Object Size Perception in Immersive Virtual Reality: Avatar Realism Affects the Way We Perceive

Nami Ogawa*
The University of Tokyo

Takuji Narumi
The University of Tokyo / JST PREST

Michitaka Hirose
The University of Tokyo

Abstract

How does the representation of an embodied avatar influence the way in which a human perceives the scale of a virtual environment? It has been shown that the scale of the external environment is perceived relative to the size of one's body. However, the influence of avatar realism on the perceived scale has not been investigated, despite the fact that it is common to embody avatars of various representations, from iconic to realistic. This study examined how avatar realism would affect perceived graspable object sizes as the size of the avatar hand changes. In the experiment, we manipulated the realism (high, medium, and low) and size (veridical and enlarged) of the avatar hand, and measured the perceived size of a cube. The results showed that the size of the cube was perceived to be smaller when the avatar hand was enlarged for all degrees of realism of the hand. However, the enlargement of the avatar hand had a greater influence on the perceived cube size for the highly realistic avatar than for the medium-level and low-level realism conditions. This study shed new light on the importance of the avatar representation in a three-dimensional user interface field, in how it can affect the manner in which we perceive the scale of a virtual environment.

Index Terms: Human-centered computing—Virtual reality;

1 Introduction

Previous studies have shown that altering one's body representations through the embodiment of virtual avatars can change how one visually perceives the world. For example, Banakou *et al.* [2] revealed that the embodiment of a virtual child resulted in an overestimation of object sizes compared with an adult. Interestingly, the effect was influenced by the level of embodiment. Taking into account evidence that the level of embodiment in an avatar is influenced by its visual realism [1, 6], it can be anticipated that if the avatar representation is less likely to be embodied, then its influence on embodied perception decreases. Therefore, we examined whether avatar realism influences embodied scale perception.

2 Related Work

It has been shown that changes in perceived body size affect the perceived sizes of external objects, because our own body serves as a fundamental reference in the visual perception of sizes and distances. For example, Van der Hoort *et al.* [8] found that when participants experienced a tiny body as their own through multisensory stimulation, they perceived objects to be larger and further away. Importantly, despite identical retinal input, the effect was greater when they experienced a sense of body ownership of the artificial bodies compared to a control condition. Linkenauger *et al.* also reported that the effect was specific to the participants' virtual hands, rather than another avatar's hands or a salient object of familiar size [5]. Banakou *et al.* [2] used a virtual reality (VR) system to embody a virtual full-body avatar of a child or adult, and suggested that higher-level cognitive processes other than body size alone could influence users' perceptual interpretations of object sizes in the external world, in addition to the importance of embodiment. Their findings suggest that the semantic aspects of the visual representation of the avatar could affect the phenomenon.

Regarding the representation of a virtual avatar hand, Argelaguet *et al.* [1] showed that the sense of body ownership increased for a realistic human hand compared with iconic and abstract ones. Lin and Jorg [4] found that the effect of embodiment was perceived to be weakest for a non-anthropomorphic block model, and strongest for a realistic hand model. Considering these studies, the reduction in avatar realism shown in Fig. 1 left:C&F is expected to result in a weaker sense of embodiment. In particular, the continuity between the hand and the limb of an avatar [7] and skin texture [3] are both considered to be one of the important factors of embodiment.

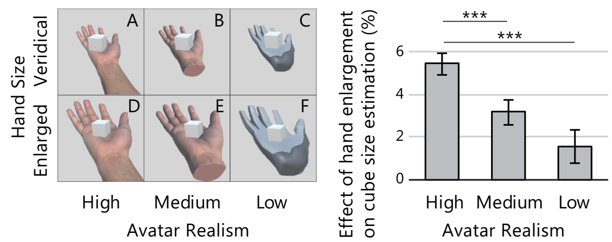

Figure 1: Left: Avatar hands used in the experiment (A-F). Right: Ratio of average size estimation in enlarged hand size condition, normalized by the corresponding value in the veridical hand size condition according to avatar realism (percentage deviation from 100 %). Error bars indicate SE. ***: $p<.001$.

3 Experiment

The purpose was to investigate the influence of hand size on the perceived size of a cube, and whether the effect was modulated by the realism of the avatar hand. In each trial, a participant carried a virtual cube (*target cube*) with an avatar hand. Following the carrying task, the target cube and avatar hand disappeared. Instead, a size-adjustable virtual cube (*answer cube*) appeared. The participants could continuously adjust the scale of the answer cube by pushing the controller so that its perceived size corresponded to the size of the target cube that they carried just previously. For each trial, the ratio of the answered cube size to the target cube size was recorded.

The experiment followed a $3 \times 2 \times 3 \times 2$ design: avatar realism (high, medium, and low), hand size (veridical and enlarged), cube size (small, medium, and large), and hysteresis direction (ascending and descending). Only avatar realism was a between-subjects factor. **Avatar Realism:** In the *high realism condition*, the avatar body had a realistic skin texture, and the arm was displayed (Fig. 1 left: A&D). In the *medium realism condition*, the arm was not displayed, but the texture was the same as in the high realism condition (Fig. 1 left: B&E). In the *low realism condition*, an iconic avatar hand was used. Its texture was changed to a cartoon style, and it

*e-mail: {ogawa, narumi, hirose}@cyber.t.u-tokyo.ac.jp

had an abstract shape, in addition to the arm disappearing (Fig. 1 left: C&F). **Hand Size:** In the *veridical condition*, the avatar hand was of the same size as the hand size of each participant. In the *enlarged condition*, the avatar hand was larger than in the veridical condition by a factor of 1.5. **Target Cube Size:** The sizes of the target cubes were randomly selected as any of 6-7.33 (6.67±10%) cm, 9-11(10±10%) cm, or 13.5-16.5 (15±10%) cm for each trial. **Hysteresis Direction:** The answer cube appeared in each trial as either 1 cm (ascending series) or 50 cm (descending series), in order to eliminate the anchoring effects.

The experimental apparatus included a Windows computer, a Leap Motion Controller, an Oculus Rift CV1, and a controller (Oculus Remote). The Leap Motion Controller could automatically detect the hand size for each subject. Its average deviation of estimated from actual positions was reported to be 1.2 mm [9].

A total of 39 individuals participated. Each participant was randomly assigned to any two of the three avatar realism conditions. As a result, the data from 26 participants was gathered for each of the high, medium, and low levels of realism. There were 24 unique types of trials (2 × 2 × 3 × 2) and each type of trial was repeated four times. All 96 trials were carried out in a random order.

4 Results

A mixed four-way ANOVA analysis revealed four significant effects. The main effects were the hand size ($F(1,75)=88.14$; $p<.001$) and target cube size ($F(2,150)=28.45$; $p<.001$). Post-hoc tests using Ryan's method showed that the sizes of cubes were estimated as significantly larger in the small cube size condition than in the medium and large conditions. In addition, there were two-way interaction effects between the hand size and avatar realism ($F(2,75)=5.42$; $p<.01$) and the target cube size and hysteresis ($F(2,150)=7.51$; $p<.001$). A simple effect of the hand size was that the sizes of cubes were estimated as significantly smaller in the enlarged condition than in the veridical condition for the all degrees of avatar realism (high realism: $F(1,75)=65.76$; $p<.001$, medium realism: $F(1,75)=16.53$; $p<.001$, low realism: $F(1,75)=16.70$; $p<.001$) (Fig. 2 left). In contrast, for different hand sizes there were no significant differences among avatar realisms. There were also simple effects from the target cube size and hysteresis direction (Fig. 2 right). In both ascending and descending series, the sizes of cubes were estimated to be significantly larger for the small target cube size condition than in the medium and large conditions (ascending: $F(2,300)=8.16$; $p<.001$, descending: $F(2,300)=35.10$; $p<.001$). In the small target cube size condition, the sizes of cubes were estimated as significantly larger in the descending series than in the ascending one ($F(1,225)=12.22$; $p<.001$).

The ratio indicating the extent to which the cube size is perceived as smaller when the avatar hand is enlarged can be obtained by dividing the value in the enlarged condition by that in the veridical condition for each degree of avatar realism (Fig. 1 right). The one-way ANOVA analysis showed a significant effect for the avatar realism ($F(2,75)=8.25$; $p<.001$). Post-hoc tests using Ryan's method showed that the amount of underestimation in the high-level condition was significantly larger than those under the medium- and the low-level conditions. There was no significant difference under the medium- and the low-level conditions.

5 Discussion

The results showed that object sizes were perceived as smaller when the hand size was enlarged with a high level of realism, as confirmed in some previous studies [2, 5] (Fig. 2 left). In addition, our results showed that the effect of body size on the object size perception is still present even in a low-level condition, but is decreased compared with a high-level condition (Fig. 1 right).

Our results regarding the tradeoff between avatar realism and the extent of the influence of body size on object size perception pro-

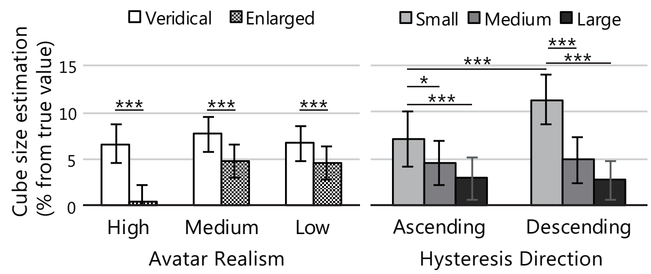

Figure 2: Average size estimation according to avatar realism and hand size as a percentage deviation from the true size. Error bars indicate SE. *: $p<.05$, ***: $p<.001$.

vides a new perspective of the effect of avatar representation on embodied perception. An avatar's representation has been considered as an entity performing an *action* in a VE. However, it also changes *perceptions* in a VE. Therefore, we must take into account the influence on embodied perception when selecting an avatar.

6 Conclusion

We investigated how object size perception is influenced by avatar hand size and the degree of avatar realism. Our results showed that perceived object sizes are underestimated when an avatar hand is enlarged compared with the veridical hand size, under all degrees of avatar realism. However, the influence of the avatar enlargement on perceived object sizes is weaker in low- and the medium-level avatar realism conditions than for a highly realistic avatar.

7 Acknowledgements

This work was partially supported by JST PREST JP-MJPR17J6(17939529).

References

[1] F. Argelaguet, L. Hoyet, M. Trico, and A. Lécuyer. The role of interaction in virtual embodiment: Effects of the virtual hand representation. *Proceedings of the 2016 IEEE Virtual Reality (IEEE VR'16)*, pages 3–10, 2016.

[2] D. Banakou, R. Groten, and M. Slater. Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proceedings of the National Academy of Sciences of the United States of America*, 110(31):12846–12851, 2013.

[3] A. Haans, W. A. IJsselsteijn, and Y. A. W. de Kort. The effect of similarities in skin texture and hand shape on perceived ownership of a fake limb. *Body Image*, 5(4):389–394, 2008.

[4] L. Lin and S. Jörg. Need a hand? How Appearance Affects the Virtual Hand Illusion. In *Proceedings of the ACM Symposium on Applied Perception - SAP '16*, pages 69–76, 2016.

[5] S. A. Linkenauger, V. Ramenzoni, and D. R. Proffitt. Illusory Shrinkage and Growth: Body-Based Rescaling Affects the Perception of Size. *Psychological Science*, 21(9):1318–1325, 2010.

[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 Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*, 2017.

[7] G. Tieri, E. Tidoni, E. F. Pavone, and S. M. Aglioti. Mere observation of body discontinuity affects perceived ownership and vicarious agency over a virtual hand. *Experimental Brain Research*, 233(4):1247–1259, 2015.

[8] B. van der Hoort, A. Guterstam, and H. H. Ehrsson. Being barbie: The size of one's own body determines the perceived size of the world. *PLoS ONE*, 6(5):e20195, 2011.

[9] F. Weichert, D. Bachmann, B. Rudak, and D. Fisseler. Analysis of the accuracy and robustness of the Leap Motion Controller. *Sensors (Switzerland)*, 13(5):6380–6393, 2013.