RealME: The Influence of Body and Hand Representations on Body Ownership and Presence

Sungchul Jung
University of Central Florida
4000 Central Florida Blvd
Orlando, Florida, USA 32816
sungchul@cs.ucf.edu

Christian Sandor
Nara Institute of Science and Technology
8916-5 Takayama
Ikoma, Nara, Japan 630-0192
chris.sandor@gmail.com

Pamela J. Wisniewski
University of Central Florida
4000 Central Florida Blvd
Orlando, Florida, USA 32816
pamwis@ucf.edu

Charles E. Hughes
University of Central Florida
4000 Central Florida Blvd
Orlando, Florida, USA 32816
ceh@cs.ucf.edu

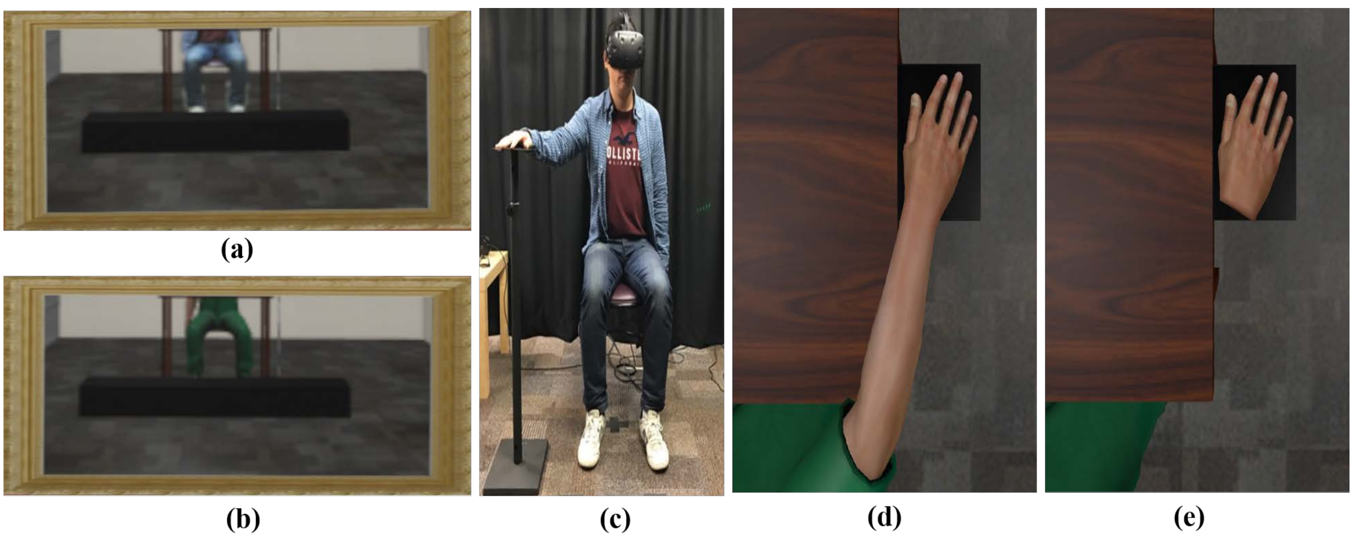

Figure 1: Experimental setup: We provided two types of body reflection through a virtual mirror while the participants looked at a virtual hand and arm from a first person perspective. (a) Visually personalized body reflection where the clothes and shape are identical to those of the participant seen in (c). (b) Generic Avatar body representation. (d,e): Two levels of hand representation. (d) Fully modeled limb from shoulder to hand. (e) Arm removed resulting in disconnected hand.

ABSTRACT

The study presented in this paper extends earlier research involving body continuity by investigating if the presence of real body cues (legs that look like and move like one's own) alters one's sense of immersion in a virtual environment. The main hypothesis is that real body cues increase one's sense of body ownership and spatial presence, even when those body parts are not essential to the activity on which one is focused. To test this hypothesis, we developed an experiment that uses a virtual human hand and arm that are directly observable but clearly synthetic, and a lower body seen through a virtual mirror, where the legs are sometimes visually accurate and personalized, and other times accurate in movement but not in appearance. The virtual right hand and arm are the focus of our scenario; the lower body, only visible in the mirror, is largely irrelevant to the task, providing only perceptually contextual information. By looking at combinations of arm-hand continuity (2 conditions), freedom or lack of it to move the hand (2 conditions), and realism or lack of it of the virtually reflected lower body (2 conditions), we are able to study the effects of each combination on the perceptions of body ownership and presence, critical features in virtual environments involving a virtual surrogate.

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CCS CONCEPTS

•**Human-centered computing → User studies; Virtual reality;** *Mixed / augmented reality;*

KEYWORDS

User Study; Virtual Reality, Virtual Body Ownership, Body Continuity, Presence; Human Computer Interaction

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1 INTRODUCTION

A person's perception of their body, called body ownership [18], and their recognition of the surrounding environment, called (physical or spatial) presence [15], are known to be factors that are critical to one's senses of identity and experience. These concepts, initially studied in psychology and neuroscience, have been extensively investigated by the Virtual Reality (VR) community, taking advantage of its ability to create realistic illusions, enabled by high resolution head mounted displays (HMDs) and accurate tracking technologies. Using VR technologies, virtual body ownership (the illusion that a virtual body is one's own) and (spatial) presence (the illusion that we are in a synthetic environment) can provide a strong sense of immersion by stimulating associations between physical and virtual body parts. However, most published studies focus on the association of a physical body part to a visually virtual counterpart without considering person-specific visual features, even though our perception is closely related to visual stimulations in the human brain [28]. In fact, humans can notice realistic body features (color, texture, etc.) because our brain forms the connection based on explicit and implicit memory associated with the actual body [7]. Based on this insight, Jung and Hughes [10] began to measure the effect of real body cues for virtual body ownership.

In the study reported here we extend those earlier experiments to investigate the interplay between arm-hand continuity, freedom of hand movement in the presence of a threat, and realism of a lower body reflection (from middle torso to legs in a sitting position) that is personalized but not directly relevant to the user's central focus. Our goal is to investigate how combinations of each of these factors influence the illusions of virtual body ownership (primary) and presence (secondary).

Recently, researchers have shown that the visually unbroken connection of body parts from shoulder to hand, called body continuity, provides a supporting factor to elicit virtual body ownership [17]. Earlier research [10] has also shown a tendency of personalized visual cues to elicit the psychological illusion of body continuity between a virtual hand and forearm corresponding to a user's real body. In our research, we investigate the effect of personalized body cues on body continuity, testing two levels of detail. Also we examine agency [27], which is the sensation of controlling the virtual body, because the coordination of movement and visual perception, visuomotor, has been shown to be a significant factor for virtual body ownership [20].

In our experiment our primary focus is on virtual body ownership; however, we are also interested in spatial presence, the sense of "being there" [23], since the sense of presence in a virtual environment is closely related to one's virtual body representation [22]. We designed our experiment to provide either a visually personalized body cue or a generic avatar body cue, always seen as a reflection of one's lower body in the absence of artificial tactile sensory stimulation.

To investigate the effect of a visually personalized body cue, we placed a virtual mirror in front of the participants so they could see their lower body reflection (See Figure 1 (a)). A virtual mirror was also used in previous research [10, 11]. Those studies showed that seeing a reflected avatar body from the first person perspective helps to elicit a greater illusion of body ownership than if there is no visual representation. The study reported here builds on those previous experiments by comparing the influence of a personalized visual body cue versus that of a generic avatar body cue.

The virtual mirror was positioned so participants could observe their reflected lower body, mainly their legs, while performing a specified task with a virtual hand. To prevent a bias from rendering artifacts as described in [10], we used the RGB pixel values and the depth information from an RGBD camera to render the participant's lower body. Because of the low resolution of our RGBD camera, the reflected image on the virtual mirror seemed relatively fuzzy, but most participants easily recognized the personalized body rendering as their own body. While participants looked at the virtual environment involving the mirror reflection, we provided two levels of virtual arm/hand representation – fully rendered from shoulder to hand, and arm removed resulting in a disconnected hand (See Figure 1 (d) and (e)) with two types of motor action – a movement-enabled hand and a movement-disabled hand.

Each participant experienced one of two body reflection types with both hand levels and both motor action conditions, so the total combinations of conditions experienced by a single participant were four. We clearly asked each participant to occasionally look at the body reflection while they were performing the given task, which means that, except for the visual difference, all conditions were identical for all participants.

To our knowledge, there is no previous experiment that compares the relative effect of a visually personalized body cue to that of a virtual body cue on the illusions of ownership and presence. The results of our experiment, which we will explain in detail in the analysis section, provide statistical support for our hypothesis that a personalized body cue enhances the sense of body ownership and presence more than does a generic one, even when the body part being displayed is irrelevant to the required task.

2 RELATED WORK

As virtual reality technology evolves, researchers are better able to investigate conditions that support a human's perception of a virtual body in a computer generated environment. Existing research has shown that an avatar's resemblance to human appearance, synchronous visuo-tactile cues, synchronous visuo-motor cues, positional congruence, and anatomical plausibility [12, 17] are all major factors for virtual body ownership illusion. In addition, the existence of visually connected body parts, called body continuity, has been shown to be a supportive factor for the virtual body ownership illusion. While the virtual body ownership illusion represents perception regarding a synthetic body, presence indicates perception regarding existence in a virtual or remote space. In this section we will present an overview of some existing research related to the illusions of virtual body ownership and presence. (Note: We will often abbreviate the term virtual body ownership illusion as VBOI and body continuity as BC.)

2.1 Virtual Body Ownership

Because the hand is the most frequently used human part during the performance of tasks, hand ownership has been studied widely in both real world and virtual reality research. Botvinick and Cohen investigated body ownership using a fake rubber hand [5]. An extended version of the rubber hand experiment was studied in virtual reality by Ye and Steed [30]. Similar to the rubber hand experiment, Petkova et al. conducted a body ownership study using a mannequin [18]. Argelaguet et al. conducted a study for virtual arm ownership to discover correlations between the human visual and motor sensory systems in a purely virtual environment [1]. They demonstrated that the morphologically realistic resemblance of the virtual hand is a significant factor for one's sense of virtual hand ownership. Hoyet et al. [9] studied body ownership issues using unnatural hand shapes with a similar setup to that of [1]. They used a virtual hand with six-fingers and showed that the six-finger hand still elicited body ownership despite the explicit structural difference from a user's real hand. Recently, Lugrin et al. investigated virtual body ownership with anthropomorphic models that included a robot avatar, a generic avatar and a human avatar, each appearing in a purely virtual environment [14].

To investigate the correlation between visual real body cues on the visual illusion of a virtual hand, Jung and Hughes [10] studied the impact of a virtual mirror reflection of a subject's lower torso. That study suggested a tendency of a trunk-centered real body cue to increase virtual hand ownership. Using a virtual mirror in a virtual body ownership experiment is not a new idea, and is one that has been addressed from a variety of research perspectives [3, 8, 11]. Using the mirror reflection, González et al. observed a relation between motor actions and virtual body ownership that suggested a synchrony of the mirror-reflected avatar with a participant's movement was an important factor in one's sense of body ownership [8]. Kilteni et al. studied the relationship of the appropriate appearance of context on virtual body ownership [11]. In their study, participants played a drum with different costumes, seeing their appearance through mirror reflection. Their study demonstrated the cognitive consequence of proper consistency between visual appearance and task context.

2.2 Virtual Body Ownership and Body Continuity

Body continuity refers to visually connected body parts, as in the connection of a hand to its shoulder through a wrist and arm. Pérez et al. experimented with a fully represented hand but no arm to connect it to the rest of the body [17]. The goal was to find the relationship of body connectivity to virtual body ownership. Their results suggest that body continuity is a supporting factor for the illusion of virtual body ownership. To further investigate body continuity, Tieri et al. studied various types of hands – full limb, wire-connected hand, removed wrist, and missing wrist replaced by a plexiglass hand to arm connection [25, 26]. They demonstrated that, while the full limb case elicited the strongest sense of body ownership, even an artificial wire connection between hand and forearm elicited an autonomic reaction, e.g., involuntary protective movement, as a virtual body ownership indicator. Also Blenke at al. studied body ownership in the context of face, hand and trunk, and argued that the multisensory signals in the space immediately surrounding our trunks is of particular relevance to self-consciousness [4].

2.3 Presence

Presence indicates the sensation of behaving and feeling as if one is in the computer generated world [19]. Presence is categorized into three classifications: social presence – the sense of not only sharing space but also sharing an experience with another entity [23], co-presence – the sense of being in a shared space with another entity [2], and physical presence or spatial presence – the perception of existing in another space [15]. In this paper, we focus on spatial presence because our study investigates the effect of visual perception to participants feeling since spatial presence is closely related to a mental feedback from unconscious human cognitive process to given environments [21]. In general, presence is measured by using questionnaires and by observing a participant's reaction to stimuli, most often in the form of threats [23].

3 EXPERIMENT

To investigate the effect of a personalized visual body representation, we developed a virtual office space that includes a virtual mirror to reflect a personal body or avatar body as a visual cue. In this experiment, we examined virtual body ownership – including body continuity and agency – and presence as dependent variables. For independent variables, we chose varying body representations, levels of hand representation, and motor action capabilities. We used subjective measures based on a questionnaire with a 7-point Likert scale. Our experiment is a 2x2x2 mixed Within-Between factorial design intended to show the effect of a personalized body representation. We divided the participants into two groups, one for personalized visual body representation, and one for generic avatar body representation (Between factor with two levels). Each group experienced both hand representations (Within factor with two levels) and motor actions (Within factor with two levels). To prevent an ordering effect, we used a counter-balanced ordering. Our experiment was approved by our organization's Internal Review Board Office.

3.1 Research Hypotheses

Starting with results from previous research [10], we conducted our experiment to find answers for the following research questions: (1) "Do personalized visual body cues influence the sense of body ownership of one's virtual hand and of one's sense of presence?" If yes, (2) "Do personalized visual body cues create psychological continuity between a participant's real body and their purely virtual hand?" The following hypotheses are based on prior results from

[10] and our beliefs concerning the effect of a personalized visual body representation.

- **Body Representation** Using a personalized visual body reflection will be more immersive than having a generic avatar body reflection.
- **Body Continuity** A virtual body with a continuous, full arm will be more immersive than a virtual arm where the limbs between hand and shoulder have been removed.
- **Body Motion** Allowing users to move their hand will be more immersive than requiring them to keep their hand in a static position.
- **Combination** The combination of personalized body representation with a full hand, enabled with dynamic motor action, will give the highest levels of VBOI, BC, agency and presence.

3.2 Participants

For this experiment, we conducted a priori power analysis to determine our sample size before recruiting participants. Using G*Power, to detect a medium effect size with a power of 0.80, we needed a minimum of 24 participants [6]. We recruited participants with normal to corrected-to-normal vision using on-campus fliers. Most participants had higher education backgrounds and were studying in diverse majors, but mainly in computer science. We conducted our experiment with 41 participants. We divided the participants into two groups, one with 21 participants (15 male, 6 female, Mean Age = 21.1, SD=2.92) for personalized visual body representation and the other with 20 participants (15 male, 5 female, Mean Age = 21.65, SD=2.50) for avatar body representation. Because of a data logging problem, we omitted one person's data (male) from the personalized body cue group. Therefore we conducted the experiment with 40 participants, evenly divided into two groups of 20 each. Most of the participants had a small number (under 5 times) of experiences wearing an HMD. We gave each a $10 gift card for their participation.

3.3 Experimental Platform

We designed a physical experiment space isolated from any visual interference. To reduce fatigue for the participants during the experiment, we had them sit on a stool and rest their right hand on a stand. We used an HTC Vive to provide the virtual environment, and the HMD was tracked using the Vive's tracking system. To render each participant's lower body, we placed an RGBD camera in front of the stool so we could capture their lower body. We created a virtual office model similar to the physical experiment space except for the presence of a table and small foot occluder in the virtual space (See Figure 2). Note that, due to physical stand' narrow width, its placement and the focus of the RGBD camera, the stand is not seen by the camera, and so only its synthetic counterpart appears in the virtual world.

In the virtual office, we included a table in front of the participants and a prop to their right side that mimics the stand present in the real space. To represent the personalized visual lower body part seen on the virtual mirror, we rendered the RGB pixel values with matched depth values on a plane and reflected the image onto the virtual mirror. Because of limited fidelity of the depth value for body parts close to the floor, the feet were not rendered correctly, so we hid that part with a block cube occluder located on the floor.

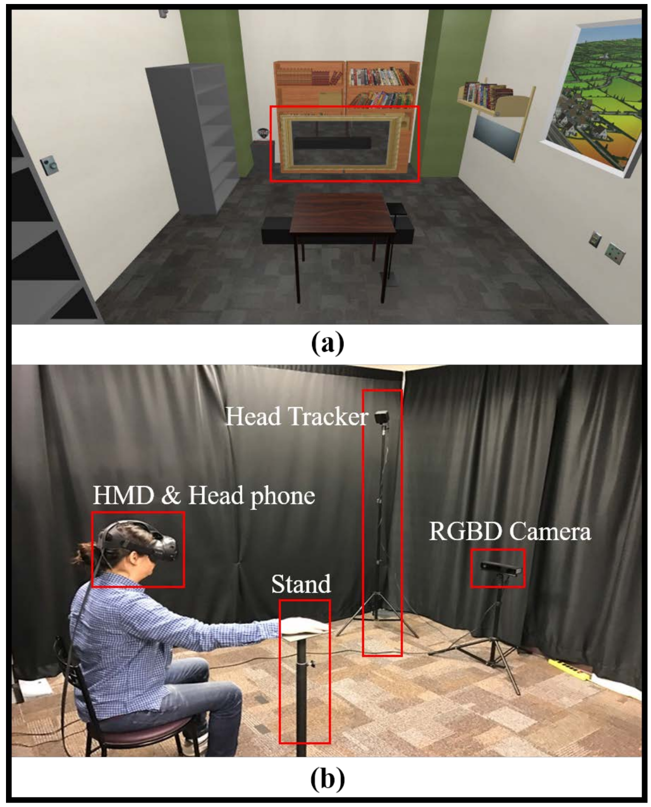

Figure 2: Experiment environments. (a) Virtual office. (b) Physical setup

3.4 Questionnaire

To operationalize our dependent measures for Virtual Body Ownership [1], Body Continuity [25], Agency [1], and Presence [13], we drew items from pre-validated survey instruments based on relevant literature. However, we modified some of the wording and chose the items that were most relevant to our current study. For example, an item selected for Virtual Body Ownership was, "I felt that my real body was endangered during the experiment." We altered this item to be more specific to the current experiment: "You felt that your hand was endangered by the falling rock." Similarly, we modified a question from previous research, "How much do you have a feeling of being in underwater? [13]" to "You felt as if you were physically present in the office room." for measuring spatial presence. To avoid distractions while immersed within the virtual environment, we chose to ask only one direct question for presence that participants heard through the headset during the experiment. We did this in lieu of adopting the more extensive presence questionnaire developed by [29]. This methodological decision was influenced by prior work also published in the domain of virtual body ownership and spatial presence [13, 30]. All items were measured on a 7-point Likert scale from 1 = Strongly Disagree to 7

Table 1: Questionnaire

Item	Question	Source
VBOI α=0.73	You felt as if the virtual hand was your own.	I felt as if the virtual representation of the hand was part of my body. [1]
	You felt that your hand was endangered by the falling rock.	I felt that my real body was endangered during the experiment. [1]
BC α=0.85	You felt as if the virtual hand started to look like your own.	I felt as if I were looking at my own hand [25]
	You felt as if the virtual hand was a part of your body.	I felt as if the virtual hand were part of my body. [25]
Agency α=N/A	You felt as if you could control the virtual hand.	I felt like I controlled the virtual representation of the hand as if it was part of my own body. [1]
Presence α=N/A	You felt as if you were physically present in the office room.	How much do you have a feeling of being in underwater? [13]

= Strongly Agree. Items for each construct were averaged to create composite indices for analysis. Because we modified questions from pre-validated survey instruments, we calculated Cronbach's alpha as a metric for construct validity [16, 24] for Virtual Body Ownership and Body Continuity. The reliability of these measures was above the acceptable threshold of 0.7 [16, 24]. Since Agency and Presence were both measured with a single item, we treated these measures as interval data (instead of as a continuous variable) in our analyses. Table 1 presents the wording of all measures used in the current study compared to the original items that were drawn from the literature. It also reports Cronbach's alpha metrics for the multi-item constructs.

3.5 Protocol

Prior to starting the experiment, we asked each participant to read our informed consent and fill out their demographic information. After they had filled out demographic data, we asked them to sit on a stool in the experiment room and gave them information about our study related to their experiencing the system. We were insistent that their initial pose have them sitting on the chair in a normal forward facing position toward an RGBD camera and that they place their right hand on the physical stand. We then placed the Vive HMD and headphones on the participant and asked them to look at their right arm, from the shoulder to hand, at least once while in the VR environment, and to look at the virtual mirror to observe their lower body representation as well. The participant listened to an announcement of instructions for the study in our virtual office. That announcement was delivered through headphones using a recorded native American speaker's voice. Each participant had two kinds of hand representations with two motor action capabilities and one of two body reflections. To avoid sequencing biases, all conditions were combined with counter balanced order. Because body representation was a between factor, we conducted just four sessions with each participant. To mitigate the influence of changing motor conditions, we divided the study procedure into two phases, one with the hand representation under static motor condition and the other one with the hand representation under dynamic motor condition. For each session, we gave the participant one minute to look at the environment, including the arm and hand, and the mirror reflection. After the participant had observed the virtual setting, we began the process of dropping a photorealistic rock onto the virtual hand five times, randomly distributed over a one-minute interval with a corresponding sound effect (See Figure 3). 15 seconds after finishing the rock dropping event, we asked participants questions through the headphones using a recorded native American speaker's voice, and participants answered these verbally in each of the four conditions while we recorded their answers. We then provided an additional 30-second break to help participants be prepared for the new hand context under an identical motor condition. During this transition time, participants continued to wear the HMD but with the HMD displaying a neutral VR scene. After finishing the first phase with both hand representations, we gave the participant a three-minute break sitting on a stool without the HMD and headphones. After the break, we resumed by redoing the two hand conditions but now in the alternative motor action condition.

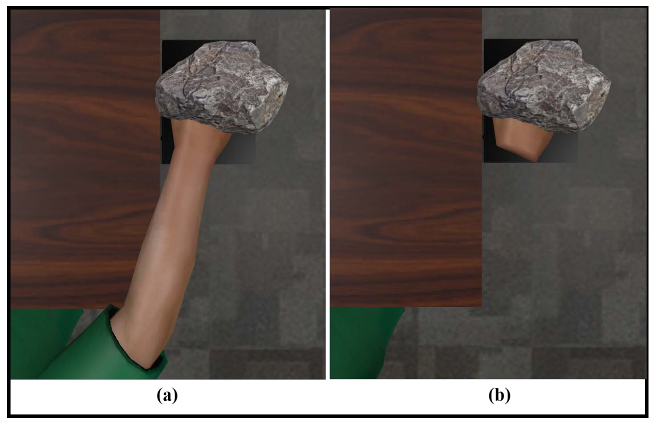

Figure 3: We dropped a photorealistic rock onto participant's virtual right hand five times. (a) Fully represented hand, wrist and arm condition. (b) Arm and wrist removed condition.

In the static motor action condition, we ignored the tracked positional data from the participant's arm and hand movement, asking them to keep their hand on the stand without movement. They could, however, still move their legs and head. In this static condition, they passively observed the rock dropping onto the virtual right hand. In the dynamic motor action condition, participants were allowed to move their real hand, resulting in a corresponding movement of the virtual right hand. Thus, in the dynamic condition, they could actively carry out certain behaviors such as avoiding, touching or hitting the dropping rock. We address details of our observations in the analysis section.

After completing all the sessions, we asked the participant to provide feedback concerning their recognition of the hand status and mirror reflected body representations. All participants distinguished the connectivity status between the two hand representations that they had experienced. Similarly most participants perceived the body reflection in the personalized representation as their own body, even though the mirror reflected image had relatively low resolution. They even reported on how the body had the specific patterns or colors of their own clothes. In contrast, most participants could recognize the generic virtual avatar as being purely virtual, and so not their real body.

4 ANALYSIS

In this section, we present our study results for the effect of the personalized visual body cue as the dominant factor for virtual illusion. As we described in the experiment section, we ran our study as a 2x2x2 mixed Within-Between factorial design. Before we analyzed the data, we clustered the measured data into identical categories. To analyze the subjective measurement, general Multivariate Analysis of Variance (MANOVA) was used for VBOI and BC, and Kruskal Wallis test was used for presence and agency since they were non-parametric data. We confirmed that VBOI and BC measures were normally distributed before analyzing these data. We provide the interquartile range box with outlier and median symbol in all box-plot graphs along with numerical statistical results (See Table 2).

4.1 Virtual Body Ownership

From the main effect result (See Figure 4), we observed the interesting outcome that body representation and hand type are more influential on VBOI, while motor conditions did not show a significant effect. We found a significant difference between personalized body representations (p<0.001) and fully rendered hand representations (p<0.001) for virtual body ownership at the 5% significance level. We did not find a significant interaction effect between body representations and hand representations, and between hand representations and motor conditions, but we found a small interaction effect between the motor conditions and body representations. Thus, as we expected, a personalized body representation with a fully rendered virtual hand and arm gave a higher VBOI than a virtual avatar representation with a hand having no connecting arm. However, there was no significant difference between the dynamic and static motor conditions for VBOI.

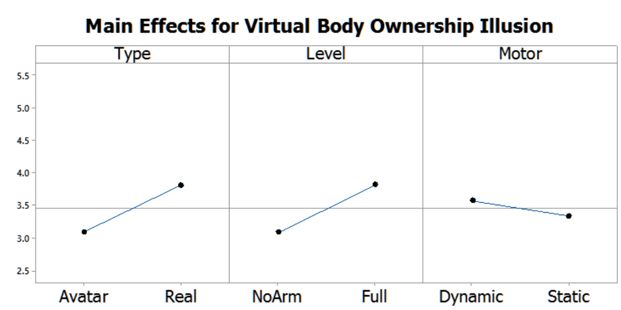

Figure 4: Body representation type and hand representation level show a significant difference in virtual body ownership.

Using mean values, we confirmed that the personalized visual body representation with fully represented arm and hand in the dynamic motor condition showed the strongest effect on virtual body ownership ($mean(sd)$=4.48(1.68)) (See Figure 5).

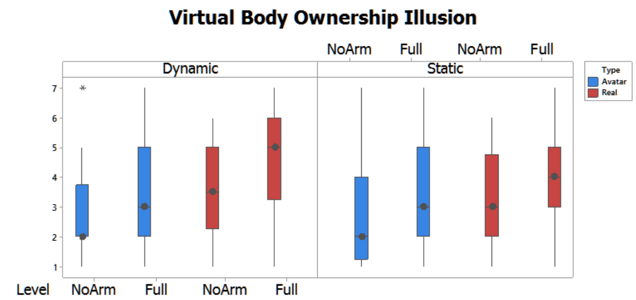

Figure 5: Personalized visual body representation shows a higher sense of VBOI than avatar body representation in all identical conditions.

4.1.1 *Body Continuity.*

Similar to virtual body ownership, we observed an interesting result explicitly seen in the main effect data (See Figure 6) that body representation and hand type are more influential on BC. However, motor conditions did not show a significant effect as we observed in VBOI. The personalized visual body representation and hand representation showed a significant difference for body continuity (p<0.001) at the 5% significance level. Again, the motor action did not show any significant difference between the dynamic and static conditions for body continuity. We did not find a significant interaction effect between body representations and hand representations, and between body representations and motor conditions, but we found a slight interaction effect between the hand representations and motor conditions.

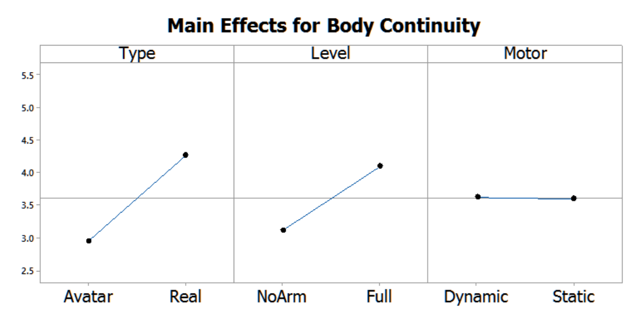

Figure 6: Body representation type and hand representation level shows a significant difference in body continuity.

Regardless of the motor action conditions, we observed that the personalized visual body representation with fully represented arm and hand showed a higher effect on virtual body ownership with dynamic ($mean(sd)$=4.90(1.61)) and static ($mean(sd)$=4.75(1.45)) than all other conditions (See Figure 7).

4.1.2 *Agency.*

From the main effect result (See Figure 8), we found that motor condition had a higher effect on agency than did any other conditions. Not surprisingly, the choice of motor condition showed a higher effect at the 5% significance level on agency (p<0.001) than any other variation (See Figure 9). We did not find a significant interaction effect between body representations

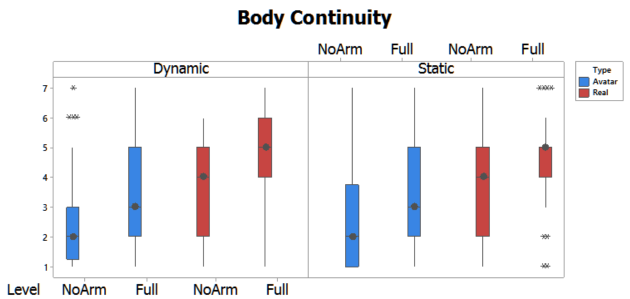

Figure 7: Personalized visual body representation shows higher sense of body continuity than avatar body representation in all identical conditions.

and motor conditions, and between body representations and hand representations, but we found an interaction effect between the hand representations and motor conditions.

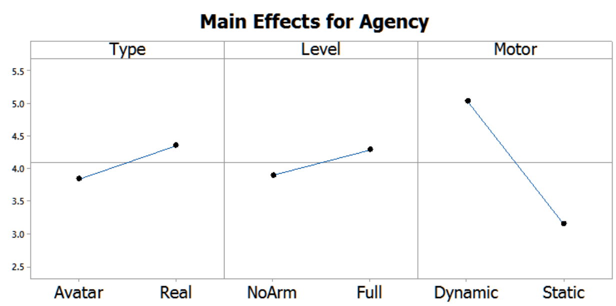

Figure 8: Only motor status shows explicit difference in sense of agency.

We noticed that the dynamic motor condition showed a strong tendency for agency in comparison to the static motor condition, with all other conditions equal. Similar to previous results, the personalized visual body representation with fully represented arm showed the strongest effect on agency (*mean(sd)*=5.50(1.05)).

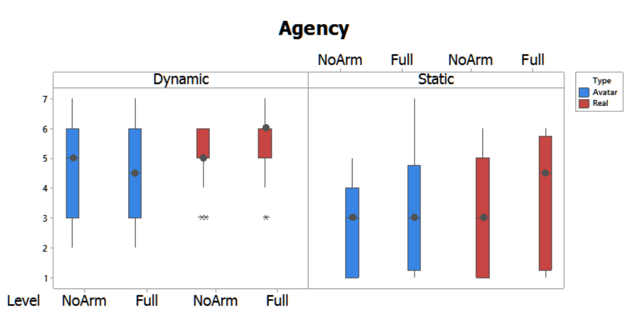

Figure 9: Dynamic motor condition shows a higher sense of agency than does the static motor condition in identical situations.

4.2 Presence

We found that body representation had a positive influence on the main effect results regarding sense of presence (See Figure 10). The personalized visual body representation shows a significant difference for presence compared to the avatar body representation (p<0.02). We did not find a significant interaction effect among independent factors.

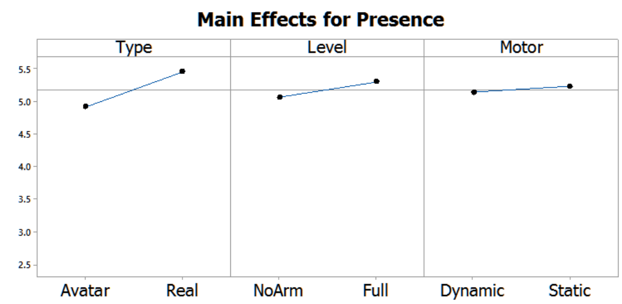

Figure 10: Only the body representation type shows significant difference in body continuity.

Using mean values, we confirmed that personalized visual body representation with fully represented arm in the dynamic motor condition showed the strongest effect on presence (*mean(sd)* = 5.65(1.23)), which is similar to previously reported results. Interestingly, most combinations of conditions for presence showed higher mean values compared to those of other dependent variables.

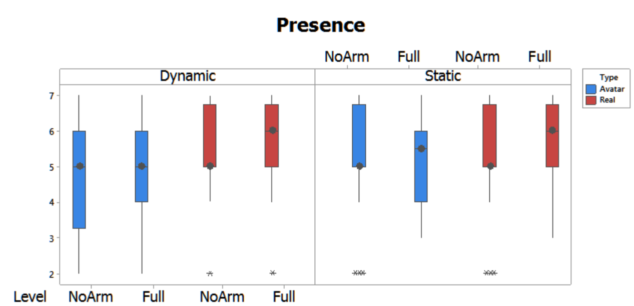

Figure 11: Personalized visual body representation shows a higher sense of presence than avatar body representation in identical conditions.

5 DISCUSSION AND LIMITATION

In this section, we provide details of observed issues in the experiment. When participants were allowed to move their hand, they showed diverse behaviors when confronted with the dropping rock. These included avoidance (the expected action), touching, and hitting, under all combinations of conditions. We conjecture that, even though the event was not seen as an extreme threat, the participants still felt differing sensations depending on the types of body representation.

Table 2: Descriptive Statistics with mean value(SD)

Item	Real		Avatar		
	Full	NoArm	Full	NoArm	Motor
VBOI	**4.48(1.68)**	3.63(1.66)	3.43(1.82)	2.75(1.46)	Dynamic
	3.95(1.81)	3.18(1.68)	3.40(1.95)	2.80(1.68)	Static
BC	**4.90(1.61)**	3.75(1.48)	3.28(1.72)	2.55(1.58)	Dynamic
	4.75(1.45)	3.65(1.76)	3.45(1.85)	2.53(1.52)	Static
Agency	**5.50(1.05)**	5.10(0.91)	4.57(1.50)	4.90(1.56)	Dynamic
	3.75(1.20)	3.05(1.82)	3.25(1.97)	2.55(1.36)	Static
Presence	**5.65(1.23)**	5.40(1.23)	4.95(1.32)	4.55(1.50)	Dynamic
	5.6(1.19)	5.15(1.63)	5(1.38)	5.15(1.63)	Static

Interestingly, we found a statistical difference between personalized visual body representation and avatar body representation regarding presence, a result that was not shown in [10]. We believe this is because artifacts were produced in the earlier experiment from the point cloud that rendered a participant's mirror reflection. These artifacts distracted participants, resulting in a decreased sense of presence. In the experiment reported here, we did not use the point cloud data for rendering the participant's mirror reflection; rather we used a 2D image based on the RGB and depth values from the RGBD camera. This approach removed the unexpected artifacts around the participant's sitting location. With this more precise experimental environment, participants reported that a personalized visual body representation gave them a stronger sense of presence than with a generic virtual avatar.

A limitation of our results is that the number of items used to operationalize our dependent measures was constrained by the experimental design of our study. Future studies should build upon these early results, which suggest significant effects for VBOI, BC, Agency, and Presence, by using more extensive and pre-validated measures to assess these constructs. However, while we cannot say that personalized body representation is the primary factor in the sense of presence, we can say it is a contributing factor to such an illusion as validated by VBOI and BC. Further study will be required to support our hypothesis that this is, in fact, the dominant contributor to the increased sense of presence reported to us by participants.

6 CONCLUSIONS AND FUTURE WORK

In this paper, we investigated the effect of a visually personalized lower body representation on dominant illusions such as virtual body ownership and presence, even when we have a purely virtual hand. To measure this from a subjective point of view, we extended and revised the experimental design from earlier research studies, adding two hand representations and two motor action capabilities. From our experiment, we found statistical support for a significant difference in virtual illusion between a personalized visual body representation and an avatar body representation. Specifically, we showed that a personalized visual body representation had an important role in eliciting a high sense of virtual body ownership, body continuity and presence in comparison to an avatar body representation. Additionally, motor action capabilities had a critical role for agency, an expected result since agency is indicative of the sense of controlling a virtual body. In our setup, even though the rendering quality of a participant's mirror reflection lacked visual artifacts, the image was not particularly sharp. Despite the lack of sharpness, most participants noticed their own body based on the color of their clothes and the shape of their legs. Overall, personalized virtual body representation showed positive influence for VBOI, BC, presence and even agency.

In summary, we believe that our experiment makes three contributions to the VR community: 1) We found a personalized visual body representation is a significant factor in eliciting desired visual illusions of those tested and we provided a best combination to arouse such illusions. Specifically, we demonstrated that a personalized visual body representation with a fully represented arm and hand, combined with a dynamic motor capability elicits the strongest sense of desired visual illusions. 2) By investigating combinations of conditions that affect VBOI, BC, presence and agency, we showed how a developer can compensate for unavailable options when there are design trade-offs. 3) We showed that removing visual artifacts improves a participant's sense of presence.

In future work, we will develop a system to measure human perception when participants have a virtual hand that seems identical to their own. As the hand is the most frequently used body part when carrying out tasks, creating a person-specific virtual hand that has features visually similar to the participant's real hand, including skin color and wrinkles, and, where worn, rings, bracelets or a watch should have a positive effect on virtual illusions. Because we demonstrated the effectiveness of personalized visual cues, even when seen indirectly through mirror reflection, we believe a personalized visual cue of one's own hand will dramatically increase their senses of illusion in a synthetic reality environment.

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REFERENCES

[1] Ferran Argelaguet, Ludovic Hoyet, Michael Trico, and Anatole Lécuyer. 2016. The Role of Interaction in Virtual Embodiment: Effects of The Virtual Hand Representation. In *In IEEE Conference on Virtual Reality.* 3–10.

[2] Wilma A. Bainbridge, Justin Hart, Elizabeth S. Kim, and Brian Scassellati. 2008. The Effect of Presence on Human-Robot Interaction. In *Proceedings of the 17th IEEE International Symposium on Robot and Human Interactive Communication.*

[3] Ilias Bergstrm, Konstantina Kilteni, and Mel Slater. 2016. First-Person Perspective Virtual Body Posture Influences Stress: A Virtual Reality Body Ownership Study. *PLOS ONE* 11, 2 (FEBRUARY 2016), 1–21.

[4] Olaf Blanke, Mel Slater, and Andrea Serino. 2015. Behavioral, Neural, and Computational Principles of Bodily Self-Consciousness. *Neuron* 88 (JULY 2015), 145–166.

[5] Matthew Botvinick and Jonathan Cohen. 1998. Rubber Hands 'Feel'Touch That Eyes See. *Nature* 391, 6669 (FEBRUARY 1998), 756–756.

[6] Faul Franz, Erdfelder Edgar, Lang Albert-Georg, and Buchner Axel. 2007. G*Power 3: A Flexible Statistical Power Analysis Program for The Social, Behavioral, and Biomedical Sciences. *Behavior Research Methods* 39 (2007), 175–191.

[7] Thomas Fuchs. 2012. *The Phenomenology of Body Memory.* Amsterdam; hiladelphia:John Benjamins Publishing Company.

[8] Mar González-Franco, Daniel Pérez-Marcos, Bernhard Spanlang, and Mel Slater. 2010. The Contribution of Real-Time Mirror Reflections of Motor Actions on Virtual Body Ownership in An Immersive Virtual Environment. In *In IEEE Conference on Virtual Reality.* 111–114.

[9] Ludovic Hoyet, Ferran Argelaguet, Corentin Nicole, and Anatole Lécuyer. 2016. 'Wow! I Have Six Fingers!': Would You Accept Structural Changes of Your Hand

in VR? *Frontiers in Robotics and AI* 3 (MAY 2016), 1–12.
[10] Sungchul Jung and Charles E. Hughes. 2016. The Effects of Indirect Real Body Cues of Irrelevant Parts on Virtual Body Ownership and Presence. In *ICAT-EGVE 2016 - International Conference on Artificial Reality and Telexistence and Eurographics Symposium on Virtual Environments*. 107–114.
[11] Konstantina Kilteni, Ilias Bergstrom, and Mel Slater. 2013. Drumming in Immersive Virtual Reality: The Body Shapes The Way We Play. *IEEE Transactions on Visualization and Computer Graphics* 19, 4 (APRIL 2013), 597–605.
[12] Konstantina Kilteni, Antonella Maselli, Konrad P Kording, and Mel Slater. 2015. Over My Fake Body: Body Ownership Illusions for Studying The Multisensory Basis of Own-Body Perception. *Frontiers in Human Neuroscience* 9, 4 (MARCH 2015).
[13] Sungkil Lee and Gerard Jounghyun Kim. 2008. Effects of visual cues and sustained attention on spatial presence in virtual environments based on spatial and object distinction. *Interacting with Computers* 20 (September 2008), 491–502.
[14] Jean-Luc Lugrin, Johanna Latt, and Marc Erich Latoschik. 2015. Avatar Anthropomorphism and Illusion of Body Ownership in VR. In *In IEEE Conference on Virtual Reality*. 229–230.
[15] Michael Meehan, Brent Insko, Mary Whitton, and Frederick P. Brooks Jr. 2002. Physiological Measures of Presence in Stressful Virtual Environments. *ACM Transactions on Graphics (TOG)* (JULY 2002), 645–652.
[16] Jum C. Nunnally. 1978. *Psychometric Theory (2nd ed.)*. McGraw-Hill, New York.
[17] Pérez-Marcos, Daniel, Maria V. Sanchez-Vives, and Mel Slater. 2012. Is My Hand Connected to My Body? The Impact of Body Continuity and Arm Alignment on The Virtual Hand Illusion. *Cognitive Neurodynamics* 6 (JULY 2012), 295–305.
[18] Valeria I Petkova, Mehrnoush Khoshnevis, and H. Henrik Ehrsson. 2011. The Perspective Matters! Multisensory Integration in Egocentric Reference Frames Determines Full-Body Ownership. *Frontiers in Psychology* 2, 2 (MARCH 2011), 1–7.
[19] Maria V Sanchez-Vives and Mel Slater. 2005. From Presence to Consciousness through Virtual Reality. *Nature Reviews. Neuroscience* (APRIL 2005), 332–339.
[20] Maria V. Sanchez-Vives, Bernhard Spanlang, Antonio Frisoli, Massimo Bergamasco, and Mel Slater. 2010. Virtual Hand Illusion Induced by Visuomotor Correlations. *PLOS ONE* 5, 4 (APRIL 2010), 1–6.
[21] Thomas W. Schubert. 2009. A New Conception of Spatial Presence: Once Again, with Feeling. *Communication Theory* 19, 2 (2009), 161–187.
[22] Martijn J. Schuemie, Peter van der Straaten, Merel Krijn, and Charles A.P.G. van der Mast. 2004. Research on Presence in Virtual Reality: A Survey. *CyberPsychology and Behavior* 4 (JULY 2004), 183–201.
[23] Mel Slater, Anthony Steed, and Martin Usoh. 2013. *Being There Together: Experiments on Presence in Virtual Environments (1990s)*. Technical Report, Department of Computer Science, University College London, UK.
[24] Mohsen Tavakol and Reg Dennick. 2011. Making sense of Cronbach's alpha. *International Journal of Medical Education* 2 (2011), 53–55.
[25] Gaetano Tieri, Emmanuele Tidoni, Enea Francesco Pavone, and Salvatore Maria Aglioti. 2015. Body Visual Discontinuity Affects Feeling of Ownership and Skin Conductance Responses. *Scientific Reports* 5, 17139 (November 2015).
[26] Gaetano Tieri, Emmanuele Tidoni, Enea Francesco Pavone, and Salvatore Maria Aglioti. 2015. Mere Observation of Body Discontinuity Affects Perceived Ownership and Vicarious Agency over A Virtual Hand. *Experimental Brain Research* 233 (APRIL 2015), 1247–1259.
[27] Manos Tsakiris, Simone Schtz-Bosbach, and Shaun Gallagher. 2007. On Agency and Body-Ownership: Phenomenological and Neurocognitive Reflections. *Consciousness and Cognition* 16 (SEPTEMBER 2007), 661–666.
[28] Max Velmans. 1998. Physical, Psychological and Virtual Realities. *The Virtual Embodied* (1998), 45–60.
[29] Bob G. Witmer and Michael J. Singer. 1998. Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence: Teleoperators and Virtual Environments* 7, 3 (JUNE 1998), 225–240.
[30] Yuan Ye and Anthony Steed. 2010. Is the Rubber Hand Illusion Induced by Immersive Virtual Reality?. In *In IEEE Conference on Virtual Reality*. 95–102.