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Influence of Hand Representation Design on Presence and Embodiment in Virtual Environment

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***Abstract* — Previous research results have emphasized the influence of avatar representations on user perception in virtual environments, including presence and embodiment. It has been reported that realistic hands present a strong sense of presence and body ownership, while there is a controversy about the sense of agency. This paper investigates the influence of virtual hand representation on user perception and the association between the sense of body ownership and agency. An experiment based on virtual reality was designed with hand representations of different levels of realism to collect users' perception data through questionnaires, and the Spearman correlation was adopted to analyze the relationship between body ownership and agency. The results show that realistic hand induces the higher sense of presence and body ownership, but there is no significant difference in the sense of agency. Moreover, a positive correlation between body ownership and agency in virtual environments was found.**

Keywords - virtual reality, hand representation, presence, embodiment, body ownership, agency

I. INTRODUCTION

The demands for virtual reality (VR) applications from all walks of life are increasingly strong nowadays, thus it becomes more significant to understand how people interact with the virtual world. VR provides immersive virtual environments (VEs) for users, and they can manipulate the controllers to interact with the virtual objects by performing specific actions [1-2]. When participants enter a fully immersive environment, they cannot see their real bodies because an opaque box obscures their vision. Hence, a virtual avatar or parts of a virtual avatar (e.g., virtual hands) can be used to create a familiar connection between users' own bodies and the virtual world. It is particularly considering that the upper limbs of users have more interaction with VEs through motion tracking techniques (e.g., Leap Motion or handheld controllers) [3-4].

Evidence from several experimental studies reveals that the representation of the virtual hand can affect the experience of participants when performing movements, such as presence and embodiment [3-6]. Presence as one of the special features of VR is defined as the overall subjective feeling of 'being there' in VEs [7]. Due to a higher sense of presence, the feeling of a more immersive environment can be produced, which can help users increase their trust in the virtual world [5-6]. Besides, when virtual avatars perform actions, users will experience the illusion that they are also doing these actions simultaneously, which is often referred to as the embodiment. The senses of body ownership, agency and location [8] are the three subcomponents of the embodiment. Body ownership refers to the feeling of 'my body belongs to me' and the special state of perception of people's own bodies [9]. The subjective sensation of controlling one's body is identified as the sense of agency, which is closely related to the awareness of action [8-10].

To date, several studies have investigated the influence of different hand representations on user perception. It has been found in literature that the sense of body ownership is higher if the virtual hands are more realistic [3, 11, 12]. However, there are conflicting results about the sense of agency. In addition, the sense of body ownership and agency were treated as two separate parts in the early study in literature [13], but both of them indicated the interactional connection in another research [9]. It is argued that there is likely a correlation between body ownership and agency [14], but their relationships in VEs remains poorly understood until now.

This paper aims to investigate the influence of virtual hand representation design on the sense of presence and embodiment. The main contributions of this paper are listed as follows: (i) evaluating users' sense of presence and agency with different virtual hand representation design; (ii) exploring the relationship between body ownership and agency under different hand representations in VEs with the Spearman correlation analysis.

II. RELATED WORKS

A. Virtual Hand Representation

The representations of virtual hands can vary from highly abstract to highly realistic. Data from a study suggests that participants react differently according to the appearance of different virtual hands, especially when they control and move those hands [11]. In fact, users expect that they can move hands naturally in VEs, moreover, there are higher expectations of user perception with the realistic hands [6].

B. Presence, Body Ownership and Agency

Few published studies have evaluated the effects of hand representations on presence. It has been identified that hand representation affects the sense of presence in VR for three reasons: deviation appearance, gender, or the own body [6]. A related study has indicated that reducing the number of fingers in a realistic hand can significantly decrease the sense of presence, but not when the hands are represented in an abstract manner [5]. Moreover, females experience less presence with male virtual hands, and users experience less presence by using non-human hands [6]. In addition, females

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have negative emotions towards hairy male arms, resulting in a reduced sense of presence.

While previous research has suggested that a higher sense of body ownership can be generated with a human-like virtual hand [3, 11, 12], the evidence for the sense of agency remains unclear. For example, a work established that the sense of body ownership is stronger with the realistic virtual hand over abstract hand in a virtual pick-and-place task, whereas the agency is weaker for the realistic hand [3]. Another research finding suggested that a higher sense of embodiment including both agency and body ownership exists in the realistic hand [14-15]. Moreover, two studies reported that there are no significant differences in the sense of agency with different virtual hands [11, 12]. In most cases, the limitation of the previous studies is that the sense of body ownership and agency are dissociated as two independent parts [13]. Nevertheless, it has been proposed that it is expected to find the association between body ownership and agency [14]. Moreover, a study has examined a positive correlation in a non-VR environment [16], whereas the relationship between body ownership and agency in VEs is still not clear.

III. METHOD

In this study, an experiment was designed with five virtual hand representations, to generate diversiform experiences from users when performing grasping and moving tasks that are typical within VEs.

A. Hand Representations

Five virtual hand models (Figure 1) were designed and prepared with different visual representations in three levels of realism (i.e., low, medium and high realism).

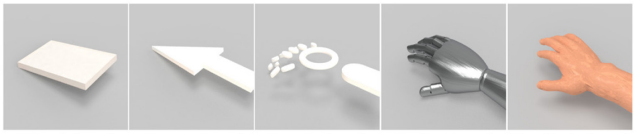
Block hand: Low realism. The simple rectangle shape represents the palm of the human hand, and there are no fingers and the wrist.

Cursor hand: Low realism. The palm of a human hand is represented by the triangle shape, and the rectangle shape represents the hand wrist.

Iconic hand: Medium realism. The simplified robotic hand has one circle and fifteen small rectangular blocks, which represent the palm and the knuckles of the virtual hand, respectively.

Robot hand: Medium realism. The number of fingers and hand joints are similar to real hands, but they look like metal with stiff finger joints and are meant to represent an artificial robotic hand.

Realistic hand: High realism. It is very similar to hands in the real world, and the design of this hand obscures the gender of the hands, such as the size of females and males.



Block hand Cursor hand Iconic hand Robot hand Realistic hand

Figure 1. Different hand representations

B. Participants and Tasks

Forty-two adult participants (21 males and 21 females) with a mean age of 22.8 years (SD = 2.7) were involved in the experiment. 27 participants had limited experience with VR, and the other participants had no VR experience. Before the experiment, all participants had signed an informed consent form. The immersive virtual environment was presented to the participants via a VR device – HTC VIVE, including one head-mounted display and one controller for the hand. The virtual scene was set as a simple laboratory room, in which a puzzle was placed on the table.

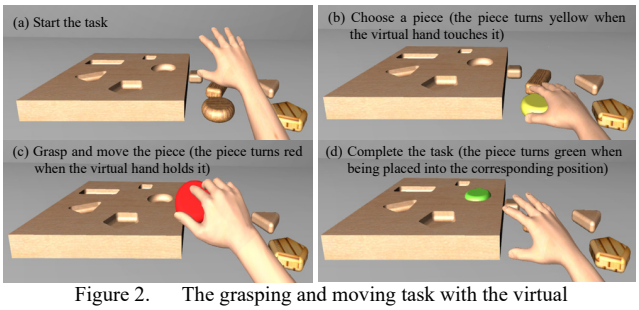


Figure 2. The grasping and moving task with the virtual hand and puzzle pieces

Each participant was required to complete the designated tasks through virtual hands with different representations. The experiment was composed of two parts: a training session and a task session. At the beginning step, the training session was provided for participants to familiarize themselves with the interaction in VEs and understand how to grasp and move the puzzle pieces. The task session required participants to grasp and move puzzle pieces into a puzzle form using the trigger button on the controller with different virtual hands (Figure 2). When all pieces had been fitted into the corresponding positions, the task was accomplished. Specifically, each participant conducted these tasks with different hand representations that appeared in random order. The questionnaire page (Figure 3) popped up automatically at the end of each task to collect participants' subjective data.

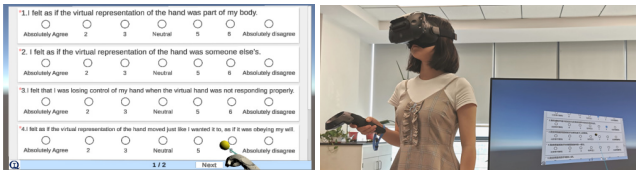


Figure 3. Questionnaire page in VR

C. Measures

In this study, a questionnaire in VR was adopted to collect the subjective data of user perception with different hand representations. According to the questionnaires in literature about presence [7, 17], body ownership and agency [3, 11], the questionnaire questions used in this study are listed in Table I. Compared with traditional paper questionnaires, the VR questionnaires, which allow participants to answer questions directly in VEs, can simplify redundant operations to improve the accuracy of results

effectively. Participants were asked to offer any free comments after the whole procedure.

After collecting the questionnaire results, the values of user perception were analyzed. The non-parametric data from each question has been statistically evaluated by mean, standard deviation and the Kruskal-Wallis test. Bonferroni's post-hoc tests were conducted to check significance for pairwise comparisons. Level of the significance level α is at 0.05. In addition, the relationship between body ownership and agency was calculated by the Spearman correlations. Only the significant differences for post-hoc tests ($p<0.05$) were reported in this research.

TABLE I. QUESTIONNAIRE RESULTS

(**P**=PRESENCE; **BO**=BODY OWNERSHIP; **AG**=AGENCY; **B**=BLOCK HAND; **C**= CURSOR HAND; **I**=ICONIC HAND, **RO**=ROBOT HAND; **R**=REALISTIC HAND)

Q_i	Items	The mean and standard deviation
1	I can interact with the environment naturally	B = (5.40, 1.25); C = (5.07, 1.45); I = (5.79, 1.14); RO = (5.86, 1.07); R = (5.88, 1.06)
2	The experience in the virtual environment is consistent with my experience in the real world	B = (5.00, 1.21); C = (4.67, 1.46); I = (5.33, 1.32); RO = (5.62, 1.25); R = (5.67, 1.05)
3	It seemed as if I can move objects on the table with the virtual hand	B = (5.88, 1.19); C = (5.88, 1.25); I = (6.40, 0.77); RO = (6.29, 0.89); R = (6.38, 0.91)
4	I felt as if the virtual hand was my part of my body	B = (3.88, 1.66); C = (4.07, 1.87); I = (4.95, 1.41); RO = (5.11, 1.40); R = (5.19, 1.60)
5	It felt as if the virtual hand I saw was someone else	B = (3.26, 1.65); C = (3.19, 1.60); I = (3.02, 1.49); RO = (2.88, 1.37); R = (2.90, 1.74)
6	It seemed as if I might have more than one hand	B = (2.67, 1.44); C = (2.64, 1.39); I = (2.50, 1.47); RO = (2.40, 1.36); R = (2.48, 1.55)
7	It felt like I could control the virtual hand as if it was my own hand	B = (5.00, 1.21); C = (5.05, 1.40); I = (5.64, 1.03); RO = (5.55, 1.17); R = (5.67, 1.37)
8	The movements of the virtual hand were caused by my movements	B = (6.12, 0.80); C = (6.05, 1.01); I = (6.33, 0.65); RO = (6.31, 0.72); R = (6.33, 0.75)
9	I felt as if the movements of the virtual hand were influencing my own movements	B = (3.43, 1.67); C = (3.38, 1.74); I = (3.57, 1.89); RO = (3.26, 1.65); R = (3.07, 1.93)
10	I felt as if the virtual hand was moving by itself	B = (2.21, 1.35); C = (2.00, 1.06); I = (1.83, 0.96); RO = (2.00, 1.13); R = (2.17, 1.64)

IV. RESULTS

The sum of results of questions (1-3) shown in Table I were analyzed to assess the value of presence. The Kruskal-Wallis test showed significant effects of presence ($H=19.209$, $p=0.001$). This study found that the mean value of presence increases in the following order: cursor hand ($M=15.62$, $SD=3.49$), block hand ($M=16.29$, $SD=3.12$), iconic hand ($M=17.52$, $SD=2.70$), robot hand ($M=17.76$, $SD=2.76$) and realistic hand ($M=17.93$, $SD=2.84$), where M stands for mean and SD stands for standard deviation. It is evident that the realistic hand indicated the highest score of presence among these five hand representations. Pairwise comparisons of presence showed significant differences for Q1-Q3 (all $p<0.05$). Specifically, significant differences between cursor hand and iconic hand ($p=0.040$), cursor hand and robot hand ($p=0.012$), as well as cursor hand and realistic hand ($p=0.005$) were found.

The results of body ownership-related questions (4-6) are shown in Table I. Significant effects with $p<0.05$ were found for Q4 ($H=22.163$, $p<0.001$), except for Q5 and Q6. Block hand was rated significantly lower than iconic hand ($p=0.024$), robot hand ($p=0.005$) and realistic hand ($p=0.002$). Moreover, pairwise comparisons revealed significant differences between cursor hand and robot hand ($p=0.030$), and cursor hand and realistic hand ($p=0.015$).

Based on the results about agency questions (7-10) shown in Table I, this work found no significant effect of hand representations on agency ($H=6.604$, $p=0.158$). In addition, realistic hand and iconic hand showed similar scores denoting higher mean value of agency than the other virtual hands (e.g., robot hand) for Q7. By applying post-hoc tests, there were no significant differences in the sense of agency under five hand representations ($p>0.05$ in all cases).

The correlation between body ownership and agency was tested by the Spearman correlations. To clearly explain Spearman's r value, the correlation of different values is defined as: negative (-1 to 0) or positive (0 to 1). The correlational analysis results between the sense of body ownership and agency with five virtual hands illustrated a positive correlation with significant differences (Spearman $r=0.381$, $n=210$, $p<0.001$). As can be seen from the detailed data in Table II, all five virtual hands (Spearman $r>0$) indicated a positive correlation between body ownership and agency. In addition, there are significant differences in the positive correlation for cursor hand (Spearman $r=0.352$, $n=42$, $p=0.022$), robot hand (Spearman $r=0.359$, $n=42$, $p=0.019$) and realistic hand (Spearman $r=0.528$, $n=42$, $p<0.001$).

TABLE II. SPEARMAN CORRELATION COEFFICIENTS BETWEEN BODY OWNERSHIP AND AGENCY WITH FIVE HAND REPRESENTATIONS

	Block Hand	Cursor Hand	Iconic Hand	Robot Hand	Realistic Hand
r value	0.257	0.352	0.257	0.359	0.528
p (sig.)	0.101	0.022	0.100	0.019	0.000

V. DISCUSSION

The results of this study have proved that all these five virtual representations elicit a sense of presence, body ownership and agency to users. Participants produced the feeling of owning and controlling virtual hands with different representations, and they experienced the virtual hand as their own hand to move the puzzle pieces to a certain extent in VEs.

The findings from the experiment indicate that the realistic hand shows higher mean values of presence and body ownership, while block hand and cursor hand present weaker scores. Participants' ratings were significantly lower about cursor hand for presence, such as cursor hand rated less than iconic hand, robot hand and realistic hand. The block hand and cursor hand were rated significantly lower

than realistic hand for body ownership. These results corroborate the previous findings on presence [6] and body ownership [4, 6, 15]. This result can be explained by the fact that the high realism of a realistic hand which is similar to the real hand can produce the sense of familiarity for users. Meanwhile, it is hard for users to trust that the representation with low realism (e.g., a block or cursor hand) can replace their real hands in VEs.

In literature, there is a controversy about the effect of hand representations on the sense of agency. In this study, no significant differences in the sense of agency were found among these five virtual hands. It is concluded that hand representations have no obvious influence on the sense of agency, which provides a consistent result with Lin and Jorg [11]. A possible explanation for this is that the realism of the hand appearance does not necessarily affect the sense of agency, because the definition of agency is the subjective sensation of controlling one's body. Moreover, participants usually have a better expectation for the realistic hand before doing the tasks, but when the hand does not have a better interaction with VEs, they will feel more disappointed with this hand. During this experiment, participants need to grasp the controller with their fingers, so the influence of the fingers is weakened. It has been proposed that more accurate finger tracking and appropriate interaction methods will assist to lead a stronger sense of agency [3-4]. Thus, other motion tracking technology such as Leap Motion can be considered for further research.

Based on the unclear association between body ownership and agency in VEs [9, 13, 14], one of the contributions of this research is exploring their relationship under different representations with the Spearman correlation analysis. The current study found that the overall results under five hand representations are positively correlated with statistical significance between body ownership and agency, which shows a similar result to the literature in a non-VR environment [16]. A possible interpretation for these results is that a strong sense of agency may be generated when the virtual hand is perceived as a part of the body. The experiment findings reveal that the relationship between the sense of body ownership and agency is complicated and is highly scenario dependent.

VI. Conclusion

The aim of the current study was to investigate the effect of virtual hand representations on presence and embodiment in VEs. All five virtual hands with different representations can produce a sense of presence, body ownership and agency. The realistic hand showed a higher sense of presence and body ownership than the low realism degree of virtual hands, and hand representations made no significant difference on the sense of agency. This study also revealed a positive relationship between the sense of body ownership and agency under different hand representations in VEs with significant differences under certain scenarios.

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References

[1] M. Huang, Y. Zheng, J. Zhang, B. Guo, C. Song and R. Yang. "Design of a Hybrid Brain-Computer Interface and Virtual Reality System for Post-Stroke Rehabilitation." in 21st International Federation of Automatic Control World Congress, IFAC 2020.

[2] D. Monteiro, H.-N. Liang, J. Wang, L. Wang, X. Wang, and Y. Yue, "Evaluating the Effects of a Cartoon-like Character with Emotions on Users' Behaviour within Virtual Reality Environments," in 1st IEEE International Conference on Artificial Intelligence and Virtual Reality, AIVR 2018.

[3] F. Argelaguet, L. Hoyet, M. Trico, and A. Lecuyer, "The Role of Interaction in Virtual Embodiment: Effects of the Virtual Hand Representation," in 2016 IEEE Virtual Reality Conference, pp. 3-10 , 2016.

[4] C. Lougiakis, A. Katifori, M. Roussou, and I.-P. Ioannidis, "Effects of Virtual Hand Representation on Interaction and Embodiment in HMD-based Virtual Environments Using Controllers," in 2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pp. 510-518, 2020.

[5] V. Schwind, P. Knierim, L. L. Chuang, and N. Henze, "'Where's Pinky?': The Effects of a Reduced Number of Fingers in Virtual Reality," in Annual Symposium on Computer-human Interaction in play, pp. 507-515, 2017.

[6] V. Schwind, P. Knierim, C. Tasci, P. Franczak, N. Haas, and N. Henze, "'These are not my Hands!': Effect of Gender on the Perception of Avatar hands in Virtual Reality," in 2017 ACM SIGCHI Conference on Human Factors in Computing Systems, CHI 2017.

[7] B. G. Witmer and M. J. Singer, "Measuring Presence in Virtual Environments: A Presence Questionnaire," Teleoperators and Virtual Environments, vol. 7, no. 3, pp. 225-240, 1998.

[8] M. R. Longo, F. Schuur, M. P. M. Kammers, M. Tsakiris, and P. Haggard, "What Is Embodiment? A Psychometric Approach," Cognition, vol. 107, no. 3, pp. 978-998, 2008.

[9] M. Tsakiris, G. Prabhu, and P. Haggard, "Having a Body Versus Moving Your Body: How Agency Structures Body-Ownership," Consciousness and Cognition, vol. 15, no. 2, pp. 423-432, 2006.

[10] M. Jeannerod, "The Mechanism of Self-Recognition in Humans," Behavioural Brain Research, vol. 142, no. 1, pp. 1-15, 2003.

[11] L. Lin and S. Jorg, "Need a Hand? How Appearance Affects The Virtual Hand Illusion," in ACM Symposium on Applied Perception, SAP 2016, pp. 69-76, 2016.

[12] B. N. Krom, M. Catoire, A. Toet, R. J. E. Van Dijk, and J. B. F. Van Erp, "Effects of Likeness and Synchronicity on the Ownership Illusion over a Moving Virtual Robotic Arm and Hand," in 2019 IEEE World Haptics Conference, WHC 2019, 2019.

[13] M. R. Longo, F. Schuur, M. P. M. Kammers, M. Tsakiris, and P. Haggard, "Self Awareness and The Body Image," Acta Psychologica, vol. 132, no. 2, pp. 166-172, 2009.

[14] K. Kilteni, R. Groten, and M. Slater, "The Sense of Embodiment in Virtual Reality," Presence: Teleoperators & Virtual Environments, vol. 21, no. 4, pp. 373-387, 2012.

[15] N. Ogawa, T. Narumi, and M. Hirose, "Virtual Hand Realism Affects Object Size Perception in Body-Based Scaling," in 26th IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2019, Osaka, Japan, 2019.

[16] A. Kalckert and H. H. Ehrsson, "Moving a Rubber Hand that Feels Like Your Own: A Dissociation of Ownership and Agency," Frontiers in Human Neuroscience, vol. 6, 2012.

[17] B. G. Witmer, C. J. Jerome, and M. J. Singer, "The Factor Structure Of The Presence Questionnaire," Teleoperators and Virtual Environments, vol. 14, no. 3, pp. 298-312, 2005.