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The Effects of Indirect Real Body Cues of Irrelevant Parts on Virtual Body Ownership and Presence

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(a) (b) (c) (d)

Figure 1: *The first person perspective of a participant seen in the four cases of mirror reflected body cues in a virtual room during experiment with logs on fire condition. We indicate the mirrors with red color rectangle line. (a) Real body reflection on a mirror, (b) No body reflection on a mirror, (c) Human Avatar body reflection on a mirror, (d) Generic Avatar body reflection on a mirror.*

Abstract

The employment of visual, auditory and tactile senses directly related to specific body limbs associated with task performance has been shown to give a person a perception of body ownership. However, there is much less evidence of the influence on body ownership of sensory data associated with parts of the user's body that are not directly associated with the task being performed. For example, if arms and hands are the functional parts in a first person perspective game, do other body parts such as the torso or legs affect the person's sense of illusion in ways that can increase or decrease the sense of body ownership? To show the effectiveness of appropriate indirect cues to an irrelevant body part, we conducted a virtual mirror based experiment. Specifically, we created a virtual reality system that has four mirror-reflected body conditions in which a participant can see his or her real lower body, a human avatar's lower body, a generic avatar's lower body or no lower body in the virtual mirror. With this system, we observed the effects of each condition on the user's sense of body ownership and presence, even when the lower body parts played no role in the participant's activities. The results represent a tendency that an indirect real body cue associated with one's legs can arouse a higher sense of body ownership and unexpected result for presence during the performance of a task involving only virtual hands.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality

1. Introduction

In a virtual reality environment, researchers try to arouse illusions in participants that give sensations called body ownership [PKE11] and presence [Sla09], and these sensations are elicited by stimulation of a sense of reality in the human brain [Vel98]. Using high resolution, real-time rendering enabled by head mounted displays (HMD), the visual sense of reality can be effectively delivered in a virtual reality environment. Also, body tracking technology helps to elicit the implied sense by matching physical movement in space with that of the virtual avatar. With these technologies, most studies of virtual body ownership are conducted by stimulating implied associations between real and virtual body parts in a

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direct fashion, e.g., stimulating a real arm and observing a virtual arm [SPMESV08].

In contrast to such a traditional research, our research motivation is to study the influence of indirect cues on one's sense of illusion. What happens if we indirectly see uninvolved parts of our real body when we are controlling a virtual hand? Will we sense the virtual hand as if it were our own hand or not? We believe that the indirect use of associations, e.g., those seen in a mirror that involve body parts and accessories that irrelevant for a given task, also have a significant impact for body ownership of those parts integral to the task. Because of a combination of cognition and perception of our body in our daily lives, our brains might access the memory of our general body information. For example, we know what clothes, shoes or watches we have on. Similarly, we knew our subtle body nuances, such as wrinkles or macules on our hands, and the color of our skin. Since background information plays a critical role in recognizing certain objects [CMS04], those bits of information might help us to recognize our body and, we conjecture, arouse one's body consciousness.

To our knowledge, there are no previous studies of the effect of indirectly applied implication of real body cues to virtual hand ownership and presence. In this paper, we suggest the answers in the context of virtual body ownership illusion and presence. We conjecture that the key for body ownership is an implied connectivity between the virtual hand and other real body information. Since we believe that implied visual connections to real body cues provide the connectivity between the body limbs in our brain, we developed a study for virtual body ownership and presence with indirect use of body cue in a virtual reality environment. We mainly focus on arousing a sense of body ownership of a realistic virtual hand when participants see their real legs as visually implicated cues from a virtual mirror-reflection in the virtual environment, and we also observe the sense of presence.

To study our research question, we placed three virtual mirrors in front of a participant's table to see their body reflection through the mirrors that are located at various angles (See Figure 1). These are positioned so the participant can observe their lower body part, legs mainly, while performing a given set of tasks with the virtual hand. Even though some participants seemed to not recognize the mirror reflection change in their legs, most participants observed these well enough to have the desired effects of the sense of illusion. The results represent an interesting tendency towards virtual body ownership but an unclear tendency for presence in that, when the participants are stimulated by the real body reflection, they have a higher sense of body ownership but an ambiguous tendency toward presence. We measured these senses using a questionnaire. The results of our study, which we will explain in more detail in the analysis section, support the answers for our research questions presented in this paper and suggest a finding to enhance the sense of body ownership in a virtual reality environment.

2. Related Work

One of fundamental challenges of virtual reality is to give a realistic illusion to human participants, and the challenge has been examined within computer science, neuroscience and psychology. To investigate the factors for illusion, researchers have focused on human perception and cognition. The sense of body ownership, which is a self-consciousness of one's own body limb, was introduced as a phenomenon to arouse realistic sensations. [BC*98] first demonstrated that a fake limb (a rubber hand) can arouse a strong sense of body ownership. With high performance VR devices, body ownership studies have been extended to virtual body limbs in VR environments.

2.1. Virtual Hand Ownership

Because the hand is the most frequently used human limb, virtual hand ownership has been studied widely in virtual reality research. [SPMESV09] conducted a study for virtual arm ownership to discover a correlation among multi human sensory systems - visual, motor and tactile in a mixed reality environment. An extended version of the rubber hand experiment in virtual reality was studied by [YS10]. With the advent of acceptable accuracy and high frame rate hand tracking technology, body ownership using the hand has been a common focus in recent studies. [AA16, HANL16] experimented with solely virtual hand body ownership in a purely virtual reality environment. [AA16] have studied virtual hand ownership in three types of hands - abstracted hand, iconic hand and realistic hand. They have demonstrated that the morphologically realistic resemblance of the virtual hand is a key to the sense of hand ownership. [HANL16] have examined interesting body ownership issues with a similar setup to that of [AA16]. They have used a virtual hand which has six-fingers and they have demonstrated that the structural difference still elicited body ownership.

2.2. Virtual Body Ownership

[PKE11] conducted a body ownership study using a mannequin which is similar to the rubber hand illusion. Their body ownership study has been moved to a virtual environment. Recently, [LLL15] investigated virtual body ownership with anthropomorphism models such as a robot avatar, a generic avatar and a human avatar. They found a correlation between human resemblance and a degree of sense of body ownership. The noticeable result was that the uncanny valley effect happened when the participant had a human avatar.

Virtual body ownership studies using a virtual mirror have been addressed from a variety of research perspectives [GFPMSS10, BGS13, KBS13, BKS16]. [GFPMSS10] conducted a study using the virtual mirror reflection to observe the relation between motor actions and virtual body ownership. They demonstrated that synchrony of the mirror-reflected avatar with a participant's movement was the most important factor to give a sense of body ownership. On the other hand, [BGS13] conducted a virtual body ownership study to show a correlation between the type of avatar body (child body and adult body) and human perception and body ownership. They demonstrated the interesting result that body ownership was elicited for both avatar body sizes without a significant difference. However, the participants reported different perceptions of the virtual world according to their avatar's body size. This shows that the implication process, a higher level of cognition, has an effect on a human's perceptual interpretation in a virtual reality environment. [BKS16] also conducted the virtual body ownership study with a virtual mirror setting to watch a virtual avatar's posture with two different viewpoints, a first person and a third person perspective. [KBS13] investigated the relationship between appropriate appearance for the context and virtual body ownership with a virtual mirror. The study asked each participant to play a drum with different costumes in the first person perspective. Thus, they could see their body directly looking at their hand or looking through the mirror. The study showed that cognitive consequence from proper consistency between visual appearance and task context was invoked. In each case, as in almost all other body ownership studies, the goal is to find a correlation between directly connected variables. In our study, we investigated the relationship between virtual hand body ownership and an indirect variable.

3. Experiment

The research questions posed here are: (1) "Does the implication of body cues create connectivity between the mirror-reflected real body and the virtual hand even though we know from visual appearance that the hand is not our own hand?"If yes, (2) "Does the indirect use of implicated body cues influence the sense of body ownership of one's hand and of one's sense of presence?"In order to investigate these research questions, we designed a simple task-based experiment in a virtual reality system. Since our main focus is the effects of the real body cue, we designed a system to compare these with other conditions - human avatar body cue, generic avatar body cue, and no body cue. To compare them, we prepared four conditions: real body, human avatar body, generic body and no body. To minimize the distraction from repeated task, we divided the four conditions into two comparison groups: (1) real body VS generic body VS no body, which we call the Rs set, (2) human avatar body VS generic body VS no body, which we call the Hs set and generic body and no body as a baseline. We also present analysis for comparison from a group: real body VS human avatar, which we call the Ts set. We assume that uncanny valley effects [LLL15] will happen in our study when we use a human avatar, and so we separated the real body case and human avatar body case into different groups to investigate this phenomenon. We conducted a within-subject test for both the Rs set and the Hs set, respectively, and conducted a between-subject test with the two sets. In this experiment, we hypothesized that the real body cue will give the most sense of body ownership and presence; that the human avatar cue and generic cue will give equivalent senses of body ownership and presence; and that no body cue will give the lowest sense of body ownership and presence to the participants. Here, we summarize our hypotheses.

H1. Observing the mirror-reflected real body will produce a strong connection between a participant's physical body and the virtual hand.

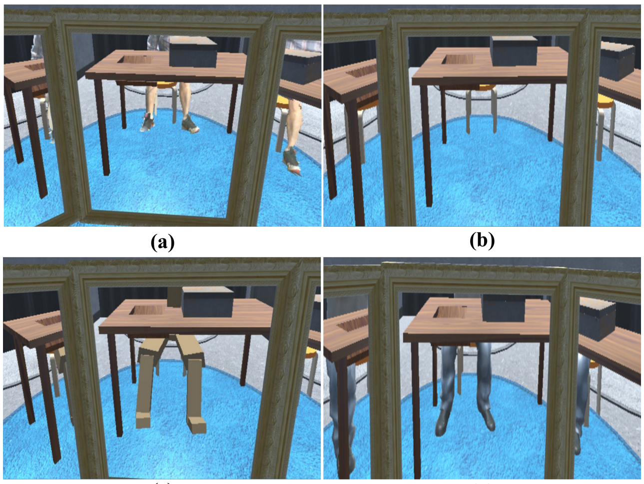
H2. This strong connection gives a sense of body ownership for the virtual hand and presence in the virtual room.

H2.1. The real body cue will give the strongest sense of body ownership and presence.

H2.2. The human avatar body cue and generic body cue will give equivalent senses of body ownership and presence.

H2.3. The no-body cue will have the lowest sense of body ownership and presence.

To explore these hypotheses, we created a room with virtual mirrors so the participant could see the mirror-reflected lower body part during the experiment (See Figure 2). As our goal was to represent only the participant's legs though the virtual mirror, we removed the body part above the middle of the torso, including the arms of the human generic avatar. However, participants could partially see their own upper parts during the real body case, a situation we will address in the discussion section.



(a) **(b)** **(c)** **(d)**

Figure 2: *Zoom in version of four cases of mirror reflection, (a) shows real lower body reflection, (b) shows no reflection, (c) shows generic lower body reflection and (d) shows human avatar's lower body reflection.*

Participants were asked to do a simple 'pick and drop'based task in a virtual reality environment. We conducted the study with counter-balanced ordering to remove any ordering effect. The study was approved by the Internal Review Board Office at University of Central Florida. We recruited participants with normal to corrected-to-normal vision using on-campus flyers. Participants were mainly university students, with a few from outside campus. Most participants had higher education backgrounds and were studying in diverse majors but mainly in computer science. We gave each a $10 gift card for their participation. The total number of participants was 32.

3.1. System Design

To include a real body in a virtual mirror room with hand interaction, a Leap Motion was attached to an Oculus Rift (DK2) and a Kinect 2 was used. We prepared a participants'interaction room that was isolated with gloomy lighting to minimize distractions. We used the point cloud from the Kinect 2 to render the real body reflection on the virtual mirrors, having placed the participant's stool 2.5 meter from the Kinect 2. Each participant was asked to sit on a stool to do a task, and they could move their head or upper body with the head tracker provided by an Oculus Rift that was placed in front of the participant's stool at the same 2.5-meter distance as used with the Kinect 2. In a separate room, we call a questionnaire area, participants were asked to fill out questionnaires while sitting on a chair. We prepared six types of hand models to match the participants'races to be reasonably consistent with each individual's skin color. In Figure 3 (b), we show realistic virtual hand models for Black, Asian and White females and males. These are selected based on demographic information and are positioned using the Leap motion to properly match the participant's hand. Similarly, we prepared a generic avatar and the human avatar with male and female versions, respectively (See Figure 3 (a)). Those avatars did not have bodies above the middle of the torso that included arms and head because those body parts were not relevant to our study and interfered with the hand interaction in the virtual environment. We did not measure the end-to-end latency of tracking, since the high tracking fidelity of the Kinect 2 for the sitting position allowed participants to see their leg movements via the virtual mirrors without any critical latency problems. On rare occasions, we asked a participant to enter a neutral position for their legs when they crossed their legs, which introduces a tracking problem. We ran our system using an Intel Core i5 with 8GB DDR memory and a GeForce 970. The virtual environment was developed using the Unity game engine.

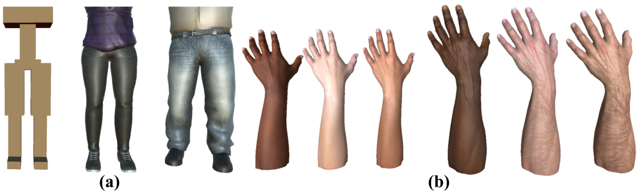


Figure 3: *Avatar models and realistic virtual hand models. (a) We have generic avatar, female avatar and male avatar respectively. (b) We have hand models for female and male with Black, Asian and White, respectively.*

Table 1: *The question component in the interval questionnaire.*

Item	ID	Question
VBOI (Connectivity)	1	You had the feeling that the mirror-reflected legs were part of your real body.
	2	You had the feeling that the virtual hand and the mirror-reflected legs were connected to your own body.
	3	You had the feeling that you observed the mirror-reflected legs and they matched your legs movements during the experiment.
VBOI	4	You had the feeling that the virtual hand was your own hand.
VBOI(Threat)	5	You had the feeling that you were in danger of burning your own hand when you moved or touched the small burning logs.
	6	You had the feeling that the temperature of your own hand was increased when you moved or touched the small burning logs.
	7	You had the feeling that you wanted to avoid the small logs often because they were burning.
	8	You had the feeling of either being amazed or disgusted as if the spiders touched your real hand when you moved or touched the spiders.
	9	You had the feeling that spiders were moving on your real hand when you moved or touched the spiders.
	10	You had the feeling that you wanted to avoid the spiders often because you were either amazed or disgusted.
	11	You had the feeling that you wanted to wash your hand with sanitizer or a tissue after finishing the experiment.
VBOI (Agency)	12	You had the feeling that you could control the virtual hand as if it were your own hand.
	13	You had the feeling that you could pick up and drop objects naturally.
Physical Presence	14	You had the feeling that the virtual environment was a real space
	15	You had the feeling that the spiders existed in front of you.
	16	You had the feeling that you were involved in the virtual environment experience.
	17	You had the feeling that you could observe the virtual room well during the experiments.
	18	You had the feeling that the hand or the legs were on fire in your space.
Dizzy	19	You became dizzy during the experiment.

3.2. Questionnaires

We prepared three types of questionnaires: demographic, interval and post. We organized the interval questionnaire into two sections, body ownership related items and presence related items using a 7-point Likert scale, 1 with Not at all, 4 with Neutral, and 7 with A Great Deal. The items for body ownership contain body connectivity related questions as well. We created some of our own questions for body ownership, adopted body ownership related questions partly from [AA16] and adopted the presence related questions partly from [WS98]. We provide the details on interval questions in Table 1.

The post questionnaire mainly consisted of body ownership and presence related items, with the purpose of comparing among three different cases after finishing all tasks. We created the post questionnaire as a force choice among three conditions within each Rs and Hs set. The details on post questions are in Table 2.

Table 2: *The question component in the post questionnaire.*

Item	ID	Question
VBOI	1	In which condition did you feel the most realistic sense of using your own hand during the experiment?
Physical Presence	2	In which condition did you feel the most realistic sense of being in a real room during the experiment?
VBOI(Threat)	3	In which condition did you feel the greatest temperature rise when you touched the small burning logs?
	4	In which condition did you feel the most amazed or disgusted when you touched the spiders?
VBOI(Agency)	5	In which condition did you feel most natural control of the virtual hands?
Physical Presence	6	In which condition did you see the mirror-reflected legs most frequently during the experiment?

3.3. Study Protocol

Participants were asked to read our informed consent and fill out their demographic information before entering the interaction room in the questionnaire area. After they had filled out their demographic data, we gave them information about our study related to a task and a manipulation of the system. Each participant had three kinds of body cue, and each case had three three-minute tasks. We explicitly told participants that they will have a virtual hand, which is not modeled on their real hand because we wanted to remove any misunderstanding of the virtual hand in their interaction. After receiving an explanation of the session activity for the study, the participant moved to the interaction room and was equipped with the Leap motion-attached Oculus rift (DK 2) and head phone while sitting on the stool. The participant listened to an announcement of instructions for the study in our virtual mirror room. That announcement was delivered through headphones using a recorded native American speaker's voice. After completing all the tasks in a session, the participant was asked to fill out a questionnaire in the questionnaire area. We repeated this three times with three different cases, respectively. Finally, we asked the participant to fill out a post questionnaire after completing all sessions.

3.4. Task

We asked each participant to do a 'pick and drop'based simple task that is similar to [AA16, SPZS16] with different obstacles and different body conditions. In the virtual room, the participant had a table that had a hole on their left side and a metal box with a button on their right side. When the participant touched the button, the box lid opened and there were 20 wooden balls in the box. The task was to pick a ball and drop the ball into the hole completing this for at least 15 balls. However, the task purpose was not the task performance but was rather to get them to observe their surroundings in the virtual room. To afford the participants sufficient opportunities to observe the virtual room, we designed the task completion time so the participants would have to spend three minutes for each task. Actually, most participants had more than one minute to look around the room after their task completion since the task was not hard. In this experiment, the mean value of reported difficulty for the task is 2.684 for Rs set (*SD* = 1.35) and 2.333 for Hs set (*SD* = 1.08) on a 7-point Likert scale. Each task took approximately 10 minutes per case to complete so about 50 minutes were spent per participant, including all steps. In this experiment, we designed three different kinds of obstacles: no obstacle, logs on fire and animated spiders (See Figure 4). As [LWBL15] showed an influence of stressful event using fire in their virtual environment, we adopted fire and spider for a stressful event based on a similar concept.

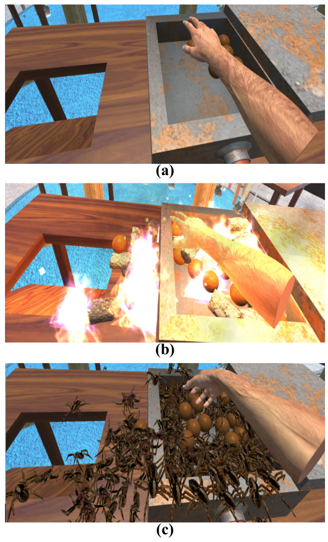


Figure 4: *We asked the participant to grab a ball in the metal box and drop the ball into the hole in the table in 3 minutes per task conditions. (a) Without any interference condition during the task. (b) With logs on fire condition during the task. (c)With an Animated spider condition during the task.*

4. Analysis

We conducted the experiment as a 3x2 mixed design with a within-subject test and a between-subject test. The within-subject factor is the representation of body cue among the three conditions in the Rs and Hs set. The between subject factor is representation of body cue between a real body and a human avatar body. Since the only variable is the mirror-reflected body condition and the corrected data is non-parametric data type, we chose to use the Kruskal-Wallis test for the within-subject test and the Mann-Whitney method for the between-subject test. In our interval questionnaire, we had an item to determine if participants had recognized their mirror reflected body condition. If they had a wrong answer for this item, we considered all answers of that type from the participant to be noise, so we filtered them out. In our experiment, one participant presented extreme arachnophobia, so we stopped the experiment immediately and filtered out that participant's data as well. We did not filter out based on sickness since the measured value for dizziness was low for all cases (*Mean* = 2, *SD* = 1.455 for Real body, *Mean* = 1, *SD* = 0 for Human Avatar body, *Mean* = 1.704, *SD* = 1.38 for Generic body and *Mean* = 1.64, *SD* = 1.319 for No body).

4.1. Interval Questionnaire Result and Analysis

Here, we explain our result for each questionnaire with its test subject types. We present the Rs set within-subject test result first, and the Hs set within subject test result next. Then we show the result from the Ts set between-subject test. Last, we show the result for the post-questionnaire.

4.1.1. Rs set with Within Subject test

The total number of participants of the Rs set was 19 —14 were male and 5 were female. There were 8 Asian, 6 White, 1 Hispanic, 3 Black and 1 unknown. The average age was 23.4 (*SD* = 5.08). We have an interesting result for the within subject test with the Rs set (See Figure 5). The strongest connectivity to the virtual hand was aroused with statistical significance when one's real lower body is observed with the results for ID1, ID2, and ID3 (*p-value* < 0.001, *p-value* < 0.002 and *p-value* < 0.001, respectively) so we believe that the results support **H1.** The result for ID 4, which is a pure Virtual

Body Ownership Illusion(VBOI) question, represents that the Real body condition has the highest score with statistical significance (*p-value* < 0.042). However, we did not find clear results with statistical significance in the threat-based VBOI. We provided two types of threats using the fire and the spiders. Most of participants did not show any phobia with our threats, except the one person who had arachnophobia. Although no phobia were exhibited, most participants received a strong emotional effect from the spiders, with a weak emotional effect associated with fire. So the average Likert value for ID 4 to ID 11 were located in similar ranges. Therefore, we could not find distinguished results for our participants'sense of VBOI using a Likert scale method. Even though there was a problem of scale, we can see a tendency that one's real body arouses a sense of VBOI by observing that the Real body condition has highest value or higher median than other conditions in ID 5, 7, 9, and 11. Thus, one's real legs had an effect on body ownership to the virtual hand under the connectivity perspective and direct VBOI perspective, but not under the traditional threat-based VBOI.

We did not find statistical meaning for presence perspective, but participants seem to have more presence in the No body condition. The noise introduced by the point cloud from the Kinect 2 distracted the participants'sense during the Real body condition. Even though we tried to prevent the noise by adjusting the Kinect 2 position, some participants observed the noise when they tried to bend their upper body extremely. We feel that this distracted their sense of presence and VBOI as well. Similar to [LLL15], participants have more Agency when they have no body since they feel it is harder to control their virtual hand even though the hand condition was identical for all cases. Thus, we could say that the consecutive hypotheses, **H2.1, H2.2** and **H2.3**, are supported only partially for VBOI (note that we do not include connectivity in VBOI) and are not supported from a presence perspective.

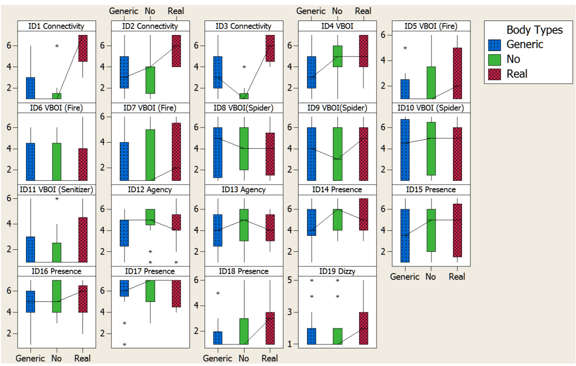


Figure 5: *Within-subject test result in the Rs set. We represent a result with median, connected line between median, interquartile range and outlier. We represented all results for all questions.*

4.1.2. Hs set with Within Subject test

The total number of participants of Hs type was 12 —9 were male and 3 were female. There were 3 Asian, 8 White and 1 Hispanic. The average age was 22.8 (*SD* = 4. 03). From this experiment, we noticed that the human avatar body did not support body ownership sensations as we hypothesized (see Figure 6). For connectivity, the Human Avatar body condition shows the highest value with ID 1 and 3 with statistical meaning (*p-value* < 0.005 and *p-value* < 0.001, respectively). However, there is no statistical significance for VBOI and presence in the Hs set. Also there is no clear tendency for VBOI among the three conditions. We hypothesize that this phenomenon is similar to the results in [LLL15] because of uncanny valley effects, so the Human Avatar body couldn't represent strong VBOI even though it has strong connectivity relatively to the other conditions. From the presence perspective, the Human Avatar body did not show a dominant tendency in the result. On the contrary, the generic body condition or no body condition shows more sense of VOBI and presence. Also it is unclear to distinguish the difference for Agency among the conditions from our results.

As a result, the Human Avatar body partially supports **H1**, but the generic and Human Avatar conditions fail to support **H2.** Thus, we did not find support for the consecutive hypotheses **H2.1, H2.2** and **H2.3**. As we mentioned above, we expected this result because of the uncanny effect from the human avatar and generic body. Neither body condition with mirror reflection produced connectivity as strong as we expected with the real body, so our results failed to support VBOI and presence clearly. However, we still have unclear result for presence. Also the participants felt more comfortable when they controlled their virtual hand in the Human Avatar body condition. In conclusion, we could say that the Real body condition strongly supports **H1** and **H2** in comparison to the Human Avatar condition.

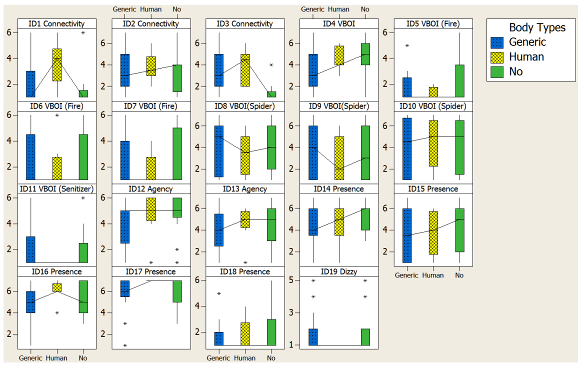


Figure 6: *Within-subject test result in Hs set. We represent a result with median, connected line between median, interquartile range and outlier. We represented all result for all questions.*

4.1.3. Ts set with Between Subject test

Finally, we conducted the between-subject test with the Real body and Human Avatar body condition using the Mann-Whitney method (see Figure 7). Explicitly, the result shows that the real body condition has stronger connectivity compared to the Human Avatar body condition with statistical significance in ID1, 2 and 3 (*p-value* < 0.008, *p-value* < 0.01 and *p-value* <0.02, respectively). From the result, we conclude that there is a clear tendency for the Real body condition to induce more VBOI than the Human Avatar body.

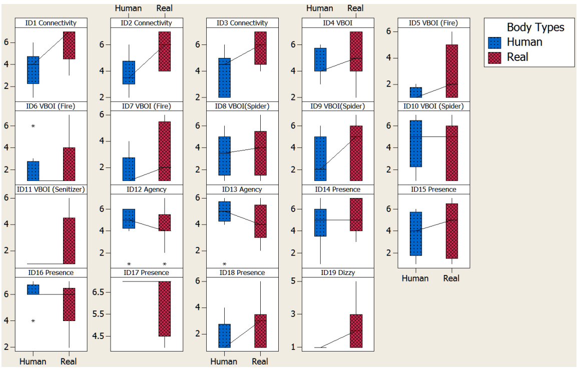


Figure 7: *Between-subject test result in Ts set. We represent a result with median, connected line between median, interquartile range and outlier. We represented all result for all questionnaire items.*

4.2. Post Questionnaire Result

To provide direct comparison among the types in the within test sets, we asked participants to fill out the post questionnaire after they had finished all the sessions. We present the questions in Table 2 in the previous section and the result chart in Figure 8. In the post questionnaire, we asked participants to choose their best sensation among conditions. In Figure 8, the bar represents the number of the participants who selected each condition. Even though the questionnaire consisted of a forced choice set, some participants failed to mark or decide. So the number is not equal to the total number of participants in both sets, respectively. The upper graph in Figure 8 shows an accumulated value of the participants'choices in the Rs set and the bottom graph shows results in the Hs set. We observed a dominant tendency that most participants were satisfied with the Real body condition for VBOI and presence compared to the Generic body or No body cases in the Rs set. The ID 1 and ID 2 sets strongly differences, which are core questions for body ownership and presence, respectively. However, there was not a clear difference in the Hs set. An interesting phenomenon was observed from ID 5 in the Rs set that indicated Agency. A result from the interval question in the Rs set indicated that the real body condition didn't give the highest sense of Agency so the results seem conflicted. We believe that the participants recognized the ID5 as a preference for their control environment, not only a functional control. Therefore, they recalled that the real body condition was most natural to control the hand because it gives greater visually correct body information than the other conditions. In conclusion, the result is not supported with statistical values, but we can observe the participants'preference in our experiment.

5. Discussion

The results represent a tendency that a real body cue elicits more sense of body ownership effects rather than other body cues with statistical difference support for some parts. However, we did not see the tendency in all statistical data, especially in presence. We conjecture the reasons that some participants did not recognize the changes in their mirror reflection was, perhaps because the mirrors were located a little too far from the participants. Also, as we conducted the study in the summer, some participants wore shorts so that they had trouble recognizing their real legs because they could not see their skin color well since we use the point cloud from Kinect 2. In comparison, the participants who wore long pants recognized their legs well (See Figure 9).

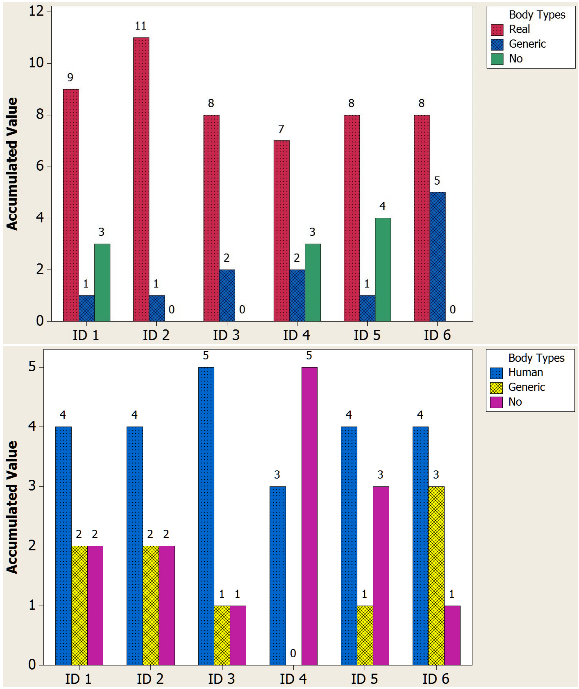


Figure 8: *Post questionnaires'result for Rs (Upper) and Hs (Lower) sets, respectively. In the Rs set, the Real body shows a dominant difference compared to the Generic and No body conditions. In contrast in Hs ID 1 and ID 2 sets, significant difference was not shown*

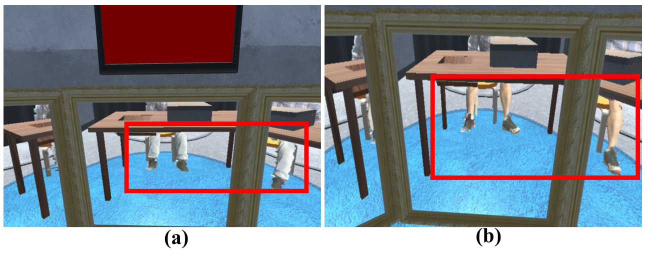


Figure 9: *The problem of misrecognition in regards to participants'costume conditions. (a) Long pants have an advantage in participants'recognizing the legs as their own. (b) With bare leg skin, participants had trouble recognizing the legs as their real legs.*

The other problem of the point cloud from the Kinect 2 was its artifacts which worked as a deal-breaker for body ownership and presence when participants see these artifacts. Because our focus was real body cue, we began the study with the Rs set first, so the total number of participants was different between the study groups, which may affect the accuracy of analysis of the experiment. Also some participants tried to see their upper body part by bending their bodies into extreme positions, but they may have felt weird when they saw the invisible upper body in the generic and human avatar cases. Otherwise, they could see their upper body part in the real body case so that it may create a bias for the result as well. Finally, the study task was more stimulating than our intention so it was hard to detect a difference among the body conditions for the sense of illusion. For example, most participants had a strongly disgusted sensation with the animated spiders; they had similar answers with our Likert scale-based questionnaire under all conditions as we mentioned.

6. Conclusion and Future Work

We explored the effect of implicated cues to virtual hand body ownership and presence in a virtual reality environment with various perspectives. To measure the effects, we conducted an experiment to compare real body cue, human avatar body cue, generic body cue and no body cue with mixed between and within tests using a subjective method. We found a tendency that the implied real body cue elicited a higher sense of virtual body ownership of the virtual hand when carrying out tasks in a virtual room. A finding is that the implicated body cue seems to create a connectivity more strongly between the mirror-reflected body and the virtual hand, when participants see their real body so that it aroused more sense of virtual body ownership in the virtual reality environment. Still we may need more statistical evidence with not only subjective tests but also objective tests , but we suggest that researchers should consider the use of indirect cue factors when designing virtual reality research. Our next research stage is to apply the indirect implication of hand to the human body. As the hand is the most noticeable limb in a person's own body, we will create a virtual hand that has features very similar to the participant's real hand using actual skin color and wrinkles, and rings, bracelets or a watch, if worn. With a virtual avatar that has a person-specific hand in a first person perspective environment, we expect to observe the effect of the hand as an indirect cue to arouse the sense of VBOI for the virtual avatar body and its presence.

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