RealME: The influence of a personalized body representation on the illusion of virtual body ownership

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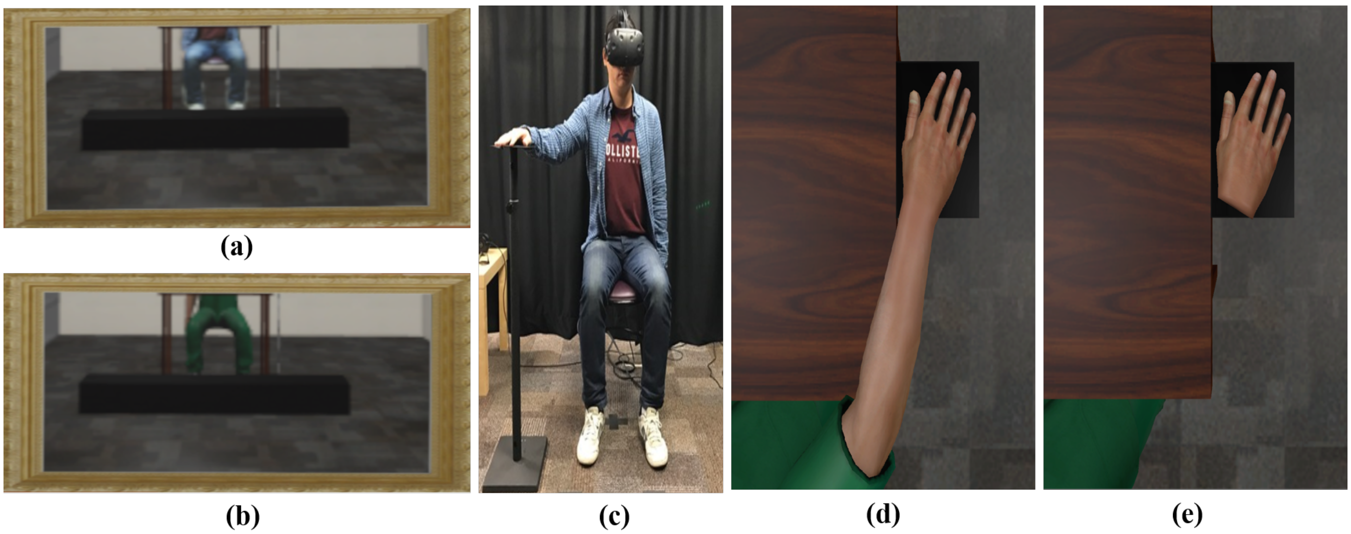

Figure 1: Overall experiment environment. In this experiment, we provided two type of body reflection through a virtual mirror while the participants looked at a virtual hand and arm from a first person perspective. (a) Visually personalized body reflection where the clothes and shape are identical to those of the participant seen in (c). (b) Generic Avatar body representation. (d) and (e) Two levels of hand representation – (d) Fully modeled limb from shoulder to hand. (e) Arm removed 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 physical presence and body ownership, 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. Only the virtual right hand and arm play a part in our scenario, and so the lower body, despite sometimes appearing realistic, is largely irrelevant, except in its influence on perception. 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 presence and body ownership, critical features in virtual environments involving a virtual surrogate.

Index Terms: H.5.1 [Information interfaces and presentation]: Artificial augmented—virtual realities

1 INTRODUCTION

A person's perception of their body, called body ownership [17], and their recognition of the surrounding environment, called (physical) presence [13], 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 VR community, taking advantage of its ability to create realistic illusions, enabled by high resolution head mounted displays (HMD) and accurate tracking technologies. Using VR technologies, virtual body ownership (the illusion that a virtual body is one's own) and (physical) 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 of these 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 [23]. In actual fact, a human can notice realistic body features (color, texture, etc.) because our brain forms the connection based on explicit and implicit

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memory associated with the actual body, [6]. Based on this insight, the authors of [9] 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 that is personalized but not directly relevant to the user's central focus. Our goal is to see how combinations of each of these influence illusions of virtual body ownership and presence.

Recently, researches 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 [16]. Earlier research [9] 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 examined agency [22], which is a sensation for 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 [19].

In our experiment we not only focused on virtual body ownership but also physical presence, the sense of "being there" [14], since the sense of presence in a virtual environment is closely related to virtual body representation [20]. 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 [9, 10]. 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 [9], 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 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 all two hand levels and both motor action conditions, so the total combinations of conditions experienced by a 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 [16, 11] 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 virtual body ownership illusion 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, hand ownership has been studied widely in both real world and virtual reality research. [4] investigated body ownership using a fake rubber hand. An extended version of the rubber hand experiment was studied in virtual reality by [25]. Similar to the rubber hand experiment, [17] conducted a body ownership study using a mannequin. [2] conducted a study for virtual arm ownership to discover a correlation among multiple human sensory systems: visual and motor in a purely virtual environment. They demonstrated that the morphologically realistic resemblance of the virtual hand is a significant factor for one's sense of virtual hand ownership. [8] studied body ownership issues using unnatural hand shapes with a similar setup to that of [2]. 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, [12] 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.

To investigate a correlation between visual real body cues and virtual illusion on a virtual hand, [9] studied using a virtual mirror reflection of a subject's lower torso. Their 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 [7, 10, 3]. Using the mirror reflection, [7] 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 to give a sense of body ownership. [10] studied the relationship between the appropriate appearance for the context and virtual body ownership. In their study, participants played a drum with different costumes, seeing their appearance though mirror reflection. Their study demonstrated the cognitive consequence of proper consistency between visual appearance and task context.

2.1.1 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. [16] experimented with a fully represented hand but no arm to connect it to the rest of the body. 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, [21] studied various types of hands – full limb, wire-connected hand, removed wrist, and missing wrist replaced by a plexiglass hand to arm. 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 [15] 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.

2.2 Presence

Presence indicates the sensation of behaving and feeling as if one is in the computer generated world [18]. Presence was categorized into three categories: social presence – the sense of not only sharing space but also sharing an experience with another entity [14], co-presence – the sense of being in a shared space with another entity [1], and physical presence – the perception of existing in another space [13]. We focus on physical presence in this paper. In general, presence is measured by using questionnaires and by observing a participant's reaction to threats [14].

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 measurement 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 the Internal Review Board Office at the University of Central Florida.

3.1 Research Hypotheses

Starting with results from our previous research, we conducted our experiment to find answers for the following research questions: (1) "Do the personalized visual body cues create psychological continuity between a participant's real body and their purely virtual hand?" If yes, (2) "Do the the personalized visual body cues influence the sense of body ownership of one's hand and of one's sense of presence?" The following hypotheses are based on our previous research results and our beliefs concerning the effect of a personalized visual body representation. For each of the first three cases, we expect to elicit significantly higher levels of perceived a) Body Continuity, b) Body Ownership, c) Presence, and d) Agency for the first of the two options specified.

- **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 hand-only virtual body.
- **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 an 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 total of 24 participants [5]. 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 21 participants (15 male, 6 female, Mean Age = 21.1, SD=2.92) for personalized visual body representation and 20 (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 total. Most of 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).

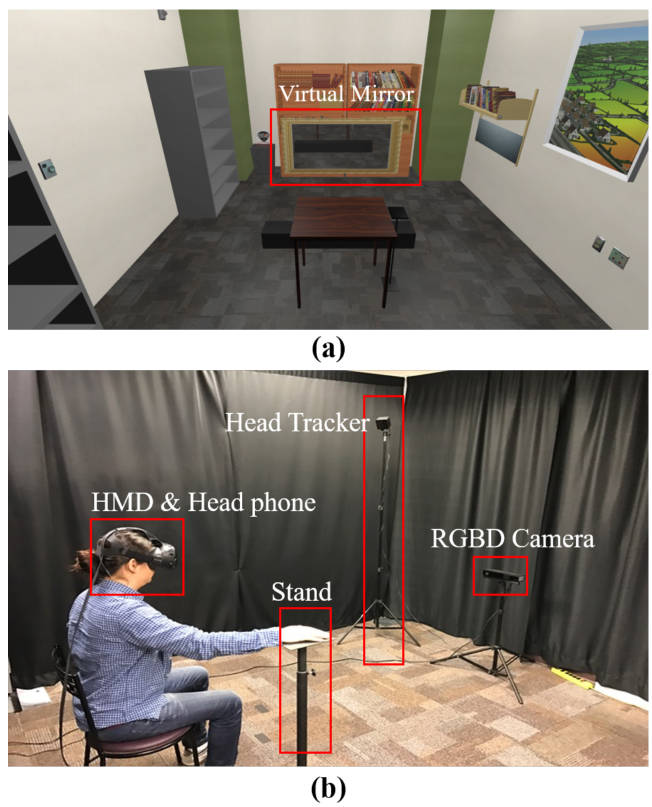

Figure 2: Experiment environments. (a) Virtual office. (b) Physical setup

in the virtual office, we included a table in front of the partic-

Table 1: Questionnaire

Item	Question
VBOI	You felt as if the virtual hand was your own.
	You felt that your hand was endangered by the falling rock.
	You felt as if the virtual hand started to look like your own.
BC	You felt as if the virtual hand was connected to your body.
	You felt as if the virtual hand was a part of your body.
Agency	You felt as if you could control the virtual hand.
Presence	You felt as if you were physically present in the office room.
	You felt as if you were in a virtual setting.

ipants 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 value with matched depth value on a plane and reflected the image onto the virtual mirror. Because of limited fidelity of the depth value for thin body parts, the feet were not rendered correctly so we hid that part with a block cube occluder located on the floor. To elicit a protective reaction, we dropped a photorealistic rock five times onto the participant's virtual right hand (See Figure 3).

3.4 Questionnaire

As a subject measurement, we created an instrument that consisted of questions about virtual body ownership, body continuity, agency, and presence using a 7- point Likert scale – 1 for strongly disagree, 4 for Neutral, and 7 for strongly agree. For virtual body ownership, including body continuity and agency, and presence questions, we used questions adapted from [24, 16, 9, 2, 21] with modifications appropriate to our study. We provide the details on interval questions in Table 1.

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 a task and manipulation of the system. We were especially insistent that their initial pose have them sitting on the chair in a normal forward facing position 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, and to look at the virtual mirror 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, so four sessions were conducted with each participant. 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 to drop a photorealistic rock onto the virtual hand five times, randomly distributed over a one-minute interval with a corresponding hitting sound effect (See Figure 3). We gave 30 seconds break time for their right hand and refreshing their sense. During the time participants wearing HMD still in turned off virtual office environment scene before begin next session.

When in the static motor action condition, participants were not allowed to move their hand and fingers. They could, however, move their legs and head. Therefore they passively observed the rock drooping events on the virtual right hand that was fixed in position. 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 avoid the dropping rock. After finishing each task, whether static or dynamic, we asked participants questions through the headphone, and participants answered these verbally. After finishing two sessions with each of the hand representations, we gave the participants a three-minute break and resumed with the other two sessions with a different motor action condition. After completing all tasks, we asked the participants whether they noticed the different hand representations and their recognition as regards the reflected body representation.

(a) **(b)**

Figure 3: We dropped photorealistic rock onto participant' right virtual hand five time. (a) Dropped rock onto fully represented hand. (b) Dropped rock onto arm removed hand.

4 Analysis

In this section, we present our results for the effect of the personalized visual body cue as the dominant 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.

Our two presence question were slightly modified versions of pre-validated ones from [24], with the first of these having an explicit reference to the office setting we used. Participants gave higher ratings to the second presence question (See Table 1); we assume that they thought the question's use of the phrase virtual setting had a stronger influence on their answers than their reporting an actual sense of presence. However, we still have a significant difference for body representation (user versus avatar reflection) in both presence questions, ($P\text{-}value<0.002$) and ($P\text{-}value<0.015$), respectively, without any interaction effect. To analyze the subjective measurement, we used general Multivariate Analysis of Variance(MANOVA) for all dependent variables.

4.1 Virtual Body Ownership

Our results show that body representation had more of an effect on VBOI than any other independent factors from the main effect result (See Figure 4). As we expected, the fully modeled arm and hand gave a higher sense than the hand-only condition. The motor action did not show any significant difference between the dynamic and static conditions for VBOI. 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 significant interaction effect between the motor conditions and body representations.

Specifically, we found a significant difference between body representations ($P\text{-}value<0.001$) and hand representations (*P*-

value<0.001) for virtual body ownership. We confirmed that all dependent measures were normally distributed before analyzing these data.

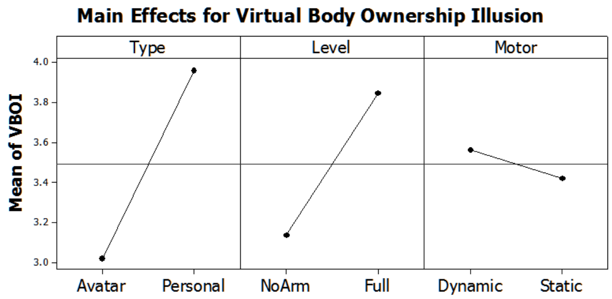

Figure 4: Body representation type and hand representation level show a significant difference in virtual body ownership.

Using mean values, we confirmed that the personalized visual body representation elicited a higher sense of VBOI (*mean*=3.958) than the avatar body representation (*mean*=3.025). Also the fully modeled arm and hand (*mean*=3.846) elicited a higher sense of VBOI than the hand-only condition (*mean*=3.138). Consequently, the personalized visual body representation with fully represented arm and hand in the dynamic motor condition showed the strongest effect on virtual body ownership (See Figure 5). We provide statistical results for VBOI in Table 2.

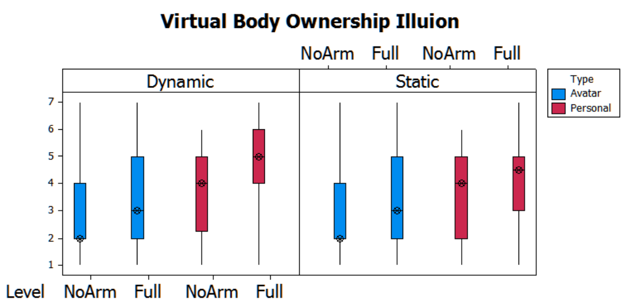

Figure 5: Personalized visual body representation shows a higher sense of VBOI than avatar body representation in all identical conditions. We represent the interquartile range box with outlier and median symbol.

4.1.1 Body Continuity

Similar to virtual body ownership, we observed an interesting result explicitly seen in the main effect result (See Figure 6). The personalized visual body representation shows a significant difference for body continuity in comparison to the avatar body representation. Also, the result shows that hand representation had more of an effect on body continuity than any other independent factor. As we expected, the personalized body representation gave a higher sense of body continuity than did the avatar body representation. The motor action did not show any significant difference between the dynamic and static conditions for body continuity as well. We did not find a significant interaction effect between body representations and hand representation, and between body representations and motor conditions, but we found a slight interaction effect between the hand representations and motor conditions. We found a significant difference of body representation (*P-value*<0.001) and hand representation (*P-value*<0.001) for BC, which is identical to the virtual body ownership result. We confirmed that all dependent measures were normally distributed before analyzing these data.

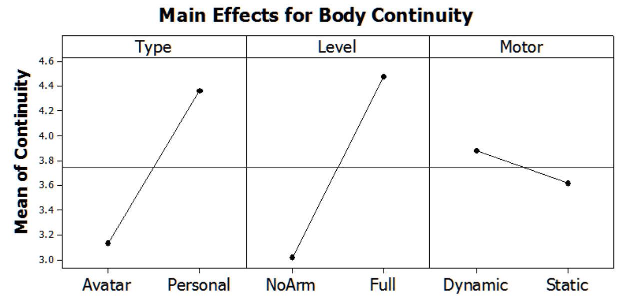

Figure 6: Body representation type and hand representation level shows a significant difference in body continuity.

Using mean values, we confirmed that the personalized visual body representation elicited a higher sense of BC (*mean*=4.363) than the avatar body representation (*mean*=3.131). Also the fully modeled arm and hand (*mean*=4.475) gave a higher sense of BC than the hand-only condition (*mean*=3.019). As a result, the personalized visual body representation with fully represented hand in both motor conditions shows a significantly higher effect on BC than other conditions (See Figure 7). We provide statistical results for BC in Table 2.

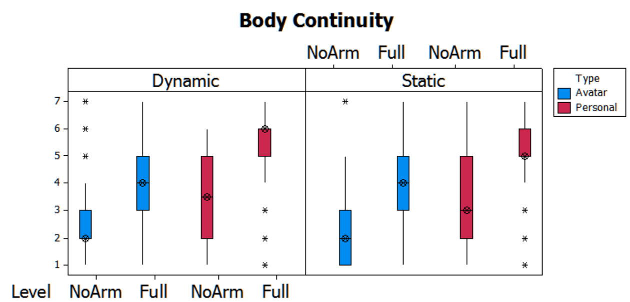

Figure 7: Personalized visual body representation shows higher sense of body continuity than avatar body representation in all identical conditions. We represent the interquartile range box with outlier and median symbol.

4.1.2 Agency

We observed an inverse result to virtual body ownership and body continuity in the sense of agency from the main effect result (See Figure 8). The personalized visual body representation and hand representation were not significant but the motor action was significant in agency. We did not find a significant interaction effect between body representations and motor conditions, and between body representations and hand representations, but we found an interaction effect between the hand representation and motor conditions. We found a significant difference of motor condition (*P-value*<0.001) only for sense of agency. We confirmed that all dependent measures were normally distributed before analyzing the data.

Using mean values, we confirmed that the dynamic motor condition showed a higher sense of agency (*mean*=5.038) than the static motor condition (*mean*=3.150. Not surprisingly, the choice of motor condition showed a significantly higher effect on agency than

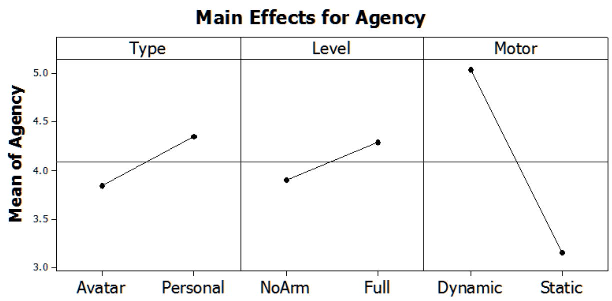

Figure 8: Only motor status shows significant difference in sense of agency.

any other variation (See Figure 9). We provide statistical results for sense of agency in Table 2.

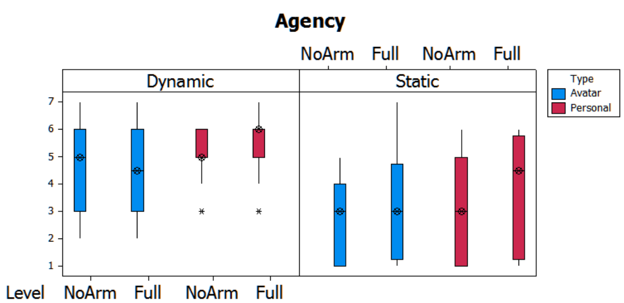

Figure 9: Dynamic motor condition shows a higher sense of agency than does the static motor condition in identical situations. We represent the interquartile range box with outlier and median symbol.

4.2 Presence

We observed interesting main effect results regarding body representation type and sense of presence (See Figure 10). The personalized visual body representation shows a significant difference for presence compared to the avatar body representation. The hand representation did not show any significant difference between the full arm and hand, and hand-only representations. The motor action did not show any difference between the dynamic and static conditions for sense of presence. We did not find a significant interaction effect among independent factors. We found a significant difference of body representation (*P-value*$<$0.001) for presence. We confirmed that all dependent measures were normally distributed before analyzing data.

Using mean values, we confirmed that the personalized visual body representation showed higher sense of presence (*mean*=5.619) than the avatar body representation (*mean*=5.056). Also, the personalized visual body representation shows a higher effect on presence than the avatar body representation in identical condition (See Figure 11). We provide statistical results for presence in Table 2.

5 Discussion

As we expected, the illusion effects of a personalized visual body representation were supported by full body continuity and vice versa but, surprisingly, motor capabilities did not have any effect on either. This interplay between body representation and body continuity can be seen in the box plots. We also investigated the effect of personalized visual body representation on one's sense of

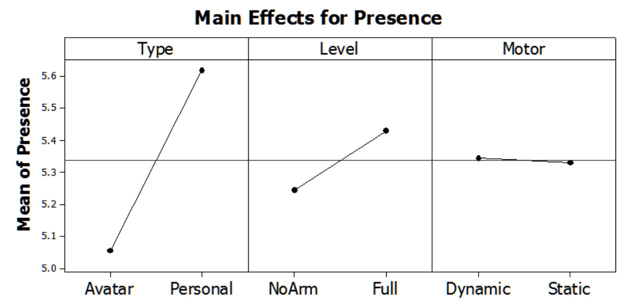

Figure 10: Only the body representation type shows significant difference in body continuity.

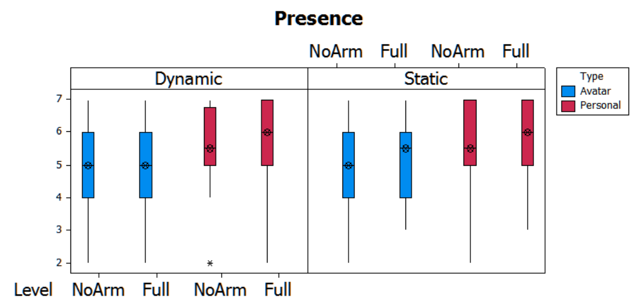

Figure 11: Personalized visual body representation shows a higher sense of presence than avatar body representation in identical conditions. We represent the interquartile range box with outlier and median symbol.

presence. Of interest, we found a statistical difference between personalized visual body representation and avatar body representation regarding presence, a result that was not shown in [9]. 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 latter 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 higher sense of presence.

6 Conclusion and Future Work

In this paper, we investigated the effect of a visually personalized lower body representation on dominant illusions such as virtual

Table 2: Descriptive Statistics with mean value

		VBOI	BC	Agency	Presence
Body	Real	3.958	4.363	4.350	5.619
	Avatar	3.025	3.131	3.838	5.056
Hand	Full	3.846	4.475	4.288	5.431
	Hand	3.138	3.019	3.900	5.244
Motor	Dynamic	3.563	3.875	5.038	5.344
	Static	3.421	3.619	3.150	5.331

body ownership and presence, even when we have a purely virtual hand. To measure this from a subjective point of view, we extended the experimental design from our previous research, 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.

In summary, we believe that our experiment has three contribution to the VR community: 1) We found a personalized visual body representation is a significant factor in eliciting desired visual illusions 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, 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 that 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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