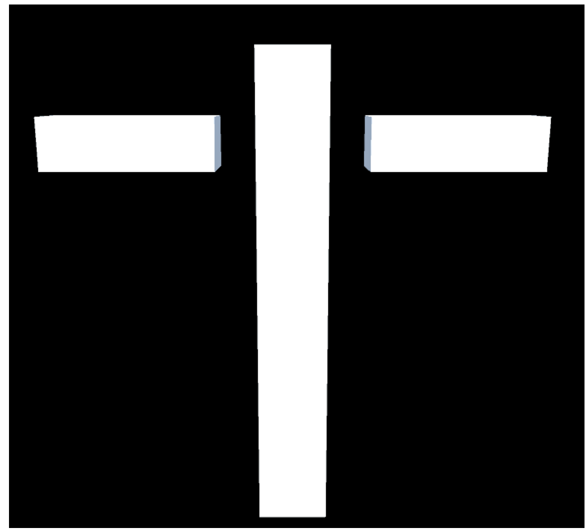
2.3 Limitations

The most unfavorable limitation encountered was the limited screen size of the Meta 1, which caused parts of the virtual avatar to be cut off. This limitation was unearthed during preliminary testing of the experiment environment, in which the placement and movement control of the avatar was tested. This limitation was most obvious in the initial experiment design in which the avatar was placed on a marker at a distance of 2.5 meters from the user. In this initial design, only the torso and head of the avatar are visible, as can be seen in Figure III.2(a). Further testing showed that even at a distance of 4 meters from the user the avatar was still cut off at the knees, see Figure III.2(b). Seeing as our study is on a whole virtual body seen in conjunction with the real body, this made the Meta 1 HMD and this implementation of the environment unsuitable for our research.

Several smaller problems appeared during the implementation. First, the implementation of the Kinect v2 using the standard unity package proved to be more complex than anticipated. The joint positions supplied by the Kinect were easily mapped, the joint rotations, however, were not. Multiple approaches were attempted to translate the supplied joint rotations to usable joint rotations for the virtual model in Unity, but these were unsuccessful. To solve this issue we requested and received a Unity asset package made by Rumen Filkov. This Unity package included a Kinect v2 avatar controller which solved our problems as it provided a simplified API to map the captured movements directly to the virtual avatar model. The second



(a) Anthropomorphic Neutral Avatar (behind)

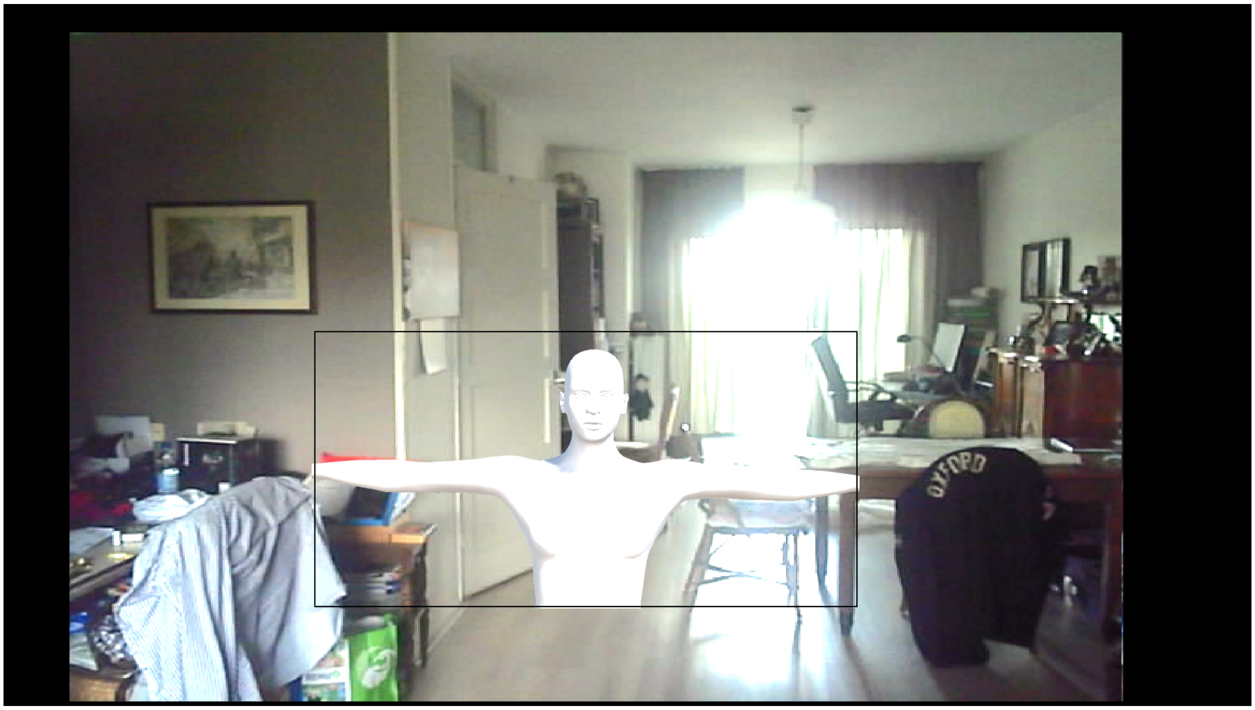


(b) Non-anthropomorphic Block Avatar (behind)

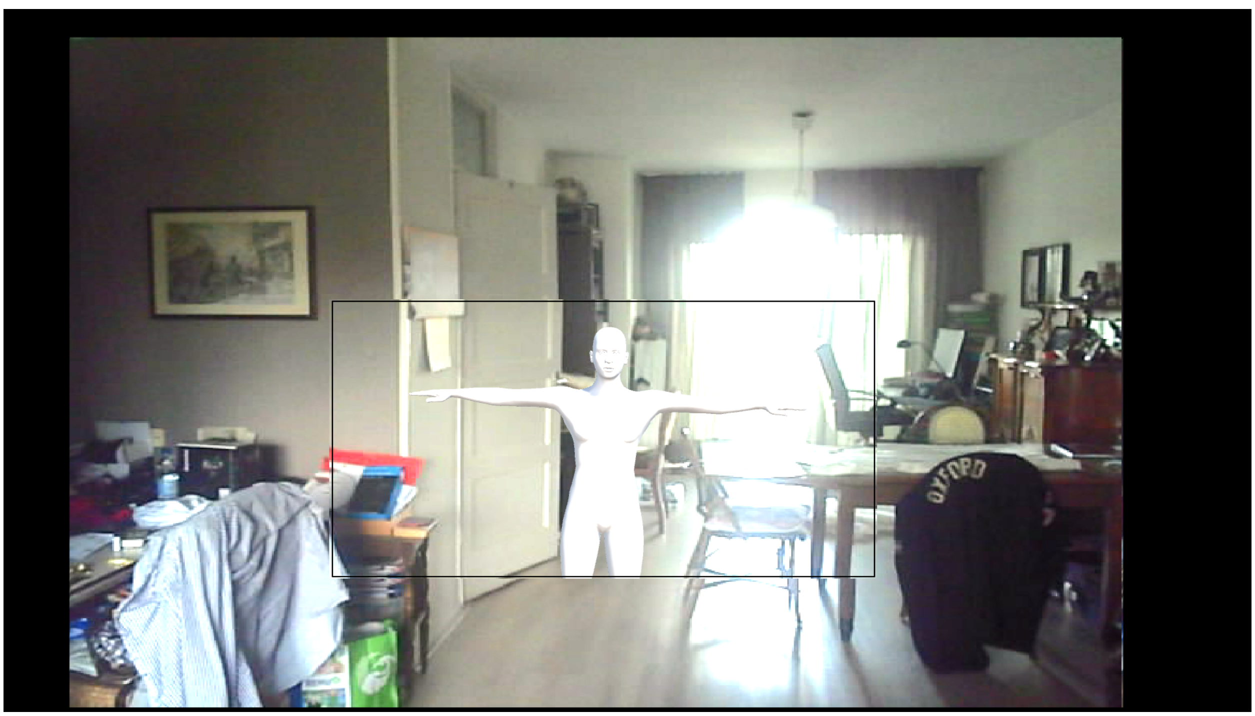
(c) Deprecated Male Avatar

(d) Deprecated Female Avatar

Figure III.1: The avatar models made during the experiment. The used avatars are shown in (a) & (b) as seen by the participant (from behind). The deprecated unused avatars are shown in (c) & (d)



(a) Avatar at 2.5 meters distant



(b) Avatar at 4.0 meters distant

Figure III.2: Screen cut-out as seen through the Meta HMD showing the portion of the avatar that is visible while viewing the AR environment.

issue we ran into was the limited visibility of the marker lying on the ground at 2.5 meters away causing it to not being recognized properly. This issue was solved by using a marker three times the size of the original. This larger marker, in turn, caused some issues in Unity. These were fixed by setting the new size of the marker and rescaling the avatar that was to be placed, to 1/3rd its size.

Finally, a limitation of the Kinect v2 tracking was discovered because irrespective of device settings the hand rotation and finger orientation tracking was inaccurate and jittery. To avoid this limitation during the experiment the hand rotation and finger orientation tracking was completely disabled and the participant was instructed not to rotate their hands or make a fist.

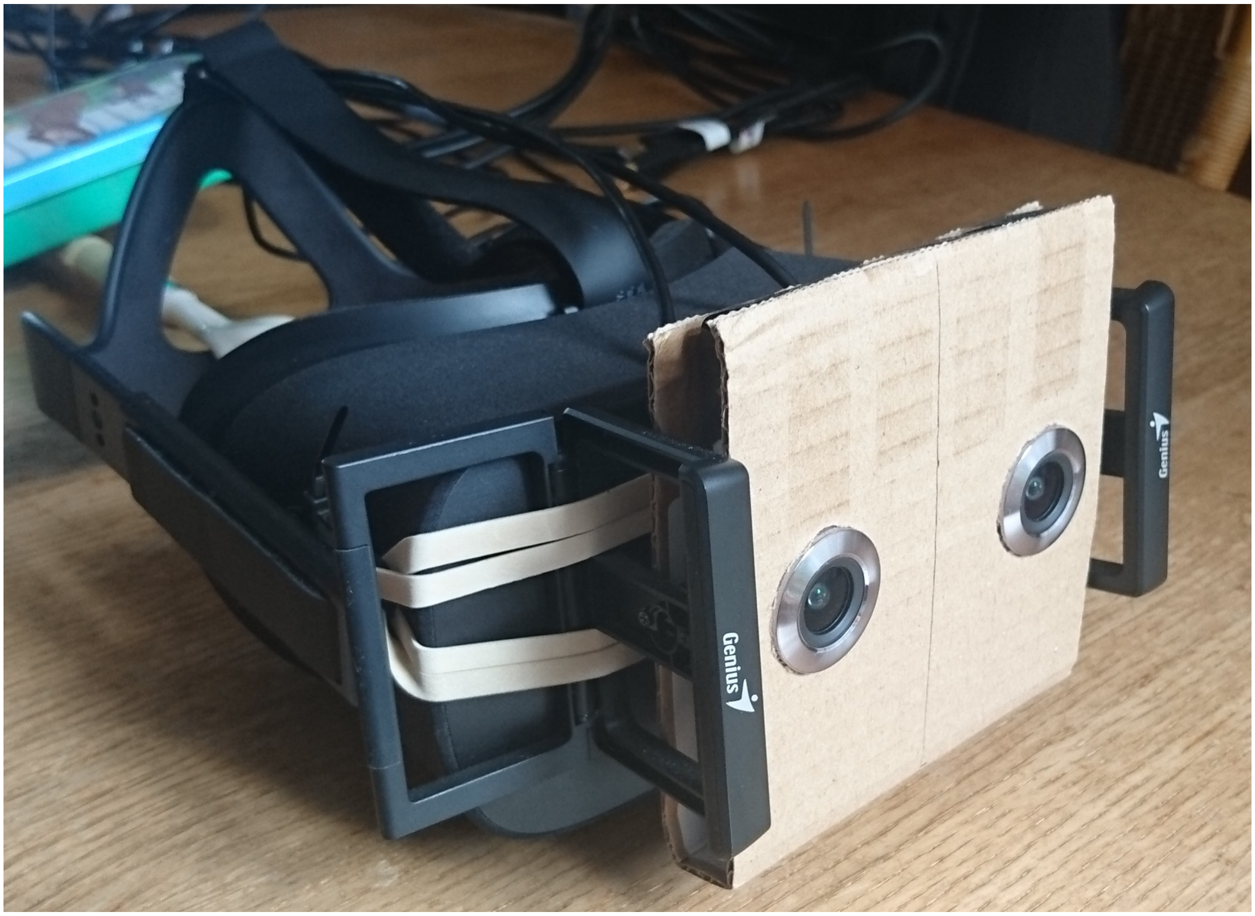
3 Second Setup - Video See-through HMD

This section describes the second setup. In the second setup we implemented an AR environment which was similar to the first environment, however, this implementation made use of a custom built video see-through HMD instead of the commercial optical see-through one. This was done to avoid the limitations that arose during the previous implementation, due to the very limited screen size of the optical see-through HMD.

3.1 Hardware

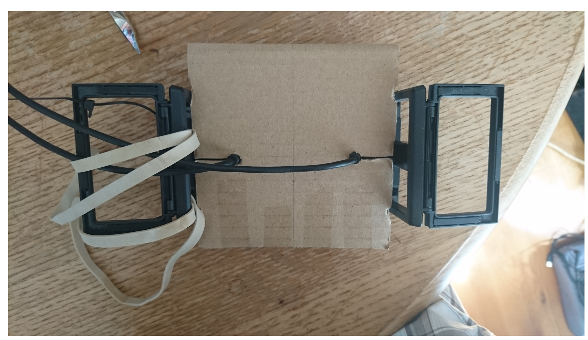
To simulate the AR environment an Oculus Rift CV1 was modified using two cameras mounted on the front of the device to provide video see-through, see Figure III.3(a). The Oculus Rift CV1 has a resolution of 1200x1080 per eye, a refresh rate of 90Hz, a 110 degrees field of view (nominal), and 6 DOF 360° head tracking. For the front-mounted cameras two Genius WideCam F100 Full HD cameras were used, because these cameras were the only commercially available cameras that contained wide 120° angle lenses. These lenses were necessary to match the field of view of the Oculus (110° nominal) as much as possible. The Genius WideCam F100 cameras provide 1080p video feed, but they ran at a resolution of 640x480 to ensure a frame rate of 30 frames per second. These webcameras have been used before in similar AR Oculus Rift projects [8]. To create the front-mounted stereo camera construct, the two webcameras were combined using a piece of cardboard and tape, this ensured the cameras would face the same direction and would stay in the same relative position to each other with a distance of 63mm between them (the average interpupillary distance), see Figure III.3(a)&(b). This contraption was then mounted onto the front of the Oculus Rift using elastic bands which were attached to the sides of the Rift and the standards of the webcams, see Figure III.3. Using this contraption kept the stereo camera securely in place and attached to the front of the Oculus Rift, but gave the option to set the location of the stereo camera.

Similar to the first implementation, the Kinect v2 for Windows was again used for capturing the movements of the participants. In this implementation, the Kinect v2 was mounted on a camera tripod placed in front of the participant at a distance of 3 meters. To place the avatar in the physical environment a large physical ArUco marker was used as an anchor. The marker was placed on the ground in front of the participant at a distance of 2 meters. To record the participant's skin conductance responses (SCR) during the experiment, a high-resolution biosignal acquisition system, the Biosemi ActiveTwo, was used. For a photograph of the experiment room set-up with the participant attached to the ActiveTwo and Kinect and marker placed see Figure III.4(a). The GSR sensors consist of 2 passive Nihon Kohden electrodes to induce an oscillator signal synchronized with the sample-rate. The sensors were applied on the index and middle finger of the left hand, and two reference electrodes were applied to the palm of the left hand, see Figure III.4(b). The instruction manual advised placing the reference electrodes on the back of the hand but preliminary tests using this method consistently showed no signal. A saline conductive paste was applied to each electrode, to improve the signal-to-noise ratio. The GSR data was recorded on a second dedicated computer through optic connection with a sample rate of 2048Hz, and the data was resampled offline at 32Hz. This second computer was connected to the main experiment computer using a parallel port.



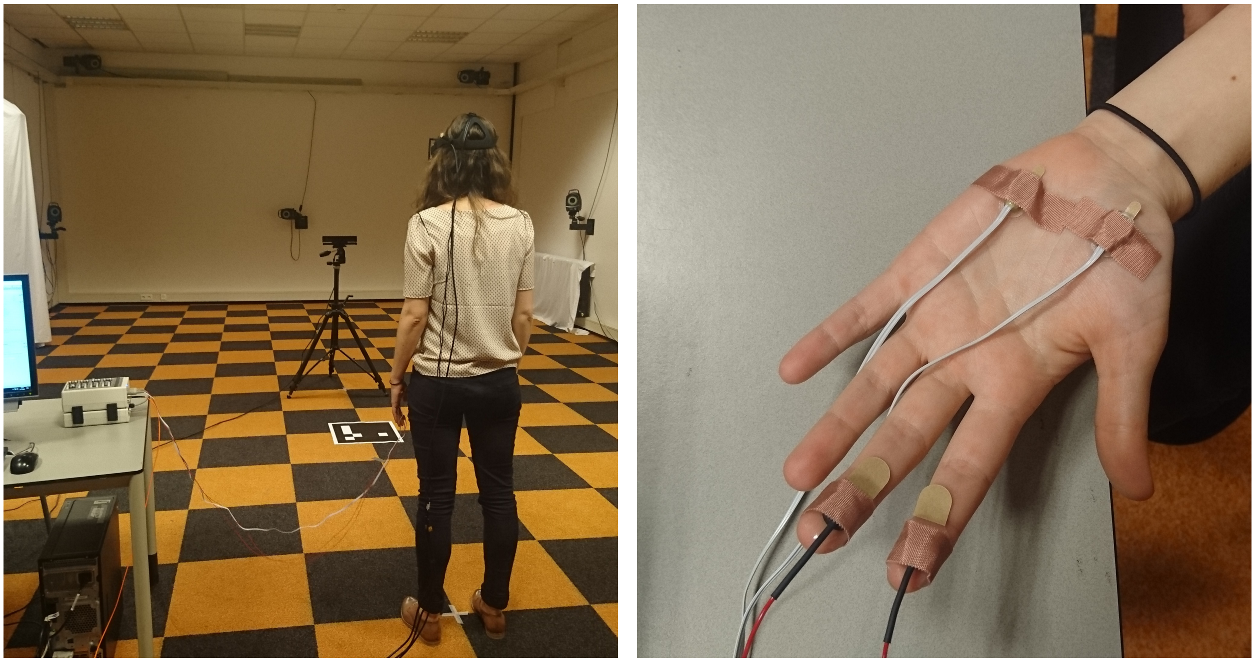
(a) The custom AR Oculus Rift

(b) Front of webcam mount construct



(c) Back of webcam mount construct

Figure III.3: Custom built Augmented Reality video see-through system in the form of an Oculus Rift with two front mounted webcams



(a) Hardware configuration in room (b) Electrode configuration on hand

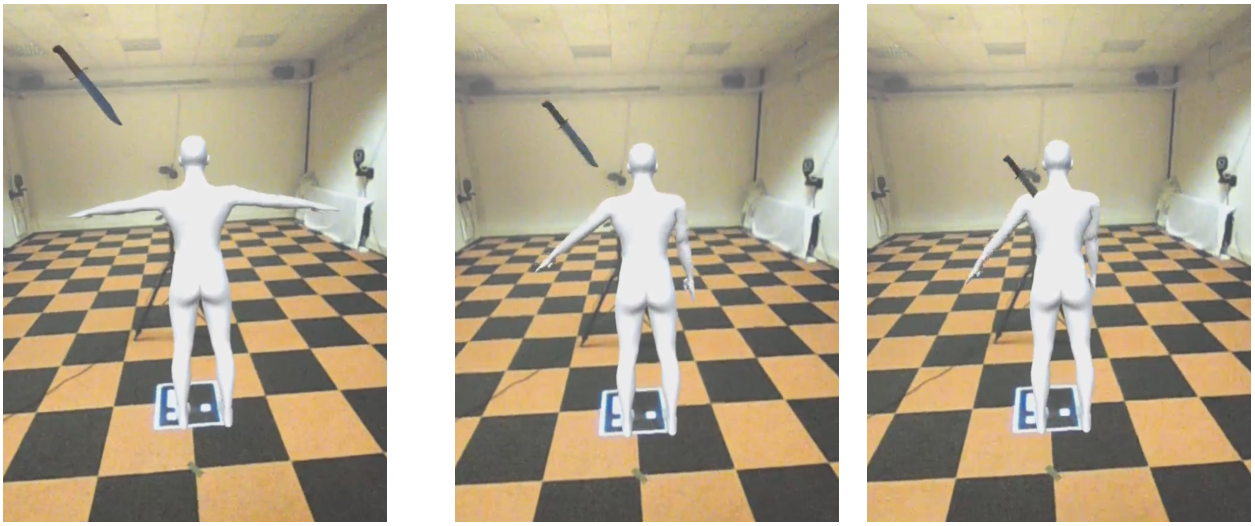
Figure III.4: Photographs of the experiment equipment set-up used in the second implementation.

3.2 Software

The entire AR environment was implemented in Unity 5.6.2. To implement the Oculus Rift's stereoscopic 3D virtual environment, the Oculus Rift SDK for Unity was used. All C# scripts for this implementation were written using Microsoft Visual Studio 2017. To display the feeds from the two front mounted webcameras in Unity the built-in WebCamTexture was used. This allowed the feeds from the webcameras to be displayed on quads in the virtual environment. The quad with the feed of each physical eye camera was attached to its corresponding virtual eye camera, placed just in front of the maximum viewing distance of this virtual camera and automatically resized to fill the screen of the virtual eye camera. This ensured the feeds from the cameras would always be displayed as the backgrounds of the corresponding eye screens of the Oculus Rifts. The 3D virtual objects were displayed over these background images using a third virtual camera which viewed only virtual objects. These virtual objects were anchored in the physical world using the large ArUco marker.

The marker detection was implemented using the asset package Open CV for Unity and its accompanying package MarkerBased AR Examples, acquired from the Unity asset store. Marker detection was run on both stereo camera feeds and the marker's location and orientation in respect to the user were estimated based on both image feeds. When the marker was visible on both camera feeds the estimation of the marker's location was done by averaging both detected locations and the estimation of the orientation was done by spherical linear interpolation between the two detected orientations. When the marker was visible on only one of the two camera feeds that feed's detected location and orientation were used. To prevent constant updating of both location and orientation, which caused severe jittery behavior, a minimum distance in detected location between the last location update and the current detected value was implemented.

Movement capture was again implemented using the Kinect for Windows SDK v2.0 in conjunction with the Kinect v2 for MS SDK Examples unity asset store package. As mentioned before, this unity package was received free of cost from its developer, Rumen Filkov. The package's avatar controller with specifically assigned model joints was used to map the movements of the participant's arms directly to the movements



(a) Static Phase (b) Dynamic Phase

Figure III.5: View of the knife threat as seen by the participant during the experiment. In (a) the knife as it appeared statically is shown. In (b) the knife in its stabbing motion is shown.

of the virtual avatar's arms. Using the same avatar controller a movement recording and playback system was implemented to provide the movements for the incongruent movement conditions. For these incongruent conditions, a set of movements were prerecorded in segments of 15 seconds and the playback system was implemented to play the entire set of segments in a predefined randomized order. This ensured that the participants experienced the same incongruent movements but never in the same order.

An experiment flow manager was programmed that allowed for timers to be easily customized in the Unity editor window. The experiment flow manager was responsible for keeping track of all the avatars and starting and stopping conditions and their accompanying scripts. The implemented timers were used to set the condition timing, the knife threatening event start and stop time and the GSR recording start and stop time. The recording of the participants GSR data was done using the ActiView program provided by Biosemi as part of the toolset that accompanies the Biosemi ActiveTwo. The ActiView program ran on a second dedicated computer and required interaction with the main experiment environment through a parallel port. For this, an open source Windows DLL and Driver InpOut32, was implemented into the Unity project to send the designated GSR recording start and stop signals.

The avatar models were the same models as the ones used in the first implementation. The anthropomorphic model was generated with the help of MakeHuman 1.1.1, the non-anthropomorphic model was custom made and rigged in Blender 2.78c. For more information on the implementation of the avatar models and visual representations see Section 2.2 and Figure III.1(a), III.1(b). The knife model was taken from a free package on the Unity asset store called HQ Bowie Knife, see Figure III.5(a). A simple stabbing motion animation for the knife was created using Unity's built-in animation tool and scripted to start the motion a predetermined amount of seconds after the knife appeared in view, see Figure III.5(b)

3.3 Limitations

The used Widecam F100 webcameras had a high trade-off between frame rate and resolution, resulting in both a sub-optimal frame rate and resolution. It is possible that this was the cause for the discomfort of the participants, and could thus also have influenced the investigated experiences to some extent.

Figure III.6: Custom Built AR Oculus Rift with OVR Vision Pro stereo camera mounted on front

4 Future Setups - Possible Upgrades

In future custom video see-through setups, to eliminate the limitations brought on by the use of the two Widecam F100 webcameras, a high-tech stereo camera should be used instead; such as the OVR Vision Pro AR Stereo Camera. This stereo camera is specifically designed to be used in converting VR HMDs into video see-through AR HMDs. The OVR Vision Pro provides a per eye resolution of 960x950 at 60 frames per second, which is substantially faster and higher than the currently used webcameras. This stereo camera is equipped with a USB3.0 connection and 115° horizontal 105° vertical lenses. Furthermore, it is accompanied by custom SDKs for a wide variety of platforms and native support for various features such as marker detection and hand tracking. Unfortunately, the delivery time on one of these stereo cameras is long and so they could not be acquired in time for the experiment performed in this thesis project. However, we did order them and received them post-experiment. Testing of the custom AR Rift system with the stereo camera shows a noticeable increase in frame rate and resolution with respect to the implementation and technical setup described in Section 3. For a photo of the AR Oculus Rift system with the OVR Vision Pro mounted on front see Figure III.6.

Chapter IV

Scientific Paper

This chapter contains the scientific paper that was written as the main result of this research project.

Self-presence and Sense of Embodiment in Augmented Reality

Jean-Paul van Bommel
Utrecht University
Department of Information and Computing Sciences
Utrecht, The Netherlands

September 15, 2017

ABSTRACT

Two concepts essential to our experience of our self and our virtual self-representations in immersive virtual environments are the concepts of Self-Presence (SP) and the Sense of Embodiment (SoE). A lot of research has been done on these concepts in Virtual Reality (VR), but little is known about them in AR because they are often considered ignorable. Also, a relation between SoE and Self-presence has often been speculated upon but no empirical proof for this relationship has been given. We investigate Self-presence and SoE in an AR scenario in which both the real body and a virtual body are visible, where congruency of the virtual body's movements and the anthropomorphism of the virtual body were alternated to study their effects. We found significant effects of movement congruency for the skin conductivity responses and most of the SoE and Self-presence questionnaire results, as well as a strong correlation between subjective body ownership and Self-presence. We conclude that the SoE was induced for the virtual body and we argue that some measure of Self-presence occurred. This means that Self-presence and the SoE can no longer be ignored in AR and some of their benefits in VR could be translated to AR. We also conclude that a positive relationship exists between Self-presence and body ownership, which means that methods used to increase one could also be used to increase the other, and research on either concept should consider the other.

1 INTRODUCTION

In today's world Virtual Reality (VR) and Augmented Reality (AR) environments are becoming increasingly commonplace. To interact with these environments we require some form of representation of our self within them. How we relate to our virtual self-representations is an important topic for investigation because as our conduits into the environment these representations can have a strong influence on our experience of the environment. Two concepts generally used to describe how we use and perceive our virtual self-representations in immersive virtual environments are the concepts of Self-presence and the Sense of Embodiment (SoE). The SoE toward a body is the sense that emerges when that body's properties are processed as if they were the properties of one's own biological body [21]. Self-presence concerns our connection to a virtual self-representation or avatar and can be defined as the psychological state in which virtual selves are experienced as the actual self [23]. Self-presence is one of the three subtypes of presence, the other two being physical and social presence [3, 23]. These, however, are outside of the scope of this paper, because there are to date no indications in the literature for a relation between these and the SoE.

A fair amount of research has been done on both concepts in VR environments, but little is known about these concepts in AR environments. The probable reason for this is the fact that the real body is usually visible in AR, whereas in VR the real body is hidden or virtually represented. The SoE and Self-presence (with respect to the real body) are considered inherent and therefore ignorable [13]. However, this logic is flawed as it does not take into consideration scenarios in which both a real body and a virtual self-representation are used. An AR scenario in which a real body and a virtual self-representation are visible simultaneously is relevant because it has a variety of possible uses. A general use for such a scenario is the interaction with out of reach virtual objects. Another more specific use such a scenario is physical exercise programs also known as exergames which are popular and effective exercise tools that use real body's movements, often in combination with a virtual self-representation [44]. Showing that both the SoE and Self-presence are inducible for a virtual avatar in AR is important because it means that they should no longer be ignored in AR research. Furthermore, high levels of Self-presence could have a variety of benefits for such AR applications, as they have been shown to raise the enjoyment of the user and the perceived exercise achievement [45, 43].

A direct relation between Self-presence and the SoE, in particular, its subclass body ownership, has been suggested often in literature [16, 37, 21, 20]. The SoE consists of three subclasses: a sense of body ownership, a sense of agency and a sense of self-location [21, 26]. Body ownership refers to one's self-attribution of a body. This concept was researched using the Rubber Hand Illusion, and it has similarly been studied in virtual environments. The existence of a direct relation between Self-presence and body ownership seems likely when considering the definitions and instances of both concepts. The empirical confirmation of a positive relation between the two concepts is important because it means that methods used to increase one of the two would also increase the other, which would yield its possible benefits if applicable as well.

The aim of this study is to investigate the possible levels of the SoE and Self-presence in an AR environment and to empirically prove the existence of the relation between body ownership and Self-presence. In particular, these concepts will be investigated in an AR environment in which the real body and a disconnected virtual body are visible simultaneously.

The remainder of this paper is organized as follows. In Section 2, more background information is provided on Self-presence and body ownership over a disconnected avatar and the relationship between these two concepts. The study's methodology is detailed in Section 3. Next, in Section 4 the results of the experiment are explicated. In Section 5, these results, any implications, and the limitations of the study are discussed. Lastly, we will conclude this work and look at possible future work in Section 6.

2 RELATED WORK

2.1 Disconnected Virtual Bodies

To make an assumption on whether Self-presence and embodiment for a disconnected virtual body can be felt while the real body is visible in an AR environment, we will discuss research on similar scenarios in other environments. In the literature on Self-presence, it has been shown many times that it can be experienced for a disconnected avatar displayed on a computer screen, while the real body is also visible. In [43], participants indicated in a questionnaire to have experienced Self-presence over a disconnected virtual avatar during a boxing video game on the Nintendo Wii, controlled using congruent player arm movements. Similarly, in [17], participants experienced Self-presence over a disconnected virtual avatar in the Wii Fitness environment, which again used congruent user movements to control the avatar. Self-presence has been shown to even occur for a user controlled avatar in an online social virtual world [2].

According to [21], the SoE over a virtual body is said to be felt when at least one of its subclasses is experienced for that body at least in a minimal intensity. Research on body ownership over a disconnected virtual avatar is limited. In one of the few studies that included a visible real body [27], a disconnected mirrored virtual avatar was shown on a large screen in front of the participant. Participants indicated in a questionnaire that body ownership over this disconnected mirrored virtual avatar occurred using direct congruent body movement control of the avatar. In a similar experiment in VR that did not include a visible real body [24], the authors experimented with a virtual avatar that was placed in front of the participant facing away. The authors found that body ownership could be induced for the disconnected virtual body by using synchronous visual-tactile stimuli and an anthropomorphic body, however, they also found that the illusion was broken when a non-anthropomorphic body was used. Similarly, in [14], the authors found that congruent active movements of the avatar could be used to induce ownership over a mirrored disconnected virtual anthropomorphic body, however, incongruent movements of the avatar were shown to break the illusion.

Agency refers to having the sense of being the author of your actions. A sense of agency is said to occur when the predicted consequences of an action and the actual consequences of an action are perceived as being congruent [7], an example of this would be congruent visual-motor stimuli during active movements. Self-location refers to the sense that one feels self-located inside a body. A sense of self-location is usually experienced as located in the physical body, however, this sense of where the self is located can be shifted to a body seen from a third person perspective by inducing an out-of-body experience [10].

Based on these studies the following hypotheses were formulated:

- **Hypothesis 1 (H1)**: It is possible to induce the Sense of Embodiment over a disconnected virtual body in an AR environment, while the real body is visible, using congruent movements and an anthropomorphic body.

- **Hypothesis 2 (H2)**: It is possible to induce Self-presence over a disconnected virtual body in an AR environment, while the real body is visible, using congruent movements.

2.2 Self-presence and Embodiment

While often mentioned together the relationship between Self-presence and body ownership has so far not been concretized. It is, however, often mentioned that Self-presence is a higher level concept in relation to body ownership [16, 37, 21, 20]. Self-presence itself has often been interpreted in a variety of ways, some in a more physical sense [17, 2], others more in the sense of identity [40]. In this study, it was chosen to interpret Self-presence at the bodily level, namely in the form of proto Self-presence, as explained by Ratan et al. [37]. This bodily level of Self-presence would relate most directly to body ownership since it concerns the integration of a virtual object into the body schema, and body ownership *is* the integration of a faux body part into the body schema.

However, body ownership is not necessarily the same as proto Self-presence, since proto Self-presence also occurs when objects other than body parts are integrated into the body schema, a lot of which should not incur any body ownership. Tools, for example, should not incur any body ownership during their use [47], while they are integrated into the body schema during use [31], and proto Self-presence should also occur when using virtual tools [39]. This again indicates that using both an anthropomorphic body and a non-anthropomorphic tool body should be a valid method of modulating the strength of body ownership during the experiment.

Based on these studies and expected results the following hypothesis was formulated:

- **Hypothesis 3 (H3)**: Body ownership is a special instance of proto Self-presence.

This hypothesis will be confirmed when the results show that in the anthropomorphic avatar cases participants that exhibit a strong sense of body ownership also exhibit a strong sense of Self-presence, but in the non-anthropomorphic cases they exhibit a weak sense of body ownership while still exhibiting a strong sense of Self-presence and that in no cases they exhibit a weak sense of Self-presence while exhibiting a strong sense of body ownership. The expected effects of avatar anthropomorphism and movement congruency on body ownership and Self-presence based on the mentioned studies are shown Table 1.

The relation between Self-presence and the other two subclasses of the SoE is not mentioned directly, but since Self-presence is said to be related to the overal concept of the SoE [21, 20], some relation between the concepts is likely to exist. Since we expect the relation of Self-presence and body ownership to be very strong it is possible Self-presence relations to the other two subclasses are because of SoE interrelations. In [21], a short summary is made of the currently found interrelations of the subclasses of the SoE which states that there are mixed results for both the relation of body ownership and self-location and body ownership and agency. However, the relation between agency and self-location is suggested to be weak to none existent based on the fact that agency is independent of the egocentric visuospatial perspective as found in [8].

3 METHODS

3.1 Participants

34 participants performed the experiment, all between the ages of 21 and 29, with an average age of 23.9. 26 participants were male, 8 participants were female. 5 participants were left-handed, 27 right-handed, and two had no hand preference (mixed-handed/ambidextrous). Due to the simplicity of the tasks involved, we do not expect these differences to have any effect. Most had little to no previous experience with AR, and none had previous experience with video see-through HMDs. The latter fact could have had an effect on the results, this is further discussed in Section 5. One participant had to stop the experiment unfinished, because of issues with the measuring equipment. His incomplete data was not considered for further analysis. Before the experiment, each participant was given an information letter explaining the experiment and a period of at least one week to reconsider participation. Each participant was also asked to sign an informed consent sheet. No participant received any form of monetary compensation for participating. Immediately after the experiment, and again approximately one week after the experiment the participant was asked several questions about their to ensure the experiment had no lasting effect. These questions were based on those from the ethics check performed by Kilteni et al. [22]. The medical ethical committee of the UMC Utrecht had no objection to the execution of this study.

3.2 Equipment

3.2.1 Hardware

The AR environment was displayed in video see-through style through a modified Oculus Rift CV1 VR HMD, see Figure 1. The CV1 has a resolution of 1200x1080 per eye, a refresh rate of 90Hz, and a 110 degrees field of view (nominal). To provide the stereoscopic vision of the real world, two Genius WideCam F100 Full HD cameras were mounted on the front of the HMD. These cameras have 120-degree wide angle lenses and ran at a resolution of 640x480 at 30 frames per second. A Microsoft Kinect v2 was used to capture the movements of participants in real-time for both the prerecorded movements of the virtual body and the online control of the virtual body during the experiment. This has a total system delay of approximately 80 milliseconds, which should be low enough to produce no unwanted effects on the tested concepts [42, 21]. To record the participant's skin conductance responses (SCR) during the experiment, a high-resolution biosignal acquisition system, the Biosemi ActiveTwo, and its accompanying tools were used. The GSR sensors consist of 2 passive Nihon Kohden electrodes to induce an oscillator signal synchronized with the sample-rate. The sensors were applied on the index and middle finger of the left hand, and two reference electrodes were applied to the palm of the left hand. A saline conductive paste was applied to each electrode, to improve the signal-to-noise ratio. Data was digitalized on a dedicated computer through optic connection with a sample rate of 2048Hz, and the data was resampled offline at 32Hz.

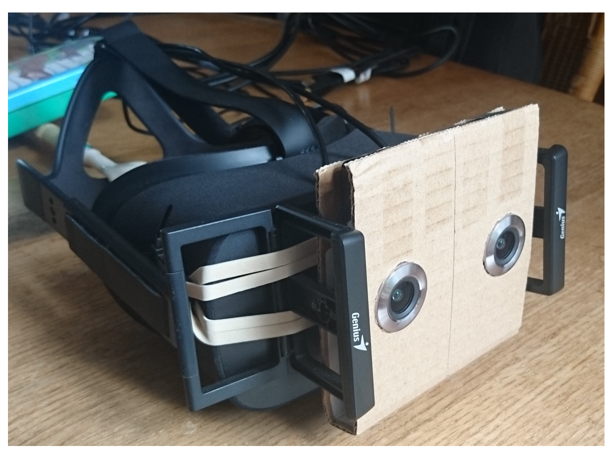


Figure 1: Custom built video see-through augmented reality glasses using an Oculus Rift and two Genius Widecam F100 Full HD cameras, flexibly mounted with elastic bands and cable ties.

Table 1: Expected effects of avatar anthropomorphism and movement congruency on body ownership and Self-presence

	Anthropomorphic		**Non-anthropomorphic**	
	Body Ownership	*Self-presence*	*Body Ownership*	*Self-presence*
Congruent	High	High	None	High
Incongruent	None	None	None	None

3.2.2 Software

The experiment environment was created in Unity 5.3.4, using the Kinect for Windows SDK, the Oculus Unity Utilities, and three assets from the unity asset store, OpenCV for Unity, Kinect v2 Examples with MS-SDK, and a knife model. The environment featured virtual objects displayed over the video feed taken from the two mounted cameras. Two virtual bodies were created using MakeHuman 1.1.1 and Blender 2.78c. All scripts used during the experiment were written in C# and C++ using Visual Studio 2017.

3.3 Design

In this study, a single-blind 2x2 within-subjects design was used. Participants underwent all 4 conditions, and the ordering of these conditions was (as far as possible) counterbalanced over the participants. The two factors alternated were, whether the movements of the virtual body were *congruent* or *incongruent* with the participants bodily movements, and whether the virtual body was *anthropomorphic* or *non-anthropomorphic*. Although synchronous visual-tactile stimuli are commonly used to induce body transfer illusions, there is not enough evidence supporting their effect on Self-presence and so they are not a reliable method to induce Self-presence. The anthropomorphic body was designed to look human, but to have as little identifying aspects as possible, such as gender, hair or skin color, see Figure 2(c). The non-anthropomorphic body was designed specifically to inhibit the feeling of body ownership. To achieve this an abstract construct of three blocks was used, as it has been shown in previous literature this significantly reduces one's felt ownership [48, 46], see Figure 2(d). A threat was included in the experiment in the form of a virtual knife, to induce a physiological reaction in the participant when the virtual body was threatened. During the experiment, the experimenters made sure that the participant's real arms were not always out of view, by following what the participant saw on a separate screen since the goal was to investigate a scenario in which both the real body and the virtual body were visible.

3.4 Procedure

At the start of the experiment, the participant was verbally given a summary of the information letter and was asked to fill in a questionnaire with general information. Before attaching the electrodes to the participant, they would first be asked to wash their hands. After these were attached, they were asked to stand on the cross in the middle of the room. A marker lay on the ground 2 meters in front of them and the Kinect was mounted on a camera stand 3 meters in front of them, see Figure 2(a). The participant's interpupillary distance was measured, correctly set on the HMD, and the participant was helped to put the HMD on.

For each condition, the participant started in a T-pose (arms outstretched), and after a verbal countdown, a life-sized virtual body appeared on the marker in front of them. This body would start moving immediately, using either the participant's own movements or prerecorded movements, and continue to do so until the end of the condition. After 3 minutes a virtual knife appeared to the upper left of the virtual body, see Figure 2(d). It would hang there for 5 seconds, and then make a stabbing motion toward the virtual body for 5 seconds, after which it would again disappear. This split into a static and a dynamic phase was chosen since pilot studies showed that having only a dynamic phase was too startling for the participant. After the knife disappeared the avatar would remain present for another 5 seconds, after which it would also disappear. The participant was then helped to remove the HMD, asked to fill in the questionnaire for the experienced condition and given a short break before continuing on to the next condition. The whole experiment lasted approximately one hour.

3.5 Measurements

3.5.1 Questionnaire

To measure the perceived levels of body ownership, Self-presence, agency and self-location, a 26 item questionnaire was used. This questionnaire was based on previously used questionnaires in embodiment research [5, 18, 19]. Four extra questions were added to this questionnaire to measure the subjective level of Self-presence, these questions were based on questionnaires used to measure the concept of proto Self-presence, as described by Ratan et al. [38, 49, 30]. One Self-presence question used in two of the three questionnaires in the referenced literature, namely *avatar was part of my body*, was already part of the body ownership questions and thus excluded from the Self-presence questions. All questions were answered on a Likert scale ranging from complete disagreement to complete agreement with the statement. The entire questionnaire was translated to Dutch, and only this translation was used during the experiment. Lastly, a final open question was added to allow the participant the chance of giving a comment on anything that was not covered by the questionnaire.

(a) Experimental setup, with participant placed on cross next to main experiment computer.

(b) Participant as seen from behind by experimenter.

(c) Anthropomorphic avatar as seen by participant.

(d) Non-anthropomorphic avatar as seen by participant including static knife.

Figure 2: Views of the experiment. Avatar appeared on marker placed 2 meters in front of participant. Kinect v2 was placed 3 meters in front of participant for movement recording. During congruent movement the avatar would perform the exact same movements as the participant and thus if the participant assumed a pose (b) so would the avatar (c)&(d).

3.5.2 Skin Conductance Response

To not only measure the presence of body ownership subjectively but also objectively, physiological measurements were included. The physiological measurement included in the study was the participant's skin conductance response (SCR) after exposing the virtual body to a knife threat event, as it has been shown in previous research this is a valid indicator of body ownership [1, 36, 15]. The SCR recording started 15 seconds before the knife appeared and stopped recording 5 seconds after the knife disappeared. Before any analysis was done the SCR data was first preprocessed. A Butterworth 2nd order low-pass filter was run over the raw data to smooth out the noise. The average over a 10-second pre knife window was taken as a baseline skin conductance level and the SCR was calculated by deducting this baseline from the highest peak found in a 10-second post knife appearance window [35, 12, 41]. After converting these values to microsiemens, all values below 0.03 microsiemens were considered zero responses. Participants exhibiting zero responses in 75% or more of the cases were marked as SCR non-responders and were excluded from further analysis (only one participant was marked a non-responder). Finally, to make them comparable to previous research, the filtered SCR values were transformed with log(value+1) [1, 6, 29].

4 RESULTS

Responses to all questionnaire items were treated as interval data, ranging from -3 to +3, to enable parametric analysis. The questionnaire responses and SCR were checked for normality with a Shapiro-Wilk test, and by visually inspecting the q-q plots. Shapiro-Wilk tests showed a non-normal distribution for all question cases (all $p < 0.02$) and all SCR cases (all $p < 0.038$), however after visual inspection of the q-q plots the data was determined approximately similarly distributed. Because ANOVAs are fairly robust against violations of normality it was decided to first analyze the data using ANOVAs, but to also include a non-parametric double check for significant results. Two-Way Repeated Measures MANOVAs, with within-subjects factors of *movement congruency* and *avatar anthropomorphism*, were run for each separate concept of body ownership, Self-presence, agency, and self-location, respectively. Visual representations were made in the form of box plots. Tukey post hoc pairwise comparisons were run for the significant effects, see Table 3. Finally, these results were double checked using non-parametric tests.

4.1 Ownership

The Two-Way Repeated Measures MANOVA on all the ownership questions and SCR data showed a significant main effect over movement congruency ($F(9,23)=9.122$, $p = 0.00001$) and a significant main effect over avatar anthropomorphism ($F(9,23)=2.592$, $p < 0.033$), but no significant interaction effect ($F(9,23)=1.216$, $p = 0.333$).

The univariate tests of the MANOVA showed significant main effects over movement congruency for all questions, see Table 2. Significant main effect over movement congruency also shown for SCR ($F(1,31)=10.093$, $p < 0.004$). Only the ANOVA on the control question *visually resembled* showed a significant main effect over avatar anthropomorphism ($F(1,31)=51.258$, $p < 0.0001$). Pairwise comparison for this question's anthropomorphic versus non-anthropomorphic found a mean difference of 1.266 ($p < 0.0001$). No other significant main effects or significant interaction effects were found for any of the questions. The ANOVA on the SCR data revealed a significant main effect over movement congruency ($F(1,31)=1.294$, $p < 0.0034$), but no significant main effect over avatar anthropomorphism and no significant interaction effect. For visual representations of the SCR and ownership question results, see Figure 3 and 4.

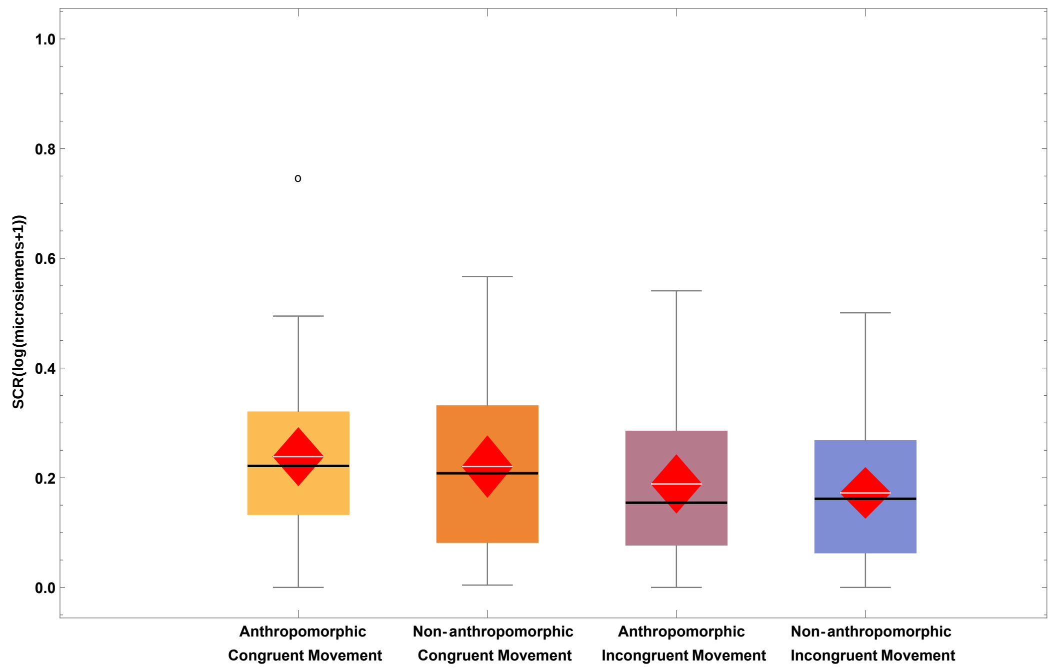


Figure 3: Skin Conductance Response Box Plots for all four conditions. Medians are indicated by black lines, means and 95% confidence intervals by red diamonds.

Table 2: Movement congruency main effects per question. The few significant Avatar Anthropomorphism main effects are given in text

Question	type	F(1,31)=	significance
It felt as if...	*Ownership*		
the virtual body was my own body	answer	21.235	$p < 0.0001$
I had two bodies	answer	16.216	$p < 0.00034$
the virtual body was a duplication of my own body	control	59.355	$p < 0.00001$
the virtual body belonged to someone else	inverse	48.261	$p < 0.00001$
the virtual body was a part of my body	answer	28.643	$p < 0.00001$
the virtual body was the reason I experienced certain sensations	answer	7.874	$p < 0.009$
the real body became digital	control	10.232	$p < 0.004$
the virtual body started to visually resemble the real body	control	17.916	$p < 0.0002$
It felt as if...	*Self-presence*		
the virtual was an extension of the real body	answer	52.448	$p < 0.00001$
I could reach through the avatar	answer	23.195	$p < 0.0004$
what happened to the virtual body, happened to the real body	answer	13.030	$p < 0.0011$
the real body and the virtual body were the same	answer	18.266	$p < 0.0002$
It felt as if...	*Agency*		
I had control over the virtual body	answer	181.549	$p < 0.00001$
I could move the virtual body, as if it obeyed my will	answer	260.255	$p < 0.00001$
the virtual body replicated the real body	answer	185.104	$p < 0.00001$
the virtual body had a will of its own	answer	312.086	$p < 0.00001$
the virtual body controlled my will	control	3.487	$p = 0.071$
It felt as if...	*Location*		
the virtual body was at two locations	answer	14.921	$p < 0.0006$
the real body was at the location of the virtual body	answer	5.382	$p < 0.028$
the virtual body was at the location of the real body	answer	4.394	$p < 0.045$
the sensations occurred at the location of the virtual body	answer	3.540	$p = 0.069$
the sensations occurred between the real and virtual body	answer	9.334	$p < 0.0046$
the real body drifted toward the virtual body	control	8.954	$p < 0.0054$
the virtual body drifted toward the real body	control	16.459	$p < 0.0004$
I could not be sure where my hand was	control	0.520	$p = 0.476$

Table 3: Pairwise comparison congruent vs incongruent movement for questions with significant main effect over movement congruency

Question	ownbody	twobodies	duplication	someoneelse	partofown	reasonsens	becamedig
Mean Diff.	1,188	1,469	2,313	-2,281	1,672	0,547	0,703
Signific.	$p < 0.0005$	$p < 0.0005$	$p < 0.0005$	$p < 0.0005$	$p < 0.0005$	$p < 0.01$	$p < 0.004$
Question	extensionreal	reachthrough	happenedtoreal	virtrealsame			visuallyres
Mean Diff.	2,438	1,641	0,781	1,266			0,922
Signific.	$p < 0.0005$	$p < 0.0005$	$p < 0.001$	$p < 0.0005$			$p < 0.0005$
Question	controlover	obeyed	replicatedreal	ownwill			SCR
Mean Diff.	3,703	4,109	3,766	-4,234			0,049
Signific.	$p < 0.0005$	$p < 0.0005$	$p < 0.0005$	$p < 0.0005$			$p < 0.004$
Question	twolocat	reallocvirt	virtlocreal	sensbetween	realdrift	virtdrift	
Mean Diff.	1,266	0,484	0,328	0,641	0,938	1,078	
Signific.	$p < 0.001$	$p < 0.03$	$p < 0.05$	$p < 0.005$	$p < 0.005$	$p < 0.0005$	

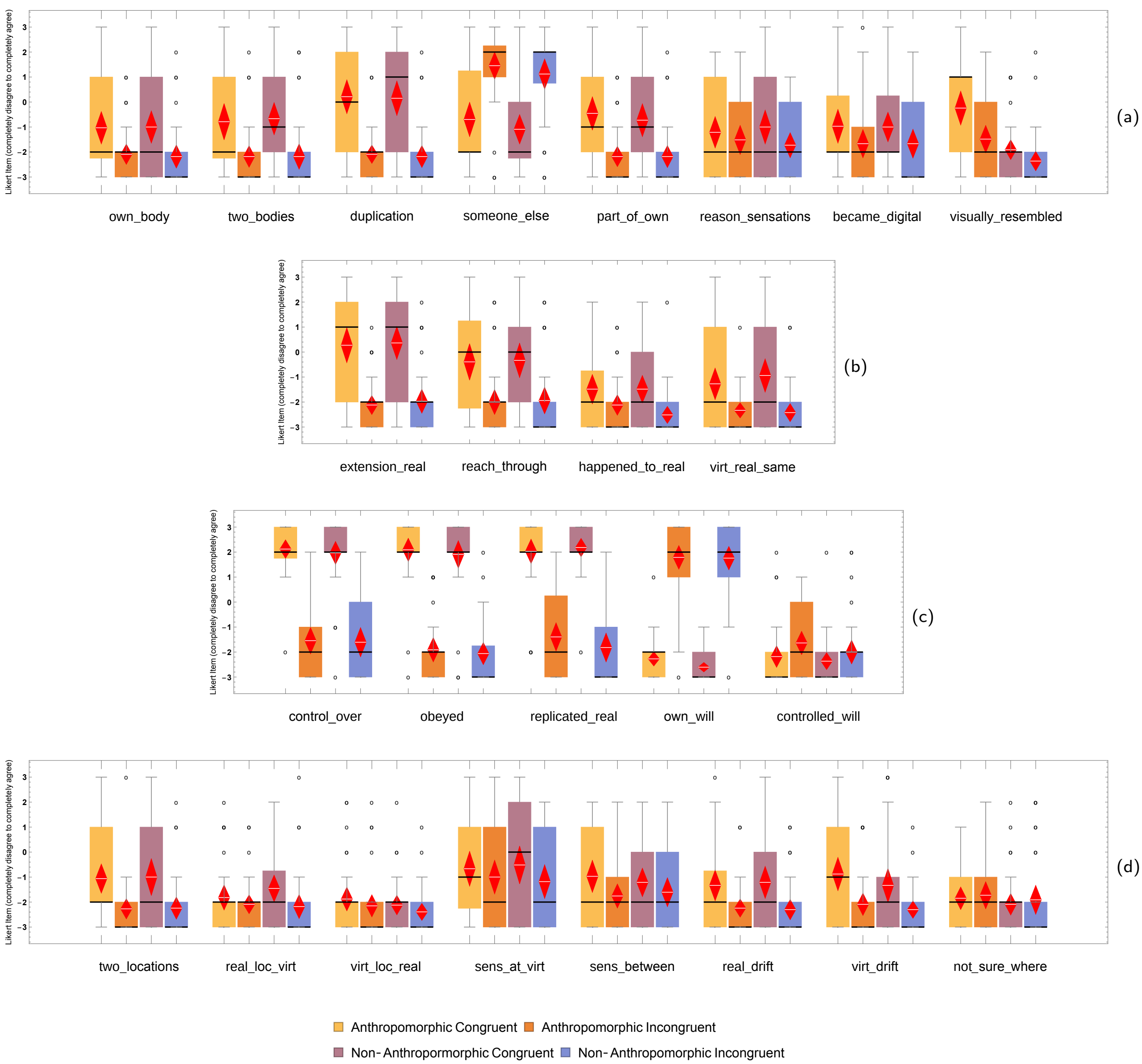


Figure 4: Boxplots of questionnaire responses for all four conditions. Medians are indicated by black lines, means and 95% confidence intervals by red diamonds. Body ownership is (a), self-presence is (b), agency is (c), and self-location is (d).

4.2 Self-presence

The Two-Way Repeated Measures MANOVA on all the Self-presence questions showed a significant main effect over movement congruency ($F(4,28)=12.163$, $p < 0.00001$), but no significant main effect over avatar anthropomorphism ($F(4,28)=0.508$, $p = 0.730$) and no significant interaction effect ($F(4,28)=0.501$, $p = 0.735$).

The univariate tests of the MANOVA showed significant main effects over movement congruency for all questions, see Table 2. No other significant main effects or significant interaction effects were found for any of the questions. For visual representations of the Self-presence question results, see Figure 4.

4.3 Agency

The Two-Way Repeated Measures MANOVA on all the agency questions showed a significant main effect over movement congruency ($F(5,27)=99.415$, $p < 0.00001$), but no significant main effect over avatar anthropomorphism ($F(5,27)=2.401$, $p = 0.063$) and no significant interaction effect ($F(5,27)=0.699$, $p = 0.629$).

The univariate tests of the MANOVA showed significant main effects over movement congruency for all questions but the *controlled my will* control question, see Table 2. Only the ANOVA on that same control question showed a significant main effect over avatar anthropomorphism ($F(1,31)=6.367$, $p < 0.017$). Pairwise comparison for this question's anthropomorphic vs non-anthropomorphic found a mean difference of 0.266 ($p < 0.017$). No other significant main effects or significant interaction effects were found for any of the questions. For visual representations of the agency question results, see Figure 4.

5 DISCUSSION

The goal of this study was to investigate the possible levels of the SoE and Self-presence over a virtual body, while the real body was also visible, in an AR environment, and how these two concepts related to each other, in particular, whether body ownership is a special instance of proto Self-presence. To achieve this we studied the effects of alternating the anthropomorphism of the virtual body and the congruency of the virtual body's movements were on the levels of Self-presence and the SoE, in such an environment.

In our first hypothesis (H1), we expected that using congruent avatar movement the SoE could be induced over a disconnected virtual body in an AR environment, while the real body was visible as well. For this hypothesis to be confirmed one of the three subclasses has to occur to some extent [21]. The body ownership questionnaire results and the SCR showed significantly stronger results in the congruent conditions compared to the incongruent conditions. This means that some measure of body ownership was experienced over the virtual body, especially because there is a significant difference in SCR indicating a larger threat response and there is a direct relation between the strength of a threat response and the strength of body ownership [11, 1, 10, 9, 21]. The fact that some measure of body ownership can occur while the questionnaire ratings were mostly negative means that future research on body ownership can not subside on questionnaire measures alone, as it might then completely miss this sense of body ownership. We believe the low results for subjective ownership over the anthropomorphic body were in large part due to the body not being accepted or perceived as anthropomorphic; this will be discussed further below. Agency, on the other hand, showed more clear results, with very strong and almost unanimously positive questionnaire results for the congruent movement conditions. These results were as expected because a sense of agency occurs when the predicted consequences of an action and the actual consequences of an action are congruent [7, 18]. The results of self-location indicate that some participants experienced some shift in their perceived self-location, some participants even indicated feeling located at two locations at once. These results could hint at an enlargement of the peripersonal space. This has been shown to happen when inducing a full body illusion [34]. However, these self-location results are inconclusive, because only a small amount of participants indicated any shift at all. Since the results show that both body ownership and agency occur at some intensity, the requirement for the SoE toward the body is met and the hypothesis H1 is confirmed. This means that the SoE should no longer be considered ignorable in AR research, furthermore, it means that embodiment of a disconnected virtual body is possible, even when the real body is still visible.

In our second hypothesis (H2), we expected that using congruent avatar movement Self-presence could be induced for a disconnected virtual body in an AR environment, while the real body was still visible as well. The results show a significant effect of movement congruency on the perceived Self-presence, with congruent movement showing significantly stronger results. This indicates that some measure of Self-presence occurred in the congruent movement cases, especially since the question *extension of the real body* was answered positively on average for the congruent conditions and this question asks exactly what a high level of bodily Self-presence implies, according to Ratan et al. [37]. Moreover, one of the participants remarked that they felt the virtual knife was rather real and that in the incongruent conditions they were no longer able to defend themselves. This could indicate they used the virtual body to defend themselves without considering the mediation involved, which indicates some measure of Self-presence [37]. An explanation for the results not being clearly positive in the congruent movement conditions is the fact that the participant's only active task during the experiment was to move their arms while viewing the avatar perform the same movements. This would have put their full focus on the avatar and its movements and indicates they were aware of how they were controlling it. This could have hindered Self-presence because Self-presence requires the avatar to be used without considering the mediation involved, which implies the user is using the avatar without being aware of how they are using it [25, 23, 37]. This would also explain why Self-presence was stronger in previous experiments [49, 43, 17, 2] because these experiments all involved active tasks that distracted the user's attention from their control of the avatar and made the avatar a temporarily transparent interface to the virtual environment. While no clear confirmation of the hypothesis H2 is found in the results, we have argued that some measure of Self-presence for the disconnected avatar occurred. This means that Self-presence should no longer be ignored in AR. We also recommend any future studies on Self-presence to include an active interaction task, to increase the overall level of Self-presence.

In the introduction (Section 1), we assumed relationships to exist between Self-presence and all SoE subclasses, as well as SoE interrelations. A direct relation was assumed to exist between Self-presence and body ownership. The relationships between Self-presence and the other two subclasses of SoE were never directly mentioned in literature but suggested to exists because of the SoE interrelations. To explicate the direct relation between Self-presence and body ownership we formulated our third hypothesis (H3) in Section 2.2, which stated that body ownership is a special instance of Self-presence. We expected this hypothesis to be confirmed by the results of alternating movement congruency and avatar anthropomorphism as displayed in Table 1. However, the body ownership results do not show the expected effects of anthropomorphism; the reason for this will be discussed further below. This means there is *no* support for the hypothesis H3. To still provide empirical proof for the relationships suggested in the introduction we ran Mantel-Haenszel tests of trend on the questionnaire results for all these relations, to determine whether linear associations existed between the answers to these questions. We made a visual model of all the relationships, see Figure 5, with the non-broken arrows denoting suggested relationships and stars denoting the strength of the found correlations. The Mantel-Haenszel tests showed the strongest results for the relation between Self-presence and body ownership, see Table 4 for an overview of this relations Pearson correlation values. This indicates that both concepts influence one another, and at least are strongly correlated, and it could indicate that both concepts show some, possibly total overlap in what they measure. Correlation implies that the concepts are not independent but it does not imply causation. To test for a causal relationship we would need a very tightly controlled randomized experiment and we can not, unfortunately, deduce this from the current data. However, to ensure the overlap between the concepts was not total, Wilcoxen Signed Rank tests were run for all pairs of questions (4x5). All but three pairs did not show a significant difference, so it is unlikely that the same effect is measured by these questions. This correlation provided the lacking empirical proof for the existence of a relationship between body ownership and Self-presence. The fact that this relationship is positive could be very important as it could indicate that methods used to induce one of the two could also be used to induce or at least increase the other, and it means future research on one should consider including the other as well. The results also show that there is a moderate relationship between Self-presence and both agency and self-location, which gives further proof of the existence of a moderate to strong positive relation between Self-presence and the overall concept of the SoE. This means that not just methods used to induce body ownership, but also the SoE, in general, could be used to increase the sense of Self-presence. It also means that future research on the SoE should consider including Self-presence in the investigation as well. Finally, the SoE interrelations show the expected pattern, with the interrelation of agency and self-location alone showing a weak to non-existent correlation.

Besides these main findings, an interesting unexpected result was found, namely the absence of an effect of anthropomorphism on body ownership. This was unexpected because previous research has shown that a non-anthropomorphic body should induce no or at least very little ownership [47, 48, 24, 9]. There is some research which contests this [29], however, it must be noted that in this particular study the SCR and questionnaire results are low (SCR values are lower than the current results). The probable reason for this is the fact that adding human-like movements to an avatar changes the way one perceives this avatar, raising or lowering the acceptability of the avatar based on one's expectations for it. This was remarked upon by multiple participants, as they felt the limited movements made the anthropomorphic avatar feel rigid and less realistic. Previous research on familiarity and likeability of virtual characters has shown that adding movement to any character, abstract or not, increased acceptability of those characters [4], this would explain the non-anthropomorphic abstract avatar being perceived as familiar and human-like. However, in [28], it was found that the most realistic avatar was less accepted, and in [32] it was found that the more realistic virtual characters appeared more unpleasant, when large movement irregularities were applied. This would explain why adding limited movement to a detailed avatar made the avatar less acceptable because of incongruencies with what was expected from it. These findings could be in line with the theory of the *uncanny valley* [33]. However, the overview by de Borst and de Gelder [4] shows research both affirming and denying this theory. Thus, further research is required to confirm these effects and verify this theory.

6 CONCLUSION AND FUTURE WORK

This study was motivated by the goal of investigating how we relate to a virtual self-representation on a bodily level in an AR environment, in which this is usually unjustly considered inherent in the fact that one can see one's real body. In particular, we investigated the SoE and Self-presence for a disconnected virtual body in a scenario in which both the real body and this virtual body were visible. For this, the virtual body's anthropomorphism and movement congruency were alternated to study their effects.

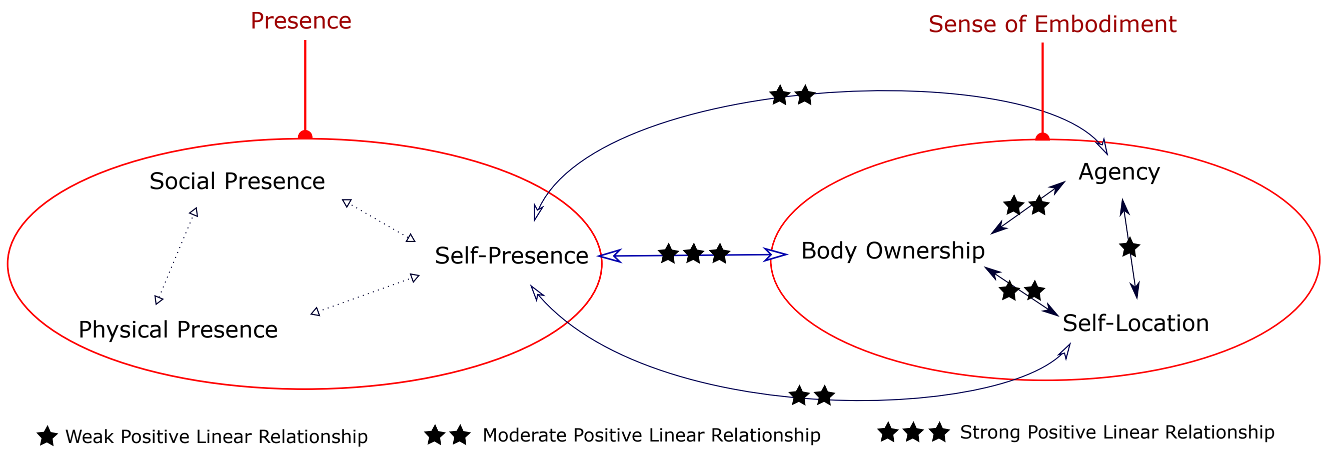


Figure 5: Illustrative overview of the relationships between Presence and SoE, including their subclasses. Stars denote the Mantel Haenszel test results.

Table 4: Mantel-Haenszel tests of trends Pearson correlation coefficients for all questions vertical body ownership x horizontal Self-presence. These numbers denote the strength and direction of the correlation between two questions. Correlation below 0.3 is weak, between 0.3 and 0.5 is moderate, and above 0.5 is strong.

	extensionreal	reachthrough	happenedtoreal	virtrealsame
ownbody	0.591	0.575	0.518	0.701
twobodies	0.645	0.609	0.425	0.593
someoneelse	-0.483	-0.364	-0.243	-0.417
partofown	0.757	0.707	0.548	0.719
reasonsens	0.431	0.557	0.677	0.516

The SoE questionnaire results showed significant effects of avatar movement congruency for body ownership, agency and a portion of the self-location questions. Skin conductivity also showed a significant effect over avatar movement congruency, confirming that some measure of body ownership occurred using congruent avatar movements, irrespective of the avatar's anthropomorphism. The agency questions showed strong results for congruent movements and the self-location questions indicated the possibility of experiencing a sense of bi-location. The Self-presence questionnaire showed significantly stronger results for congruent avatar movement, indicating Self-presence occurring to some extent. Further anecdotal evidence also indicates some Self-presence occurring. We conclude that the SoE for the disconnected virtual body was induced to a certain extent using congruent avatar movements irrespective of the avatar's anthropomorphism. Based on the found indications we argue that some measure of Self-presence for the disconnected avatar occurred in the congruent avatar movement conditions. Empirical proof was found for a strong positive relation between subjective body ownership and Self-presence. Coupled with the moderate relationship between Self-presence and both agency and self-location, we conclude that a moderate to strong positive relation exists between Self-presence and the SoE.

The main issue that presented itself during the study was the fact that the anthropomorphism of the avatar did not have the expected effect on body ownership. This precluded our confirmation of the hypothesized explicit relation between body ownership and Self-presence. The argued reason for the absence of this effect is the fact that adding human-like movement to an avatar changes one's experience of that avatar based on one's expectations for that avatar.

This study showed the possibility of the SoE and Self-presence for a disconnected virtual body in an AR environment and made a first step in explicating their relation to each other, giving empirical proof of a moderate to strong positive relation between the two. A next step would be to further explicate the relation between body ownership and Self-presence, using a tightly controlled randomized experiment to determine whether the relationship is causal in nature. Another step would be to investigate the influence anthropomorphism of a virtual body has on both the SoE and Self-presence, using a larger set of virtual bodies. A third study that is required is an investigation of the effect various types of movement has on the perceived anthropomorphism and acceptability of a virtual avatar. Moreover, the levels Self-presence need to be evaluated in tasks with varying levels of activity and interactivity. We remark that future research on Self-presence and the SoE should consider both for investigation. Additionally, we remark that future research on body ownership should include a physiological measurement because solely subjective measurements are insufficient. Finally, we remark that this study indicates a promising new direction for research by showing that Self-presence and the SoE are viable in AR.

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Chapter V

Reflections on Data Analysis

In this chapter, we describe and reflect upon steps in the processing and analyzing of the experiment data that did not into the scientific paper. First, in Section 1 we detail how we processed the raw GSR data acquired during the experiment into SCR results suitable for analysis. Next, we clarify the chosen computation of the SCR values and justify the choice of computation in comparison to other methods of computation in Section 2. Finally, in Section 3 we recount all non-parametric tests that were run as second opinion tests to confirm the parametric tests described in the scientific paper, see Chapter IV.

1 SCR Data Preprocessing

To read and process the raw BDF files, the format in which the ActiView program stores all GSR data, a custom application was written in C++. This application incorporates EDFlib, a programming library for C/C++ to read and write EDF+/BDF+ files. This application reads a predefined channel from a set of predefined BDF files (four BDF files per participant, one for each condition), and downsamples the data to 32 Hz (this is the sample rate at which the GSR records). To remove noise and smooth the data a Butterworth second order low-pass filter is applied, this filter will be discussed later in this section. The application then calculates a baseline and a threat response skin conductance level (SCL), based on the average or maximum of a predefined window of time. A comparison of the various methods these SCL can be calculated is discussed in Section 2. The skin conductance response (SCR) is calculated by deducting the threat response level from the baseline level and is output to a text file in both its raw value as well as its microsiemens value. The application also automatically outputs all raw and filtered skin conductance values to a separate text file for every BDF file it reads. This custom application is easily customized for various timing setups, participant amounts, and SCR calculation methods. Thus, it should be used or adapted in similar future research projects which the ActiveTwo for GSR measurements because it will significantly ease the processing of the GSR data.

Before the aforementioned application was implemented, a preprocessing step was done to simplify the processing of the BDF files. EDFbrowser, a free and open source program that can read and edit BDF files, was used to split sequentially recorded files, remove the extra non-GSR channels from every file and downsample all the data to 32 Hz. However, the implementation of the aforementioned custom application made this process redundant and thus it is no longer a required step in the use of the custom application for processing GSR BDF files.

Visual inspection of the SCL data showed a high frequency of noise, so to smooth the data a filter had to be applied. A Butterworth second order low-pass filter was chosen for this purpose (1 Hz cut-off frequency). Using this filter the signal noise in the SCL data can be almost completely eliminated. For visual representations of all the filtered data see Figure V.1 and V.2

After calculation and aggregation of all SCR data, all values below 0.03 microsiemens were considered zero responses. Participants who exhibited zero responses in all conditions were classified as SCR non-responders and were excluded from further analysis [1]. Next, all remaining SCR values were transformed with a log(value+1) transformation. This transformation step was performed to make the data comparable to previous research [1, 4, 22]. To be able to include occasional zero responses for participants not classified as SCR non-responders, the log transformation was done using log(value+1) instead of simply log(value), because the logarithm of zero is not defined.

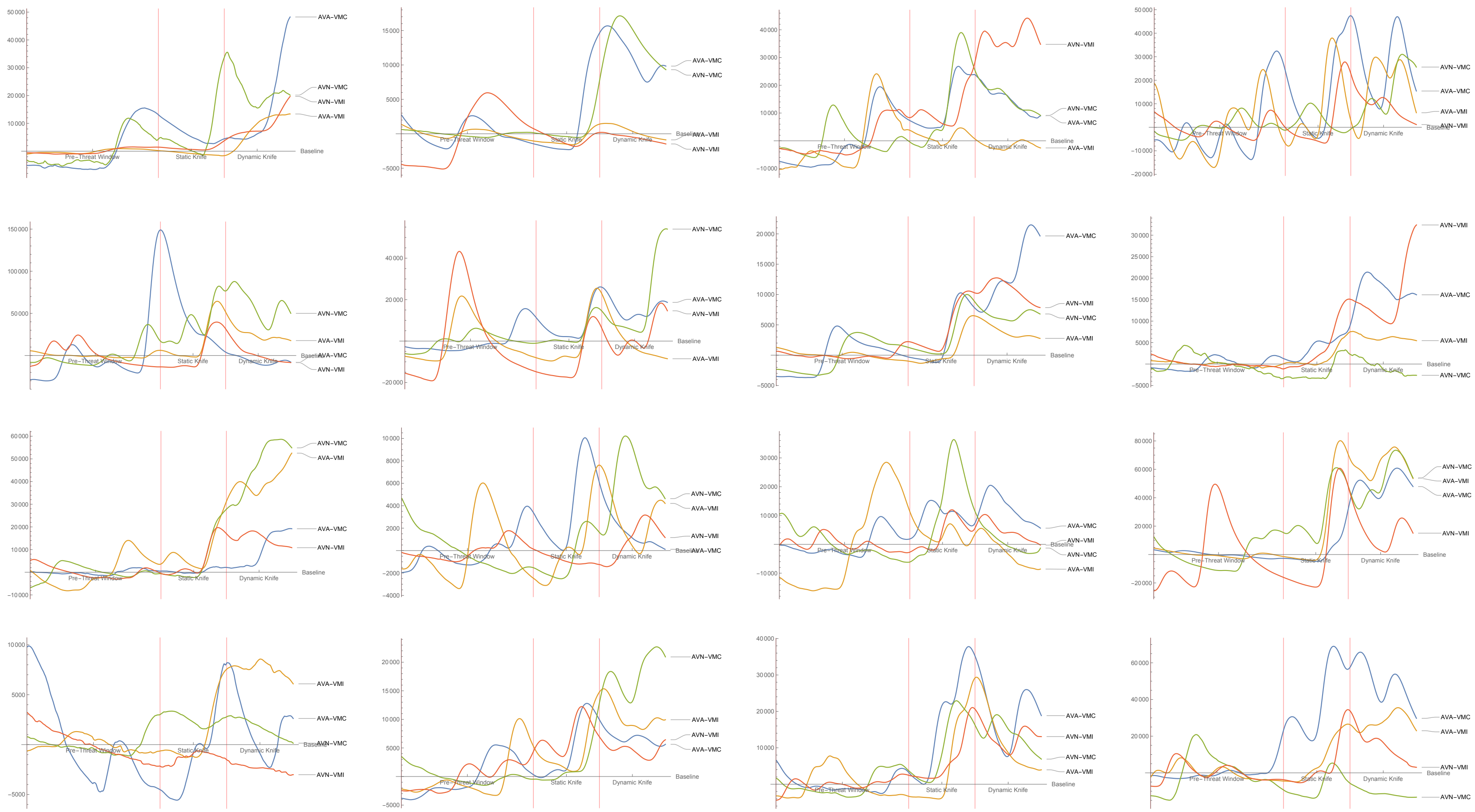

Figure V.1: All low-pass filtered GSR data of the first 16 participants represented as a line per condition. Blue line corresponds to anthropomorphic avatar congruent movement (AVA-VMC), green line corresponds to non-anthropomorphic avatar congruent movment (AVN-VMC), yellow line corresponds to anthropomorphic avatar incongruent movement (AVN-VMC), and red line corresponds to non-anthropomorphic avatar incongruent movement (AVN-VMI). The vertical axis denotes raw GSR values (division by 32000 gives microsiemens). The vertical position of a line is determined by the baseline offset (0 is always the baseline, which is calculated as average of 10 second pre-threat window). Horizontal scale always denotes 20 seconds with three blocks: first block is 10 second pre-threat window, second block is 5 second static knife window, and third block is 5 second dynamic knife window.

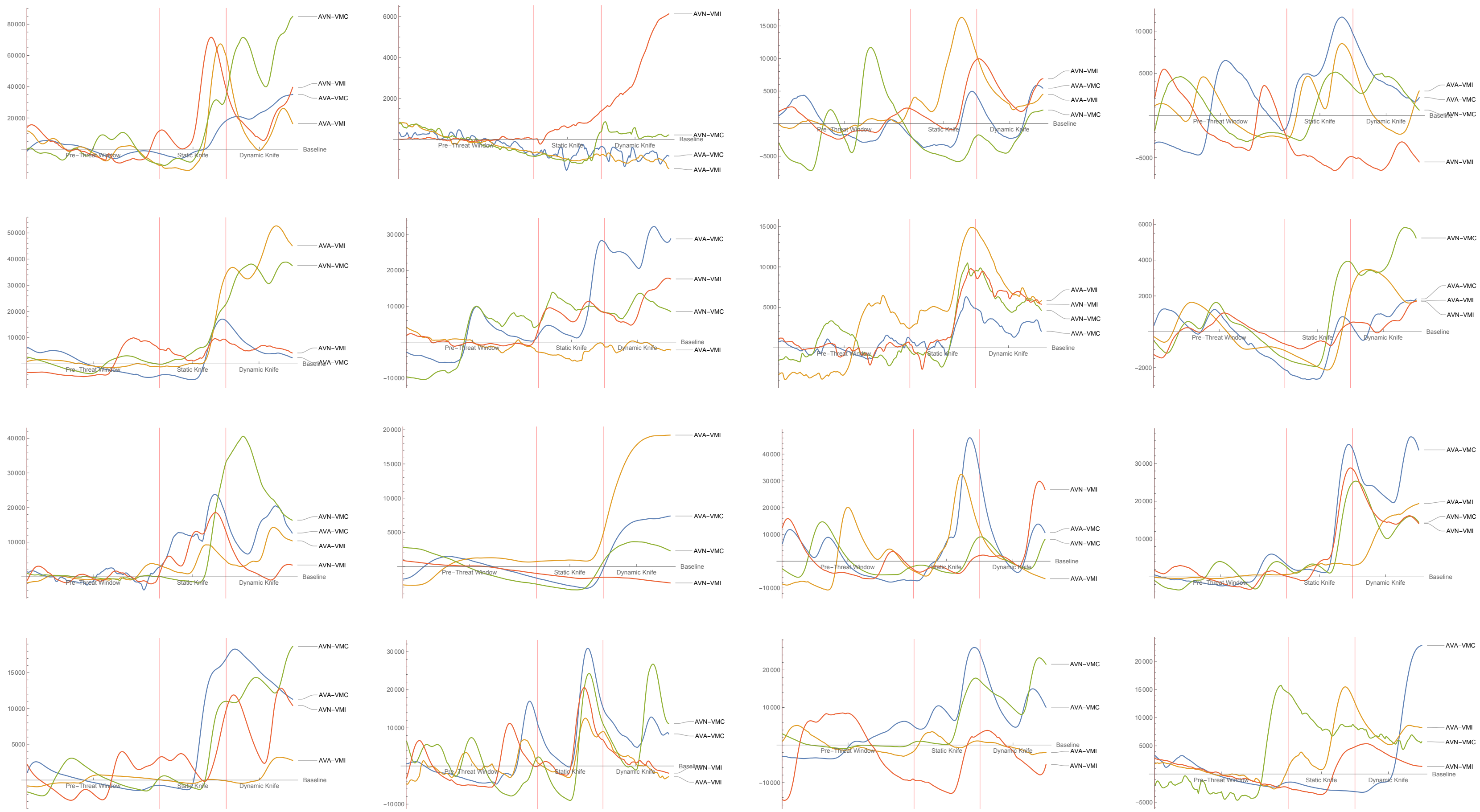

Figure V.2: All filtered GSR data of the second 16 participants represented as a line per condition. Blue line corresponds to anthropomorphic avatar congruent movement (AVA-VMC), green line corresponds to non-anthropomorphic avatar congruent movment (AVN-VMC), yellow line corresponds to anthropomorphic avatar incongruent movement (AVN-VMC), and red line corresponds to non-anthropomorphic avatar incongruent movement (AVN-VMI). The vertical axis denotes raw GSR values (division by 32000 gives microsiemens). The vertical position of a line is determined by the baseline offset (0 is always the baseline, which is calculated as average of 10 second pre-threat window). Horizontal scale always denotes 20 seconds with three blocks: first block is 10 second pre-threat window, second block is 5 second static knife window, and third block is 5 second dynamic knife window.

2 SCR Analysis Methods Comparison

The literature on previous studies using SCR as a measurement is inconclusive concerning how exactly the SCR values should be calculated from the SCL values. Most agree the SCR is calculated by deducting a baseline SCL from a threat response SCL, however, very little congruent implementations are found for the calculation of these baselines and threat responses. In this thesis project the baseline and threat response calculation were implemented as follows, for the baseline the average over 10 seconds before the threat was taken, and for the SCR the highest peak 10 seconds after the threat was taken. This was done because the knife threat in our experiment environment was visible for 10 seconds. Support for this average before threat maximum after can be found in multiple examples present in literature [27, 34].

However, since multiple different implementations of these calculations can be found in literature, it was determined prudent to investigate the effect of a set of these calculation implementations on our analyses and experiment results. The implementations investigated included taking the maximum values in the time window for both the baseline and threat response SCL, as well as taking the average value of the time window for both the baseline and threat response SCL. In addition to this, the different time windows of the static and dynamic knife threat phases were also investigated for all the implementations. These investigations showed similar results for all the investigated cases, except for the cases in which only the static knife window was taken. In these cases, the difference in SCR over avatar movement congruency was not significant. However, when taking a 6-second post-threat window we again find similar results. Because threat responses can occur 6 seconds after threat we can not be sure that this is due to late threat responses or the fact that the static knife is not considered a threat. These findings, however, have no influence on our results as the knife threat is shown to be effective in inducing a higher threat response for the congruent avatar movement cases.

We do consider the SCR to be a valid indicator of body ownership seeing as the experiment results did show the expected pattern. The expected pattern being the strongest average result for the anthropomorphic congruent movement condition and the weakest average result for the non-anthropomorphic incongruent movement condition. However, because there are so many interpretations on how to calculate and analyze the SCR data and many seem arbitrarily chosen a standardization of this measurement method is direly needed. Until such a standardized method is created future research projects should make similar considerations as we made above and choose the methods that allow the best comparison to similar research. Besides this, the question remains whether it is the most suitable physiological measurement of body ownership. Future research should consider making a comparison between the various used physiological measurements, such as skin conductance response, heart-rate deceleration and changes in body temperature.

3 Non-Parametric Confirmation Tests

The questionnaire data is in the form of Likert items and these are ordinal. However, for the purposes of the analysis, the data was considered as interval data, since this allowed the analysis to be done using parametric methods. In addition to this, the tests for normality on all questionnaire and SCR data showed that the data was non-normally distributed, yet the decision was made to analyze the data using parametric methods, namely MANOVAs and ANOVAs. This was done because MANOVAs and ANOVAs are considered robust against violations of normality and visual inspection of the q-q plots showed the data to be approximately similarly distributed for each question. To be sure that our analyses using parametric methods are not simply false positives since our analysis makes two assumptions on the nature and robustness of the used tests, second opinion non-parametric tests were run for all parametric tests. For this, we used Friedman ANOVAs and Wilcoxen signed-rank tests. Using these non-parametric tests we confirmed our parametric tests as these tests flagged no results as false positives. All the results of the non-parametric tests are displayed in Table V.1 & V.2, except for the few pairwise comparison Wilcoxen tests for the univariate significant main effects over avatar anthropomorphism which are stated here in the text. The ownership control question *visually resembled* showed a significant difference over anthropomorphism (Z = -4.418; $p < 0.0001$), and the agency control question *controlled my will* did as well (Z = -2.125; $p < 0.035$).

Table V.1: Per Question Friedman test over all cases

Question	type	$\chi^2(3)=$	significance
It felt as if...	*Ownership*		
the virtual body was my own body	answer	17.493	$p < 0.001$
I had two bodies	answer	28.308	$p < 0.0005$
the virtual body was a duplication of my own body	control	40.636	$p < 0.0005$
the virtual body belonged to someone else	inverse	49.980	$p < 0.0005$
the virtual body was a part of my body	answer	29.078	$p < 0.0005$
the virtual body was the reason I experienced certain sensations	answer	12.585	$p < 0.006$
the real body became digital	control	18.563	$p < 0.0005$
the virtual body started to visually resemble the real body	control	29.200	$p < 0.0005$
Skin Conductance Response	(SCR)	12.066	$p < 0.007$
It felt as if...	*Self-presence*		
the virtual was an extension of the real body	answer	51.929	$p < 0.0005$
I could reach through the avatar	answer	40.719	$p < 0.0005$
what happened to the virtual body, happened to the real body	answer	16.891	$p < 0.001$
the real body and the virtual body were the same	answer	22.279	$p < 0.0005$
It felt as if...	*Agency*		
I had control over the virtual body	answer	72.147	$p < 0.0005$
I could move the virtual body, as if it obeyed my will	answer	72.963	$p < 0.0005$
the virtual body replicated the real body	answer	70.793	$p < 0.0005$
the virtual body had a will of its own	answer	76.638	$p < 0.0005$
the virtual body controlled my will	control	11.648	$p < 0.009$
It felt as if...	*Location*		
the virtual body was at two locations	answer	25.409	$p < 0.0005$
the real body was at the location of the virtual body	answer	12.092	$p < 0.007$
the virtual body was at the location of the real body	answer	15.443	$p < 0.001$
the sensations occurred at the location of the virtual body	answer	2.813	$p = 0.421$
the sensations occurred between the real and virtual body	answer	11.983	$p < 0.007$
the real body drifted toward the virtual body	control	12.117	$p < 0.007$
the virtual body drifted toward the real body	control	26.434	$p < 0.0005$
I could not be sure where my hand was	control	1.836	$p = 0.607$

Table V.2: Pairwise Wilcoxen signed-rank test congruent vs incongruent avatar movement for questions with significant Friedman test result and SCR

Question	ownbody	twobodies	duplication	someoneelse	partofown	reasonsens	becamedig	SCR	visuallyres
Z =	-4.155	-4.494	-5.794	-5.575	-5.099	-2.820	-3.341	-2.862	-4.076
Signific.	$p < 0.0005$	$p < 0.0005$	$p < 0.0005$	$p < 0.0005$	$p < 0.0005$	$p < 0.005$	$p < 0.001$	$p < 0.004$	$p < 0.0005$
Question	extensionreal	reachthrough	happenedtoreal	virtrealsame					
Z =	-5.824	-5.020	-3.326	-4.643					
Signific.	$p < 0.0005$	$p < 0.0005$	$p < 0.001$	$p < 0.0005$					
Question	controlover	obeyed	replicatedreal	ownwill	controlmywill				
Z =	-6.766	-6.922	-6.662	-6.940	-2.428				
Signific.	$p < 0.0005$	$p < 0.0005$	$p < 0.0005$	$p < 0.0005$	$p < 0.015$				
Question	twolocat	reallocvirt	virtlocreal	sensbetween	realdrift	virtdrift			
Z =	-4.524	-2.507	-2.322	-3.305	-3.400	-4.234			
Signific.	$p < 0.0005$	$p < 0.012$	$p < 0.02$	$p < 0.001$	$p < 0.001$	$p < 0.0005$			

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