Is That Me?—Embodiment and Body Perception with an Augmented Reality Mirror

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Figure 1: left—operator controlling 3D point cloud body size; center—three different body sizes; right—participant wearing the HoloLens in front of the Kinect capture sensor

ABSTRACT

Virtual reality has been used intensively to study embodiment and body perception, in particular for research purposes in psychological domains. Virtual avatars are used to resemble users' appearance and to implement interactively simulated behaviour. To make this a realistic and believable experience users should feel embodiment, i.e. ownership, agency, and self-location/presence.

State-of-the-art capture and display technologies allow for extending virtual reality embodiment to the realm of augmented reality for higher efficacy—instead of seeing a virtual reality body one would see a captured, 3D representation of their own body naturally controlled by their real body movements within the context of the present real environment. However, it is unclear whether users would experience embodiment with their augmented reality avatar and whether findings from virtual reality targeting body perception can be replicated.

Here we present an augmented reality system comprising a 3D point cloud capturing system (Microsoft Kinect) and an optical see-through head-mounted display (Microsoft HoloLens), both connected to a purpose-developed application displaying a user's body in a virtual 3D mirror embedded into the real environment. In a study with 24 participants, we evaluated embodiment and body weight perception as a proof of concept. This is based on a similar study conducted in Virtual Reality. Our findings show that users experience ownership and agency with the mirrored body and that body weight perception in virtual and augmented reality systems is similar.

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Index Terms: H.5.1 [Information Interfaces and Presentation (e.g. HCI)]: Multimedia Information Systems — Artificial, augmented, and virtual realities

1 INTRODUCTION

When we see ourselves in a mirror, we normally have no doubts that this is our body we are seeing and when we lift our arms then we safely assume the mirrored arms will respond accordingly. An optical mirror is a reliable instrument to show a high resolution, zero latency, and mirrored image of ourselves. While it provides this high-quality reflection, it is just limited to that—an optical reflection. A recent example of an optical mirror is found in [1] where an mirrored optical image is augmented with virtual content for the purposes of anatomy education.

In contrast, a virtual reality (VR) mirror is highly flexible in what it can show to a user, but due to its technical limitations, we cannot safely assume the same guaranteed sense of ownership and agency—those attributes must be actively supported by the VR system and require research and careful engineering. In order to achieve that users perceive the virtual bodies as realistic it is highly important that users feel embodiment. This means that they develop a sense of ownership, feel that they are in control of their virtual body (agency), and feel that they are part of the virtual environment (presence). Once we achieve embodiment, such a VR mirror setup opens a host of possibilities for control and measurements, e.g. for the treatment of people with body diphormism, for studies on body perception and behaviour, for out-of-body experiences, gender-, age-, race-manipulations, etc., e.g. [6]. A disadvantage of VR mirror setups is that the real environment, and more importantly, the real body of the user is completely replaced by the virtual content when only the virtual mirror is investigated. This can raise the question how many of the findings from the VR setup can be transferred into the real world. One possibility to add more realism into such mirroring is to use Augmented Reality. In this case, we combine the best of VR and reality. Between those two there is a spectrum of possibilities on the Mixed Reality (MR) continuum [18]—ideally, we combine the controllability of VR with the "naturalness" of reality. However, while embodiment has been studied intensively in VR, it is not clear if the same findings apply for Augmented Reality (AR).

In this work, we address this gap and describe an Augmented Reality Mirror system that combines point cloud-based body capturing, manipulation, and an optical see-through head-mounted display. Our system displays the human body in a virtual mirror spatially aligned to the real environment. We use this system to investigate if we can replicate findings from VR mirror systems in an AR mirror system by replicating parts of a bigger VR mirror study on body weight perception [4]. We found that our implementation of an augmented reality mirror is effective, that users experience ownership and agency with the mirrored body and that body weight perception in virtual and augmented reality systems is similar, i.e. generally underestimated. We could not reliably measure augmented reality presence due to the absence of appropriate instruments.

Our findings might encourage others to consider augmented reality technologies as an alternative to virtual reality techniques when developing applications that rely on acceptance, efficacy, and feasibility of body ownership and agency.

2 RELATED WORK

The feeling of embodiment inside a virtual body within a virtual reality context has been studied intensively during the last couple of years [2], [3], [4], [5], [6]. Here, normally, a human body is represented by an avatar of varying appearance and fidelity. This avatar is controlled by motion capturing techniques, automation, or combinations of both. Those studies also helped to investigate the concept of embodiment and to develop measures for its constituting components.

Kilteni et al. describe embodiment as the feeling of oneness with one's own virtual body [3]. They further suggest a definition of embodiment by the feeling of being in control of this body (also called agency), being able to feel ownership of it, and the sense of being self-located within one's body. In the real world, this feeling is always present and normally our body cannot be dissociated from ourselves. In VR, the real body *is* dissociated from the virtual representation, but it has been shown that embodiment can be effectively achieved for body parts, e.g. Slater et al. [6] or for a fully captured and presented body, e.g. Piryankova et al. [4].

Longo et al. provide an operational definition for embodiment by performing a systematic analysis of questionnaires from an experimental procedure that involved the examination of embodiment from a rubber hand [10]. Using Principal Component Analysis (PCA), they extracted significant components that were felt when participants were embodying a rubber hand: Participants reported that they experienced ownership and that their hand was felt to be located within the rubber hand, a feeling which was then termed self-location or in some cases as self-presence [8].

Examples of investigations on perceived embodiment with virtual avatars are the system developed by Latoschik et al. where the user is captured and different avatar representations are shown on a large monitor [9]. Alternatively, the system developed by Van Bommel et al. where a video see-through head mounted display is used for an AR view, and a MS Kinect for body tracking [11]. The virtual avatar is then placed in front of the user; hence the user sees the avatar's back side (same orientation as themselves) within the context of the real laboratory environment.

From all those studies we learn that embodiment with virtual avatars is achievable. However, it remains unclear, whether an actual AR representation would lead to embodiment too. We see this as an important question to ask due to the growing ubiquity of AR devices. We hypothesize (1) that users will feel being present in the AR environment, (2) ownership and agency will be experienced with a captured and mirrored point cloud avatar, and (3) that these embodiment components are maintained during manipulations of the point cloud avatar.

3 AR MIRRORING SYSTEM

To be able to test our hypotheses about embodiment and body perception we developed a system comprising a body capturing, a processing, and a display component.

3.1 Body capturing component

As a capturing device, we opted for a Microsoft Kinect. It allows for relatively high resolution capturing of color and depth data while being affordable. The Kinect has been successfully used in a number of studies. With the mirror image in mind, we placed the Kinect sensor bar at height of 2.12m, facing downwards at a 33-degree angle, mounted to a neutral colored and lit wall (see Figure 1, right). We marked a desired, initial standing position for the person to be captured with a white stripe on the floor. We briefly discuss how we attain the marked distance later in this section.

3.2 Processing component

The Kinect is connected to a PC (Intel® Core™ i7-6700 CPU @ 3.4 GHz with 16 Gigabytes of RAM; MS Windows 10) where LiveScan3D [12] is receiving and handling the captured RGBD data. The LiveScan3D application is configured based on two components: 1) a server application that handles the transfer of data between the Kinect capture side and the visualization side, and 2) the capture application that connects to the server and delivers the Kinect RGBD data. Because LiveScan3D is open source, we were able to tailor it to our needs. Since we aim to create a virtual mirror representation of the user's body, we only want to work with the virtual representation of the user's body, not the entire room that is also captured by the Kinect. For this purpose, we changed LiveScan3D so that it only considers RGBD points from the user's body, and from the body alone. This is possible, because the Microsoft SDK labels points as belonging to the body based on its skeleton tracking model.

In addition to visualizing the user's body within the Augmented Reality Mirror, we were also interested in investigating aspects of body manipulations. To achieve the desired body scaling effects (body mass index perception) the point cloud is scaled in the x- and z-directions, but not in the y-direction (along the body axis) to keep the height the same and just to change the body shape (cylindrical scaling). To avoid increasing gaps in-between the points the size of the points themselves was scaled with the overall x/z-scaling (see Fig 1, center). The body scaling is performed within the LiveScan3D server application, so we are able to perform scaling of the body in real-time. Nine scale increments are implemented for the purposes of the study ranging from 0.6 - 1.4 in 0.1 factor increments (i.e. 0.6, 0.7, …, 1.4).

3.3 Display component

For the display component, we opted for a Microsoft HoloLens. The HoloLens offers acceptable resolution and augmentation quality for indoor applications, in particular overall brightness and ratio of environment/display brightness. The rather narrow FOV of the HoloLens often has negative effects on user experience though it is of lesser importance for our application scenario. Many AR applications contain a lot of virtual content which increases the break in visual coherence when the FOV cuts that content off. As we are only displaying a virtual 3D mirror aligned to the real environment and no other objects, this is much less of an issue. The vertical FOV of the HoloLens is still quite small and can become an issue should the user move too close to the mirror, though if the user stands far enough away from the wall (mirror) they are able to visualize most of their body. This is again less of a problem as users are required to stand at a certain distance from the wall. The position the user should stand considers three main things: 1) the distance required for the Kinect's skeleton tracking to work effectively and for the Kinect to capture enough of the user's body, 2) the field of view (FOV) of the HoloLens (a user should stand far enough back that they can see the whole picture), and 3) how far a person would normally stand from a real-world mirror.

The major advantages of the HoloLens over alternative solutions, like the Epson BT series head-mounted displays, are its wearability (self-contained computing and AR system) and its built-in, high quality and robust SLAM-based tracking. Other possible mediums that could allow for a similar effect include stereo-projection systems or potentially a large vertically oriented stereo monitor mounted on a wall, however these means are far less portable as visual mediums and require substantially more instrumentation of the environment. While similar evaluations have been conducted in fully immersive VR mediums, they appear not to have been conducted in this context using an optical see-through HMD such as the Microsoft HoloLens. A well-known system using the HoloLens is found in the work of Orts-Escolano et al. from Microsoft Research [16] and presents a similar outcome in terms of point-cloud representations of a space. Our system implements further manipulation functionalities as has been discussed.

The HoloLens runs our display component of the software. This is based on Unity3D, and is then built and ported to the HoloLens. Upon startup, the display component connects to the LiveScan3D server described above which allows for the flow of data. The captured and processed 3D point cloud data (per point x,y,z and rgb color) is sent to Unity3D via a wireless TCP connection. The point cloud is transformed (translated, rotated, and uniformly scaled, and mirrored) so that a 3D point cloud mirror image appears in front of the user as if a real mirror was placed on the wall where the Kinect is mounted to. For correct world coordinate system reference tracking the HoloLens is initialized at the starting position and orientation (facing the wall). A pinch gesture (HoloLens SDK) allows the experimenter to translate the point-cloud in x, y, and z axes in the case that any minor adjustments need to be made to the positioning after initialization.

Finally, a control GUI was developed which is tailored to the needs of the user study described below comprising mechanisms to handle the setting of the scale factor at pre-defined values, randomizing the order of conditions, and the logging of data. This GUI is only visible to the experimenter and not to the user. The user only sees the effects of the control; no other user interface elements are shown to the user.

4 User Study

In our user study, we are interested in the effect of our augmented reality, optical-see-through display, real-world aligned Augmented Reality Mirror on embodiment and body perception. The study is designed after Piryankova et al.'s experiment on the investigation of women's sensitivity of changes to their perceived body weight when seeing their avatar in a VR setting [4]. In their study with 13 female participants, they used a full 3D body scanner and anthropometric measurements and control with the purpose of investigating factors affecting body size perceptions. We built our study on top of theirs with four main alterations: (1) instead of a virtual reality environment we are using our augmented reality setup, which (2) displays a visually captured user instead of a virtual reality avatar (cf. also Van Bommel et al., [11]), (3) we are using a simpler scaling model than the original study, and (4) we are using only a subset of Piryankova's study as a proof of concept, not the whole, very comprehensive design. We keep the question about the effects of self-esteem and in addition, we are interested whether there is a difference in body perception between the genders. Our focus is more on whether a user achieves the same sense of embodiment as in the Virtual Reality system and less on the body perception factors so the changes made are not to the detriment of the study. Given this focus, our data analysis is also less elaborate.

In our one-factorial, within-subjects design, the independent variable is the displayed body scale (cylindrical scaling) with nine levels ranging from 0.6 to 1.4 in 0.1 scale steps. Our dependent variables are embodiment, decomposed into ownership, agency, and presence and the perceived body weight.

4.1 Participants

Our participants have been recruited from the student and staff population at the University of Otago. In total, there were 24 participants (13 female, 11 male) with an age range from 18 to 53 years. As a point of difference from the Piryankova et al. study, we used both male and female participants. None of the participants had any self-reported visual impairments or experienced cases of simulator sickness. The participants received a $20 voucher for their participation in the study. The study was approved by the University of Otago Ethic Committee (approval number: D17/313).

4.2 Apparatus

The aforementioned and described AR mirroring system was used for the study. An experimenter sat at a desk next to the Kinect capture space and controlled the application on screen (see Figure 1).

Apart from a demographics questionnaire, four different questionnaires were used to measure our dependent variables: (1) the Rosenberg (1965) [13] self-esteem questionnaire, (2) an embodiment questionnaire, (3) a body-perception questionnaire and (4) the simulator-sickness questionnaire [19].

The self-esteem questionnaire consists of 10 questions with 4-point Likert-like items anchored between strongly agree and strongly disagree. This instrument was administered to later compare self-esteem with weight perception.

The embodiment questionnaire is composed of items from previous research: The ownership questions were taken from Banakou et al. [14], Llobera et al. [15], Piryankova et al. [5]. Some questions were modified slightly to suit the nature of our experiment. Agency questions were taken from Longo et al. [10], again the agency questions being modified to fit with the nature the experiment. The presence questions were taken from Schubert et al. [17]—a validated instrument to measure the sense of presence within virtual environments. This was taken because of the absence of a tailored AR presence instrument—so, we at least try to measure presence, admittedly with a "blunt" instrument.

The body perception questionnaire was taken from Piryankova et al. [4]. With the purpose to measure the link between one's general body perception and one's body-weight perception. The body-perception questionnaire was measured with 7-point Likert-like scale items, ranging from fully disagree to fully agree.

Finally, to assess the actual state of possible experiences simulator sickness Kennedy et al.'s instrument was administered [19].

In addition, our control GUI operated by the experimenter interactively recorded participants' responses to verbal questions about their body perceptions.

4.3 Procedure

After they were instructed and provided consent, participants answered the demographics and self-esteem questionnaires. Meanwhile, the experimenter was setting up the Augmented Reality Mirror environment, which then ran for the entirety of the experiment. The participant was asked to wear the optical see-through head-mounted display and was led to the capturing space, standing at approximately a distance of 2 meters facing the capturing device. The participant was instructed to look straight in the direction of the capturing system. The augmented-reality mirror was shown and the participant was asked whether they saw a virtual body and a virtual mirror in the direction of the capturing device.

The augmented-reality mirror disappeared, and the participant was presented with the first session of the experiment. Within this first session, the participant was presented with their body from the augmented reality mirror in nine different sizes. Only one body size was presented at a time, but the nine sizes were presented 5 times time in total, making the overall total of 45 times that the participant saw their body in various sizes in a randomized order. The sizes ranged in scale factors from 0.6 to 1.4 with 1.0 being the normal size. When one body was being shown, the participant was asked the question of whether the body they were seeing in the Augmented Reality Mirror had the same perceived weight as theirs. They could answer either a yes or a no depending on how similar the weight of the body in the Augmented Reality Mirror was to their weight. Once they had answered the question, the next body size was shown, again by asking the question about the perceived weight similarity. This cycle continued for all the various sizes until the first session was completed. The experimenter recorded on a computer the participant's yes or no answers to the question of whether the body they were seeing had the same weight as them.

After the first session was finished, the participant was presented with the second session. In the second session, the participant was asked to do an adjustment task for the body in nine varying body sizes. Again, only one size was shown each time and the order of the sizes shown was randomized. Within the adjustment task, the participant was asked to iteratively adjust the body to the size that was most like theirs by telling the experimenter to increase or decrease the body size until best similarity was reached. The experimenter recorded the answer to the participant-adjusted size on the operating computer. The process is then repeated but asking participants to adjust until their "ideal" body size. All answers were logged by the control system operated by the experimenter.

After the adjustment task was done, the participant was asked to fill in the embodiment questionnaire, the body-perception questionnaire, and the simulator-sickness questionnaire. Finally, the participant was thanked for their time and compensated with a 20-dollar grocery voucher for their participation.

4.4 Results

Data of all 24 participants and of all trials have been used for analysis—no data was excluded.

In short, ownership and agency have been reported to be high (significantly above mid-point), while we could not measure high ratings for presence with the virtual reality instrument available. Most participants chose the 0.9 scaling factor as their normal body scale.

In the following, we present a more detailed analysis.

4.4.1 Embodiment

For the embodiment components ownership, agency, and presence, all Likert-like scales have been transformed into 1-7 scales. To determine the effect of each of the components we tested against the mid-point of the scale (4.0).

Agency (B5, B8) (M=5.26, SD=1.38) and ownership (B1-B4, B6-B7) (M=4.906, SD=0.803) were significantly higher than the midpoint ($p<0.05$) as measured by a one-sample Wilcoxon significance test (data not normally distributed (Shapiro)).

Out of the five Presence questions (P1-P5), data was not normally distributed either and differences against mid-point (M=3.57, SD=0.062) were found non-significant.

Table 1 summarizes the means and standard deviations for each individual question of the embodiment questionnaire with slightly modified questions taken from different sources (see Related Work).

Table 1: Means and standard deviations for individual items of embodiment components (embodiment questionnaire on 7-point Likert-like scales)

		Abbreviated Question	M	SD
Presence	P1	Virtual Mirror was part of the surrounding environment	3.458	1.527
	P2	Just perceiving pictures	3.000	1.528
	P3	Looking into a mirror rather than camera image	3.750	1.507
	P4	How real did the virtual mirror seem	3.708	1.541
	P5	Virtual mirror consistent with a real mirror	3.917	1.681
Ownership	B1	Was own body	5.000	1.414
	B2	Virtual body resembled own body re features	4.625	1.317
	B3	Feeling of two bodies	5.458	1.581
	B4	Virtual body was your body	3.600	1.676
Agency	B5	Movements were your movements	5.400	1.594
Own	B6	Virtual body was another person	5.850	1.284
	B7	Heavier (bigger, fatter) than usual	3.475	1.700
Agency	B8	Was in control of the virtual body	5.100	1.863

We found, that out of the six questions that were ownership related, two were non-significant. One question was related to whether one would feel that their body was getting larger (B7) (M=3.475, SD=1.7); the other question was related to whether the participants felt that the virtual body was their body (B4) (M=3.6, SD=1.675).

Out of the five presence questions, only one was significantly different to mid-point (lower). The question was related to whether the participants felt that they were rather perceiving pictures (P2) (M=3.0, SD=1.527).

Also, weak Cronbach's alphas (αPres(5)=.327; αOwn(6)=.517; αAgen(2)=.366;) indicate low internal consistency with two main ramifications: (1) Instruments to measure presence in VR are not suitable to measure presence in AR and (2) existing measures for embodiment, not only in VR but AR too, have to be refined before they can become an accepted standard in research.

4.4.2 Body Perception

For the first task (choosing the correct body size/weight) participants have been presented with a randomized order of their body representations. We analyzed the frequency of the “yes” answers the participants were giving on whether the differently scaled bodies were perceived as the same weight as them. Using a two-sample Wilcoxon test, the difference between ratings on smaller versus larger body was significant ($p<0.0001$). The mean value for the scale of 0.9 (M = 0.725, SD = 0.304) was greater than the norm of 1.0 (M = 0.633, SD = 0.3036). The difference between the scores was not significant ($p>0.05$). The mean value of a scale of 1.1 (M = 3.917, SD = 0.329) was significantly less than the norm of 1.0 ($p<0.05$). Figure 2 shows the number of “yes” responses to whether the differently scaled bodies were perceived as the participants’ actual weight. It peaks at the scale of 0.9.

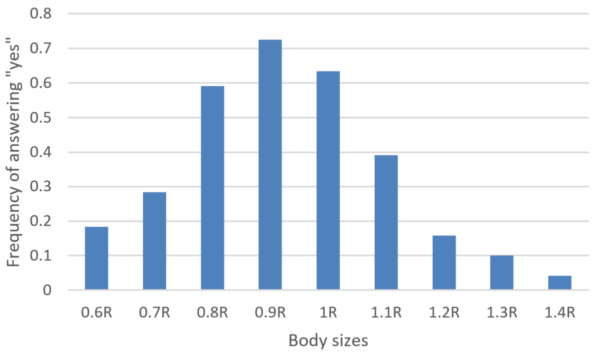

Figure 2: Frequency of “yes” answers to correct body size peaking at 0.9 * real body size.

For the adjustment task, where participants told the experimenter to change the body size in 0.1 scale factor steps until the desired, perceived normal body size and ideal body size was reached, respectively. The average factor for size that the participants thought was their size was 0.932 (SD=0.078), significantly less than 1.0, which is the body at normal scaling ($p<0.001$). The factor for ideal body size on average was 0.877 (SD=0.036), significantly less than 1.0 ($p<0.001$). The ideal and the similar-weight factors were significantly different from each other ($p<0.001$).

While Piryankova et al. only studied women [4] we recruited a gender mix. The average male estimation of the size as similar to their body size is 0.941, while the average female estimation of size to be the same body size is 0.9299. The difference was not significant ($p>0.05$). The average for male estimation of their ideal size is 0.874, while the average for the female estimation of their ideal size is 0.846. The values were not significantly different from each other ($p>0.05$).

4.5 Discussion

As with Piryankova et al.’s study [4], we have been interested whether there is a relationship between reported self-esteem and body perception. Participants with low self-esteem (score less than 15) and participants with normal self-esteem (score equal or greater than 15) showed no significant differences in weight perception and ideal weight. The mean for low self-esteem individuals’ size perception was 0.918 and the high self-esteem mean size perception was 0.934. The mean ideal size in low self-esteem individuals was 0.856 and the mean ideal size for high self-esteem individuals was 0.863. However, only two participants were below 15, so no actual conclusions can be drawn here. A larger sample size would potentially yield more informative results for correlations between self-esteem and body perception.

Our first hypothesis that users would achieve a sense of presence within our system is not confirmed in the data. We speculate the main reason for this is that the presence questionnaire is designed and validated primarily for fully virtual environments. Another possible factor might have been that several of the questions had to be modified to fit the AR context. There is a gap in the domain of Presence research to address the role of Presence within Augmented Reality contexts. The second hypothesis that users would achieve a sense of ownership and agency within the system was confirmed. Finally, the third hypothesis that embodiment components (ownership, agency, and presence) are maintained throughout manipulations of the body is partially confirmed based on a non-supported first hypothesis and a supported second hypothesis.

5 Conclusion

We presented an Augmented Reality Mirror system capable of displaying a captured 3D point cloud representation with an optical see-through head-mounted display of one’s own body. Our approach was able to provide a sense of ownership and agency. In addition, we could confirm findings from a VR study on body perception by controlling perceived body weight with our system. We could not show that a sense of presence developed in the AR environment. We assume that a VR presence questionnaire is unsuitable to measure AR presence. More research is needed here.

While our findings derived from our specific system implementation using a MS Kinect and a MS HoloLens setup, we think that our research is generalizable and that more system developments and studies should consider the mixed reality spectrum for the realization of body ownership and agency.

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