# The Effect of Avatar Realism in Immersive Social Virtual Realities


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**Figure 1: Social interaction phase with user waving back to virtual communication partner. Left: Own abstract avatar and other's realistic avatar generated from photogrammetry scan. Right: Own realistic avatar and other's abstract avatar. Right: Sensory-equipped user in the real environment while interacting in the Virtual Environment (VE).**


## ABSTRACT

This paper investigates the effect of avatar realism on embodiment and social interactions in Virtual Reality (VR). We compared abstract avatar representations based on a wooden mannequin with high fidelity avatars generated from photogrammetry 3D scan methods. Both avatar representations were alternately applied to participating users and to the virtual counterpart in dyadic social encounters to examine the impact of avatar realism on self-embodiment and social interaction quality. Users were immersed in a virtual room via a head mounted display (HMD). Their full-body movements were tracked and mapped to respective movements of their avatars. Embodiment was induced by presenting the users' avatars to themselves in a virtual mirror. Afterwards they had to react to a non-verbal behavior of a virtual interaction partner they encountered in the virtual space. Several measures were taken to analyze the effect of the appearance of the users' avatars as well as the effect of the appearance of the others' avatars on the users. The realistic avatars were rated significantly more human-like when used as avatars for the others and evoked a stronger acceptance in terms of virtual body ownership (VBO). There also was some indication of a potential uncanny valley. Additionally, there was an indication that the appearance of the others' avatars impacts the self-perception of the users.



## CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; *Collaborative and social computing devices*; • **Computing methodologies** → **Virtual reality**; *Computational photography*; *Mesh geometry models*;




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## KEYWORDS

Social Interaction, Avatars, Lifelike, Virtual Reality

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## 1 INTRODUCTION

Avatars are our digital alter-egos in artificially generated virtual environments. Their appearance and presentation to users as owners of the avatars, as well as to others potentially sharing the same Virtual Reality (VR) via their own digital replicas, can cause interesting effects. With owners we here refer to the users directly controlling the individual avatars in a VR and receiving the according generated feedback from the system.

From our own perspective, psychophysical effects like the *illusion of virtual body ownership (IVBO)* [IJsselsteijn et al. 2006; Lugrin et al. 2015; Slater et al. 2008] or the *Proteus* effect [Yee and Bailenson 2007] can (temporarily) change our own body schema and self-image. Various experiments have been conducted to investigate the resulting design space, e.g., by changing avatars' gender [Slater et al. 2010], posture [De la Peña et al. 2010], figure [Normand et al. 2011], skin color [Peck et al. 2013], age and size [Banakou et al. 2013], or degree of realism and anthropomorphism [Latoschik et al. 2016; Lugrin et al. 2015; Roth et al. 2016a].

From the others' perspective, avatar-based social interaction systems [Bente et al. 2008; Blanchard et al. 1990; Roth et al. 2016b; Steed and Schroeder 2015] have been used to investigate behavior changes caused by modification and manipulation of social channels such as gaze behavior [Roberts et al. 2009] and their impact on communication quality [Garau et al. 2003]. First approaches also did investigate the impact of behavioral realism and form realism on others in dyadic scenarios [Bailenson et al. 2006]. Still, none of these approaches explored the effect of the change of avatar realism and anthropomorphic appearance on the owner as well as on the virtual counterpart sharing the VR with us.

### 1.1 Contribution

The work reported in this paper investigates the impact of avatar realism and anthropomorphic human-like appearance in fully immersive full-body dyadic avatar encounters. The developed simulation system provides a social VR where users can inspect their own virtual body to successfully evoke IVBO and to engage in a virtual encounter with a social interaction partner later on. The system includes facilities to generate high fidelity human-like avatars generated from state-of-the-art photogrammetry scans and post-processing procedures in advance for later usage in the simulation.

We compared a) a neutral abstract avatar representation based on a wooden mannequin with b) high fidelity scans of real humans (see Figures 1 and 5). These avatar representations were alternately used as avatars for the own self of the user as well as for the interaction partner cohabiting the same VE.

With IVBO and presence we measured potential effects thought to mainly be caused by the own avatar and the general virtual environment and quality of the presentation. With measures for uncanny valley, co-presence, social presence, rapport, and trust we investigated the social aspects of the dyadic virtual encounter potentially being affected by the other's avatar and quality of presentation. The realistic avatars were rated significantly more human-like when used as avatars for the others and evoked a stronger acceptance as own bodies when used for the users. There also was some indication of a potential uncanny valley. Additionally, there was an indication that the appearance of the others' avatars additionally influences the self-perception of the users.

### 1.2 Structure

The paper will continue with a review of the related work. This will be followed by a description of the experimental design and the methods applied, including a description of the used technical apparatus and the system for the photogrammetry-based avatar generation. Section 5 describes the performed experimental procedure which is followed by a documentation of the results. The paper closes with a discussion and final conclusion.

## 2 RELATED WORK

Various psychophysical effects of virtual embodiment are known today. For example, the *Proteus* effect [Yee and Bailenson 2007] describes a potential behavior change caused by alternative visual and behavioral characteristics of the users' avatars as the digital alter-egos in the artificial virtual environments. The Proteus effect itself is strongly correlated to the IVBO. The IVBO effect describes the users' acceptance of artificial body parts or the whole artificial body to be their own.

The IVBO effect can be routed back to the classical rubber hand illusion [Botvinick and Cohen 1998]. In according experiments, users accept a physical rubber replica, e.g., of one of their forearms and hands, to be their own. This effect is called body ownership (BO). A successful BO has to be provoked and initiated first. For example, in the physical realm this can be achieved by visuo-tactile coherence like stroking the artificial and the real body parts at the same location in synchrony. Successful BO of an artificial body part can be verified. A drastic measure is to cause a threat to the artificial replica. Such a threat usually results in a stress reaction of the user proving the acceptance of the artificial part.

The IVBO effect transfers the BO into the computer generated digital world [IJsselsteijn et al. 2006; Slater et al. 2008]. Like in the real world BO, IVBO is dependent on specific conditions and trigger stimuli to be successfully induced and evoked. For example, bottom-up factors like a visuomotor synchrony between physical movements and virtual imitation is a prominent factor to cause IVBO.

Various effects of avatar embodiment and the change of the avatar appearance are known and are studied in fully immersive VR systems (e.g., [Spanlang et al. 2014]) as well as in partly immersive VR systems (e.g., [Latoschik et al. 2016]). Avatar variants explored include change of gender [Slater et al. 2010], posture [De la Peña et al. 2010], figure [Normand et al. 2011], skin color [Peck et al. 2013], age and size [Banakou et al. 2013], or degree of realism and anthropomorphism [Latoschik et al. 2016; Lugrin et al. 2015; Roth et al. 2016a]. Such studies vary avatar appearance as well as stimulus presentation (e.g., degree of immersion, user perspective) to find out the effects of our own avatars and their presentation on said psychophysical effects.

On the other hand, social interaction in immersive virtual environments has also been investigated using avatar-based systems [Bente et al. 2008; Blanchard et al. 1990; Steed and Schroeder 2015]. These approaches examine social channels such as gaze behavior [Roberts et al. 2009] and their impact on communication quality [Garau et al. 2003] or the dampening of behavioral channels such as head movement and facial expression [Boker et al. 2009].

Similarly to the studies regarding the self-effective avatar impacts, effects of behavioral and form realism have been explored in social virtual encounters using an anthropomorphic interface to transform behaviors to alternative feedback metaphors [Bailenson et al. 2006]. Although this work used a desktop-VR-based system, it was not based on artificial avatars but used video conferencing and the form manipulation did not change the visual appearance but enabled/disabled the latter. Hence, to our best knowledge there currently is no approach investigating the self-effects of our own avatar appearance as well as of the other's avatar appearance in a virtual social encounter.

## 3 DESIGN AND METHODS

We designed a virtual room combining a virtual mirror metaphor as well as a virtual window metaphor to study the impact of avatar appearance of our own avatar as well as of an interaction partner's avatar in one experimental session. See Figure 2 for an overview and Figure 3 for some example renderings as seen by the participants and by the operator. This setup allows to confront participants with their own appearance (direct inspection of the own body from 1st person perspective and in the mirror) as well as with the appearance of another virtual person appearing in the virtual window.

Two evaluation phases were designed according to the spatial setup of the virtual room: Phase 1 is targeting the evocations of IVBO using the mirror metaphor. Participants will first see their own avatars from an ego-centric view via a head-mounted display (HMD) directly looking at their virtual body parts as well as by looking into the virtual mirror (see Figure 3). Audio instruction tell the participants to execute specific movements with their arms and to inspect the resulting display of their virtual body directly or mirrored.

The design of the Phase 2 targets the effects caused by seeing the avatar of a virtual interaction partner. The avatar of the interaction partner appears in the virtual window and waves at the participants. The participants are asked to reply and to wave back. Transition from phase 1 to phase 2 is initiated by audio instructions. A green marker is shown on the floor and users are asked to move to the markers and to look into a specific direction.

### 3.1 Avatar Choice: Pre-Study

8 avatars were tested in a pre-study as suitable candidates for full evaluation. 5 avatars were created from photogrammetry, one avatar was created by a character generator, and two avatars were abstract humanoid characters (wooden mannequin, robot). The pre-study sample included 21 student participants (14 females) with an average age of ($M = 20.90,\ SD = 1.92$). The sample was recruited

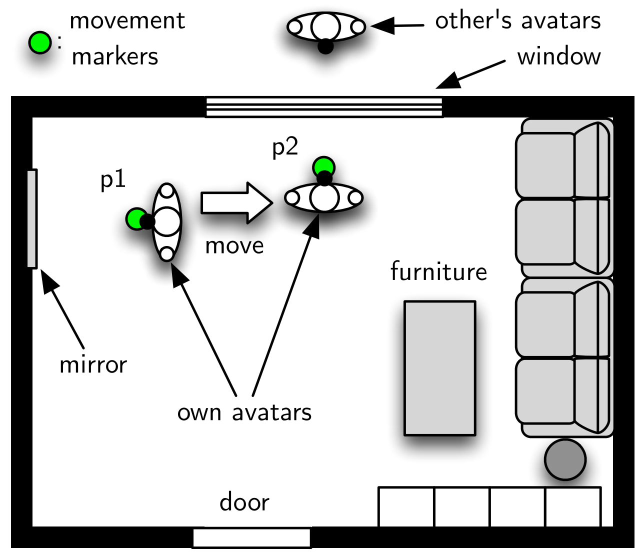


**Figure 2: Spatial layout of the virtual room. p1: place in front of mirror for the embodiment phase. p2: place in front of the window for the social interaction phase. Audio instructions tell users to change position from phase 1 to phase 2.**

**Table 1: All four conditions as combinations of the two factors with two levels for each one.**

| | | Self avatar | |
|---|---|---|---|
| | | 1. woodie | 2. realistic |
| Other's | 1. woodie | a) SWOW | c) SROW |
| avatar | 2. realistic | b) SWOR | d) SROR |

separately from the main study using an internal recruitment system of a medium-sized university. The pre-study was conducted using a computer questionnaire that presented the avatar images followed by the measures. Aside from additional measures we measured *Trust* [Chun and Campbell 1974], *Humanness* and *Eeriness* [Ho et al. 2008], and the *Self-Assessment Mannequin* [Bradley and Lang 1994] used here by the subjects to assess the avatars instead of the self. Figure 4 shows the mean values of the results.

The final selection of avatars chose comparable candidates by equality of ratings across all factors besides humanness and a preferably neutral look (cloths, cloth colors, haircuts). Two types of avatars were chosen for the conditions (see Figures 1 and 5). Avatar type 1 is a wooden mannequin. It has been selected due to its general anthropomorphic form but neutral composition and gender-less properties not trying to resemble any individual human. Since bottom-up visuomotor synchrony is a primary cause for IVBO evocation, this avatar is thought to still deliver a successful IVBO effect given an adequate motion tracking. Avatar types 2 are generated from 3D photogrammetry scans of real persons to achieve an as close to reality look as possible with today's state-of-the-art technology. Type 2 includes female and male avatars (see Figures 5 right and middle respectively) to match the participants' gender.

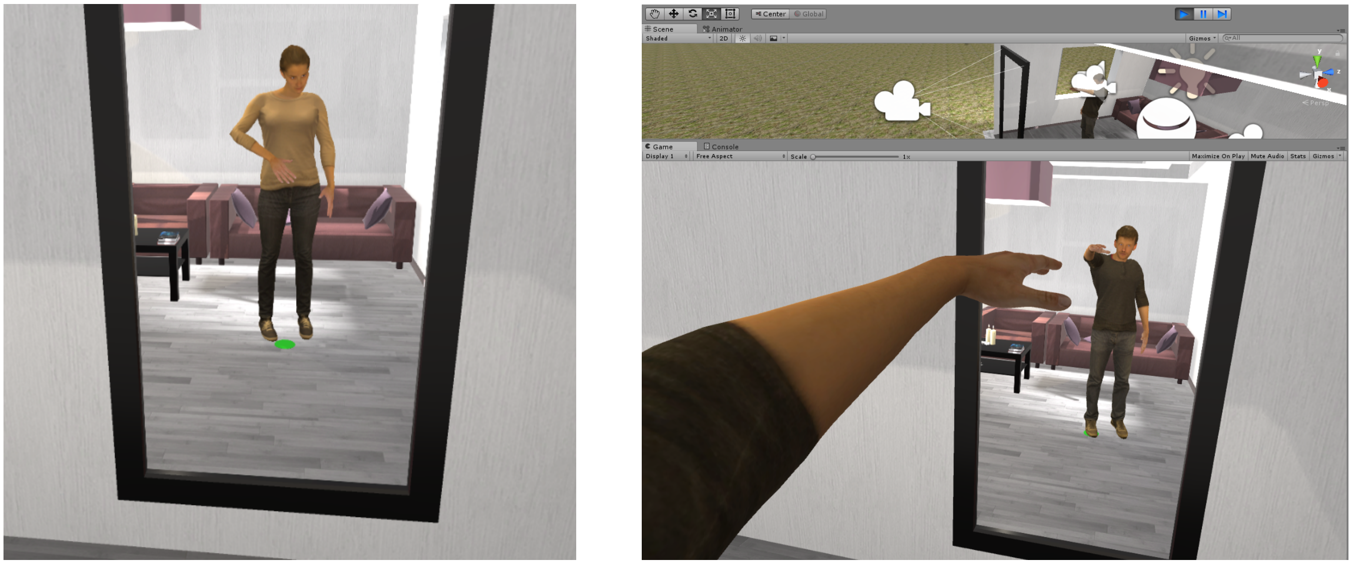

**Figure 3: Embodiment phase 1 to evoke IVBO. Left: User sees her own female avatar in the virtual mirror. Right: Operator control view of a male user inspecting movement of his left arm from 1st person perspective looking down his body and looking in the mirror.**

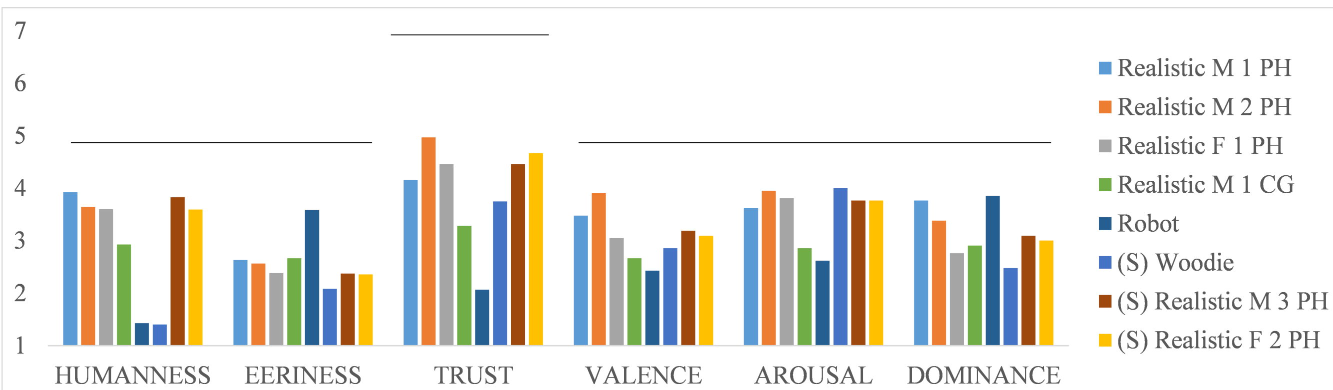


**Figure 4: Results of the pre-study for avatar selection. Selected candidates are denoted by (S). Overall they are comparable in almost every factor besides humanness, which is inline with the target of the main study.**

The two types of avatars are then used as two levels for the two factors (1) participants' own avatars and (2) avatars of the respective interaction partner of phase 2 in the window. The resulting 4 potential combinations are listed in Table 1. The combinations were then applied as randomized test conditions in the experiment using a 2 x (self-avatar) x 2 (other-avatar) within-subjects design. Figure 1 illustrates the two resulting asymmetric conditions.

## 3.2 Measures

The following measures were taken for each condition to analyze the effect of the change of avatar appearance on the participants:

(1) **IVBO** [Roth et al. 2017] with the three components *Acceptance* (e.g. "I felt as if the body I saw in the virtual mirror might be my body.", "The virtual body I saw was humanlike."), *Control* (e.g. "The movements I saw in the virtual mirror make seemed to be my own movements", "I felt as if I was controlling the movement I saw in the virtual mirror"), and *Change* (e.g. "At a time during the experiment I felt as if my real body changed in its shape, and/or texture.", "I felt an after-effect as if my body had become lighter/heavier."). Measured in Likert style response format (1="strongly disagree", 7="strongly agree").

(2) **Uncanny Valley** [Ho et al. 2008]. Semantic differential with the three components *Humanness* (e.g. "human-made" vs. "humanlike", "artificial" vs. "natural"), *Eeriness* (e.g. "reassuring" vs. "eerie", "numbing" vs. "freaky"), *Attractiveness* (e.g. "unattractive" vs. "attractive", "ugly" vs. "beautiful").

**Figure 5: Close-up of the three avatars used in the study. From left to right: The gender-neutral woodie avatar. The male avatar generated from 3D photogrammetry scans. The female avatar generated from 3D photogrammetry scans.**

Measured in a five point bipolar response format (semantic differential).

(3) **Co-presence** [Nowak and Biocca 2003] with the components *Self-reported copresence* (e.g. "I tried to create a sense of closeness between us.", "I wanted to make the interaction more intimate."), *Perceived other's copresence* (e.g. "My interaction partner seemed to find our interaction stimulating.", "My interaction partner created a sense of closeness between us."). Items were adapted for the purpose of the study (i.e. "conversation" was replaced with "interaction") and measured in Likert style response format (1="strongly disagree", 7="strongly agree").

(4) **Rapport** [Gratch et al. 2015], (e.g. "I felt I had a connection with my interaction partner.", "My interaction partner communicated coldness rather than warmth." ). Adapted for the purpose of the stude (i.e. "the listener" = "my interaction partner") and measured in Likert style response format (1="strongly disagree", 7="strongly agree").

(5) **Telepresence** [Nowak and Biocca 2003], (e.g. "How involving was the experience?", "To what extent did you feel immersed in the environment you saw/heard?" ). Measured in Likert style response format (1="not at all", 7="very much").

(6) **Social presence** [Nowak and Biocca 2003], (e.g. "To what extent was this like a face-to-face meeting?", "To what extent did you feel you could get to know someone that you met only through this system?"). Measured using a sliding scale format (not agreeing to the statement vs. agreeing to the statement).

(7) **Trust**, according to three items designed on the basis of [Chun and Campbell 1974]). "The following statements refer to the other character, that you stood in front of in the virtual environment. Please indicate on the scale how much the following statements apply according to your opinion.". "I think the virtual character has good intentions.", I would count on the virtual character.", "I would trust the virtual character.". Measured in Likert style response format (1="does not apply at all", 7="applies totally").

The list reflects the order of measurements taken after each condition. Measures 2 (IVBO) and 6 (presence) analyze psychophysical effects on the participant thought to mainly be caused by the own avatar and the general virtual environment and quality of the presentation. Measures 1, 3–5, and 7 investigate social aspects of the dyadic virtual encounter potentially be affected by the other's avatar and quality of presentation.

## 4 SYSTEM DESCRIPTION AND APPARATUS

The simulation system was developed using the Unity engine V 5.6 64bit running on a Windows 10 host system. Figures 6 (left) and 7 illustrate the operator view of the running system. Movement of the participants was captured via an optical *Optitrack* tracking system based on infrared retro-active markers (see Figure 8). Participants had to wear motion capture suits to cover all body movements (see Figures 1 (right), 6 (right), and 8).

The virtual scene was displayed to the participants via the consumer version of the Oculus rift HMD. It supports a 110° (diagonal) field of view with two 1080×1200 pixels OLEDs per eye at a 90Hz display refresh rate for a combined resolution of 2160 x 1200 pixels. The built-in earphones were used to deliver the required audio feedback and audio instructions.

**Figure 6: Left: Operator station with investigator monitoring the execution phase with an additional virtual view (right monitor) of the participant and the sensor layout. Right: Final gear-up of participant in the physical experimental space.**

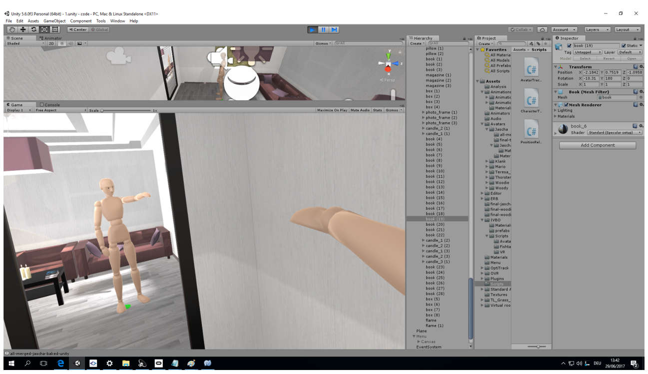

**Figure 7: Screenshot of the operator view of the running system with two rendered views of the scene. Top left: 3rd person view of the virtual room. Bottom left: 1st person view of the participant. Right: Unity inspector views.**

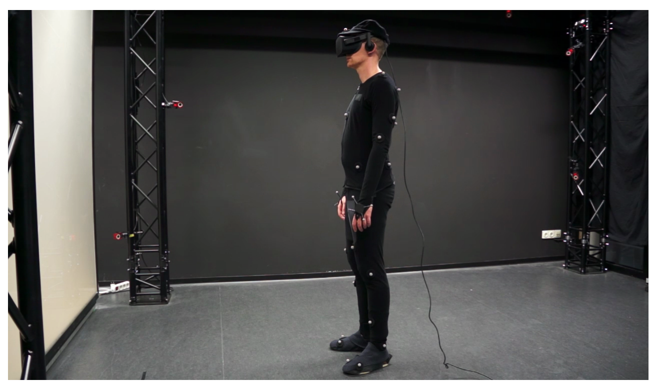

**Figure 8: Participant at start of the execution phase in the physical experimental space.**

## 4.1 Avatar Generation

The realistic avatars were generated by scanning two real persons using a multiview-stereo rig consisting of 40 DLSR cameras capturing the full body (see Figure 9) and 8 DLSR cameras dedicated to the face region (see Figure 10). From this data two 3D point clouds (body, face) were computed using the commercial multiview reconstruction software Agisoft PhotoScan.

In order to cope with missing data and to be able to animate the resulting characters, a fully rigged template model with all required animation controllers (built with Autodesk's Character Generator) was fit to the two scanner point clouds. High quality texture images were derived from the camera images. A detailed description of the scanning system and the respective pipeline for data processing can be found in [Achenbach et al. 2017].

# 5 PROCEDURE

The overall procedure of each experimental run was separated into 7 steps:

(1) Preparation: Registration of next participant in the online survey system used to present the different questionnaires. Registration of initial condition for the participant. Lay out of required forms (e.g., consent form). Cleaning of equipment (HMD etc.).

**Figure 9: The developed photogrammetry rig used to scan the full bodies.**

**Figure 10: The developed photogrammetry rig used to specifically scan the faces to achieve higher texture resolution.**

(2) Welcome: Explanation of the general process of the trial. Introduction into the desktop-based questionnaire setup. Inform about the option to ask for help or assistance or to give comments at any time.
(3) Consent: Filling out consent form and providing information about potential health issues.
(4) Gear-up: Find fitting motion capture suit and dress-up of participant (in privacy). Placement of tracking markers afterwards.
(5) Demography: Filling out demography and trait empathy questionnaires [Spreng et al. 2009] online using the desktop system. Pointing to available online help and assistance.
(6) Execution: Participant turns to investigator and delivers initial start code. Inform participant about potential cyber sickness and that they should instantly flag such incidences to investigator. Inform participant about the structure of the upcoming execution phase and about the audio instructions they will hear via headphones.
The continuation of step 6 is split in 3 phases and executed 4 times for each participant. Each participant is tested with the conditions from Table 1 in randomized order.
   (a) Phase 1 (Self avatar embodiment): Participants enter the virtual word and step in front of the virtual mirror. Audio instructions tell them to alternately perform 4 movements of the right and left arm and to inspect the results of their virtual body and its mirrored image to induce IVBO. Duration: 120s.
   (b) Phase 2 (Other avatar interaction): Participants are asked to move away from the virtual mirror to a specific position (marked by a green spot on the floor) in front of the virtual window. A virtual interaction counterpart appears in the window and participants are instructed to repeat the shown behavior (waving with right hand) of the other. Duration: 60s intro + 10s interaction.
   (c) Phase 3 (Report): Participants leave the virtual world and fill-out the self-reports of the taken measures at the desktop station.
(7) Closing: participants are de-equipped, equipment is stored and participants are bid farewell.

## 5.1 Participants

A student sample of 21 German participants was recruited. One participant had to be excluded because of problems in data logging. The final sample consisted of 11 female and 9 male students between 19 and 24 years of age ($M = 20.25, SD = 1.21$). Participants were recruited using an internal recruitment system of a medium-sized German university. None of the participants reported severe motor, auditive or visual disabilities/disorders. 5 participants had to correct eye-sight (glasses or contact lenses), 2 of them executed the trials without corrective measures. 16 participants had experienced a VR system before. Three participants had to be excluded due to technical and organizational reasons. 4 Participants were left-handed.

# 6 RESULTS

Data were analyzed using two factorial ANOVAs for repeated measures on all measures taken.

## 6.1 Humanness, Eeriness and Attractiveness

We analyzed the participants judgment of the virtual interactant ("Other Avatar") that was present in front of the window during the interaction phase on the basis of the *Humanness*, *Eeriness* and *Attractiveness* factors from [Ho et al. 2008].

Results revealed a significant main effect for "Other Avatar" ($F_{1,19} = 10.91,\ p = .004,\ \eta_p^2 = .365$). Pairwise comparisons showed

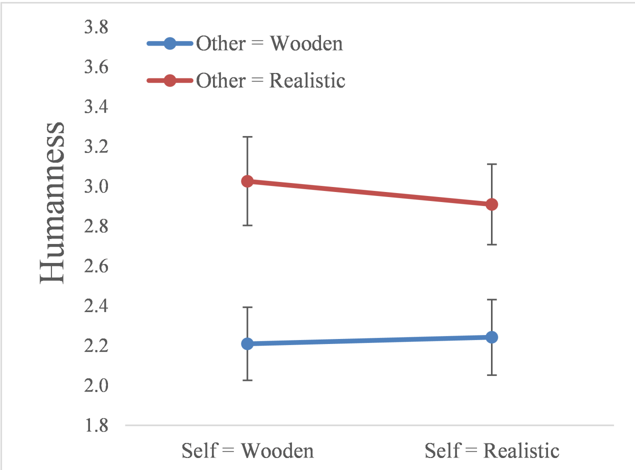


**Figure 11: Results for the *Humanness* factor from the uncanny valley measure. Intervals display standard error of mean values.**


**Figure 12: Results for the *Acceptance* factor from the IVBO measure. Intervals display standard error of mean values.**

a higher score for *Humaneness* for the realistic avatars constructed with photogrammetry ($M = 2.97$, $SE = 0.16$) compared to the wooden mannequin ($M = 2.23$, $SE = 0.20$) (see Figure 11). Analysis for *Eeriness* revealed a slightly higher value for the human avatars ($M = 2.703$, $SE = 0.14$) compared to the wooden mannequin ($M = 2.556$, $SE = 0.15$), however none of the factors reached significance. Analysis for *Attractiveness* revealed a slightly higher value for the wooden mannequin ($M = 3.220$, $SE = 0.11$) compared to the human avatars ($M = 3.160$, $SE = 0.11$), but did not reach significance. No other significant main effects or interaction effects were found in this category of measures. Scale reliabilities were acceptable to good with $\alpha$'s>= .762.

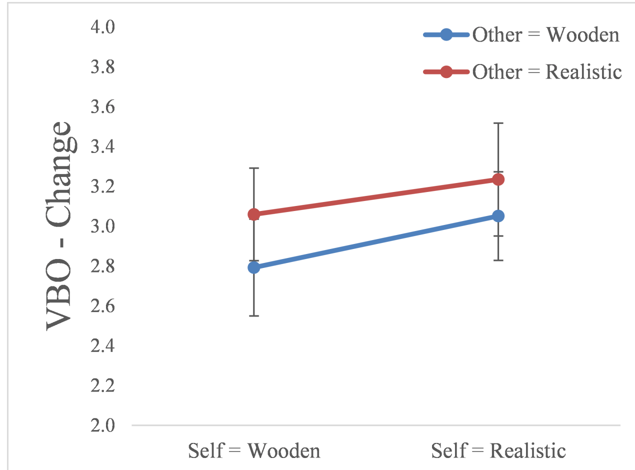


**Figure 13: Results for the *Change* factor from the IVBO measure. Intervals display standard error of mean values.**

## 6.2 Virtual Body Ownership

Analysis for the *Acceptance* factor showed a significant main effect for "Self Avatar" ($F_{1,19} = 6.19$, $p = .022$, $\eta_p^2 = .246$) (see Figure 12). Pairwise comparisons showed a higher rated *Acceptance* for the realistic photogrammetry avatars ($M = 4.63$, $SE = 0.24$) compared to the wooden mannequin ($M = 3.72$, $SE = 0.308$), indicating that the human avatar body had higher acceptance to be "the own body".

Interestingly, we found a marginal significant effect for "Other Avatar" in the factor *Change*, that measures the change in self-perception toward the own body ($F_{1,19} = 4.21$, $p = .054$, $\eta_p^2 = .181$). This might indicate that the perception of the own body and the perceived ownership of the own virtual body is affected by the interactant's avatar. Pairwise comparisons showed a higher value for the perceived *Change* if the interactants Avatar ("Other Avatar") was a realistic human ($M = 3.15$, $SE = 0.23$), than if the "Other Avatar" was a wooden mannequin ($M = 2.91$, $SE = 0.20$).

No further interaction or main effects were found in this category. Scale reliabilities were acceptable to good with $\alpha$'s>= .733 with the exception of the *Control* factor scale in the self - wooden mannequin / other - wooden mannequin condition.

## 6.3 Other Measures

We did not find any significant results in the analysis of the measures for presence, trust, and rapport.

## 6.4 System and Performance

The overall end-to-end motion-to-photon latency (tracking to display) was measured by manual frame counting similar to [He et al. 2000]. Several hand-clapping motions were recorded multiple times with a high-speed camera as well as with the simulation system and the resulting sequences were compared to each other. The comparison images were taken with the built-in video camera of the Apple iPhone 6 series, which operates at 240 Hz in the so-called slow-motion mode. Measurements revealed an overall motion-to-photon system latency of $M = 80.8$ ms, $SD = 14.62$ ms.

Notably, the reference images were taken from the operator's screen and not the HMD. Hence these results do not reflect the motion-to-photon latency to the HMD but to a second reference screen operating at 60 Hz. In out experience such typical desktop monitors deliver an inferior performance w.r.t. latency compared to today's consumer HMDs and the major goal was to verify the overall latency to be acceptable for an interactive experience.

## 7 DISCUSSION

The found main effect for *Humanness* of the uncanny valley measure for the realistic avatar was expected from the experimental design. It verifies the scanned avatars to look more humanlike and hence realistic than the woodie avatar which in general confirms the overall capabilities of the developed 3D scan and post-processing pipeline. The slightly higher but not significant values for *Eeriness* for the realistic avatars and for *Attractiveness* for the woodie avatar might indicate a potential uncanny valley effect which might either be caused by some of the constraints of the overall experimental design and/or the overall degree of realism achieved with current technology for 3D body scans and avatar reconstruction.

With respect to the experimental design we decided to exclude face tracking and to limit the actual social interaction phase to an imitation of one non-verbal behavior displayed by the avatar of the interaction partner in a short sequence. Both decisions were made to ensure avoidance of potential confounds while the duration was still long enough to provoke appropriate responses following [Ambady and Rosenthal 1992]. Still, mimics convey important social cues which we will incorporate in upcoming work to identify their absence to potentially contribute to *Eeriness* and *Attractiveness*.

The realistic avatars also evoked a significantly higher *Acceptance* of the virtual body to be one's own body concerning the illusion of virtual body ownership. This is in line with prior results which do identify a human appearance to be important as a top-down factor for IVBO. The system's end-to-end latency performance was well below 150ms often considered as an upper threshold necessary for an interactive VR experience. Since as a result all tested conditions had a comparable bottom-up visuomotor synchrony, we conclude that here the appearance of the avatar as a top-down factor came into effect.

The marginal significant effect found for the *Other Avatar* for *Change* came as a surprise. It indicates an impact of the appearance of the other's avatar on self-perception towards the own body. The latter is known to be of a certain plasticity if the own avatar's appearance is changed with respect to, e.g., gender [Slater et al. 2010], posture [De la Peña et al. 2010], figure [Normand et al. 2011], skin color [Peck et al. 2013], age and size [Banakou et al. 2013], or degree of realism and anthropomorphism [Latoschik et al. 2016; Lugrin et al. 2015; Roth et al. 2016a]. Our results indicate that in social interactions in VR, the appearance of the other's avatars additionally influences our self-perception. In our results, a more realistic looking other avatar seemed to increase our impressions of the changed own body and hence it helped to increase the suspension of disbelief for the respective avatar owners.

## 8 CONCLUSION

In this work we investigated the effects of personalized avatars generated with a state-of-the-art photogrammetry 3D scan pipeline we have developed. Our results demonstrated a number of effects that initially could have been expected but nevertheless benefited from empirical confirmation. It also confirmed the quality of our scan pipeline. The scanned avatars do appear to be more humanlike and they stimulated a higher body ownership of the artificial bodies. There also was a novel finding. Related work demonstrated the impact the appearance of their own avatar has on users, e.g., with respect to virtual body ownership or the Proteus effect. Our results indicated, that additionally the appearance of others' avatars in social encounters does also affect users in their self-perception towards their own body.

Realistic-looking virtual humans will potentially play an important role in future embodied interfaces based on Augmented and Virtual Reality technology. Recent advances in 3D scan technology paves the way for personalized avatars which resemble the appearance of their biological real-world owners. Such personalized avatars with a realistic appearance are important even beyond their straight-forward applications, e.g., in virtual dressing rooms. Identity is an important aspect of our selfs and the way we look significantly contributes to our self-perception and identity.

Future immersive virtual encounters might free us from our restrictive physical bodies but as in real world social encounters, situations may arise which call for congruent identities between physical and virtual realms, e.g, in situations of mixed real/virtual encounters, business scenarios, or for believability or even for legal matters. If and how realistic human-like appearances of avatars contribute to the psychophysical effects known form VR experiences is hence important to know about. In this work we could show that current 3D scan technology is capable of increasing the human-likeliness of avatars in immersive social Virtual Realities and we could also identify potential interesting cross-effects the look of the other has on our own self-perception.

### 8.1 Future Work

Future work will proceed in the following directions: On the one hand we will optimize the overall 3D scan and post-processing pipeline to be able to further reduce the overall overhead necessary to generate personalized rigged and blend-shaped avatars. Also, we'd like to optimize the final real-time lighting and shading to include, e.g, specialized shaders for subsurface scattering etc., to increase the realistic appearance of the avatars.

On the other hand, further evaluations will adopt the optimized avatars to investigate the potential uncanny valley and the potential localization of our avatars with respect to the latter. In addition, upcoming studies will investigate the impact of more avatar variations and longer pantomimic interaction phases which will include face tracking, specifically on the effects of the other's look on the self-perception of the interacting user.

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