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Poster

The Effect of Finger-to-Neck Haptic Remapping Considering Spatial Location of Fingers on Sense of Body Ownership

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Abstract

This paper investigates sense of body ownership (SoBO) over a virtual hand when finger haptics is remapped to the neck, taking account the location of the fingers and of tactile feedback. We conducted two user studies to assess SoBO over a virtual hand induced by finger-to-neck haptic remapping (HR). The first user study experimented whether finger-to-neck haptic remapping induced SoBO. The second user study compared SoBO induced by remapping based on the fingers themselves with by remapping based on the specific finger locations. The result of the first user study showed that finger-to-neck HR successfully induced SoBO. The result of the second user study revealed that remapping based on the specific finger location achieved higher SoBO compared to remapping based on fingers. Our results suggest a potential of dynamic HR to enhance SoBO.

CCS Concepts

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

1. Introduction

In immersing in a virtual environment with an avatar, the occurrence of sense of body ownership (SoBO) enhances virtual experience. SoBO are induced by multisensory feedback, such as visuo-tactile stimulation. In eliciting SoBO with visuo-tactile stimulation, presenting tactile cues at the location spatially congruent with visual cues is effective.

However, recent studies reported that SoBO occurred even if the tactile cues were provided at different location from the visual cues [STA*14, KHK24]. Scandola et al. showed that SoBO over a rubber hand occurred in tetraplegic patients by providing haptic stimulation to their cheek synchronized with the brush moving on the rubber hand [STA*14]. Kameoka et al. revealed that finger-to-face haptic remapping (HR) using suction pressure induced SoBO over a virtual hand [KHK24]. Although the previous studies employed the face to remap finger haptics, stimulating the face may cause discomfort due to its high sensitivity and susceptibility to injury. Also, the experiments in the previous studies [KHK24] did not consider hand posture changes. However, if the hand posture is changed, the spatial relationship between their fingers and the location where haptic feedback is provided can be altered, potentially affecting SoBO.

This study investigates SoBO induced by remapping finger haptics considering spatial correspondence between fingers and remapped locations. We adopted the neck as the location for remapping finger haptics since the haptic stimulation to the neck is less likely to cause discomfort. We investigate the following research questions (RQs) through two user studies:

- RQ1: Does remapping finger haptics to a neck induce SoBO?
- RQ2: Does HR based on specific finger locations improve SoBO compared to HR based on fingers themselves?

2. User Study and Result

We conducted two user studies to investigate RQs. To remap finger haptics considering locations, we chose the fingers located at the center and the edges of both sides of the hands, thumb, middle, and pinky fingers. We remapped haptics of thumb, middle, and pinky fingers of the right virtual hand to the left, center, and right of the back of the neck. We provided haptic feedback with a microcomputer (AE-ATmega328-mini, Akizuki Denshi Tsusho) and three coreless vibrotactors (FM34E, T.P.C.DC MOTOR, 13000 rpm, 17.6 m/S^2) when a cube dropped on a virtual finger. The vibrotactors were supplied power with a 3.3V AC adapter. We recruited 18 participants (17 males and 1 females, age: M = 21.89, SD = 0.66) in both user studies. We created a 5-point Likert scale questionnaire (Table 1) by extracting questions from Avatar Embodiment Questionnaire [PGF21] and questionnaire in the previous study [STA*14].

User Study 1. User study 1 assessed whether finger-to-neck HR induced SoBO. We compared SoBO under the conditions with and without HR. The participants wore a head-mounted display (HMD) (Meta Quest 3, Meta), sat on a chair, and put their right hand on a cushion with their palms facing up. Then, a virtual hand was displayed in front of the participants and the participants observed cubes dropping on the virtual thumb, middle, pinky fingers 30 times for 60 seconds without moving their hands. After observation, the

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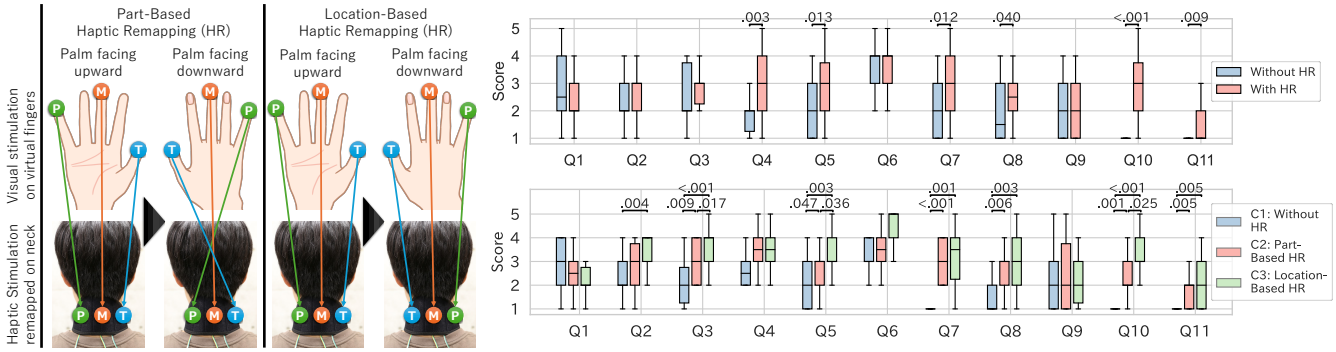

Figure 1: *(Left) HR based on Finger, the Parts of the Hand. (Center) HR based Location of the Fingers. (Right Top) Result of User Study 1. P-values are shown above the pairs of conditions where statistically significant differences were revealed. (Right Bottom) Result of User Study 2. For the pairs of conditions in which statistically significant differences were found, p-values are indicated above the pair of conditions.*

Table 1: *Questionnaire*

Q1	I felt out of my body.
Q2	It felt as if my real hand were turning into a virtual hand.
Q3	I felt a immersive sensation in my body when I saw my finger touching the object.
Q4	I felt that my own hand could be affected by virtual hand.
Q5	I felt as if the virtual hand was my hand.
Q6	I felt as if my hand was located where I saw the virtual hand.
Q7	It seemed as if I felt the touch of the cube in the location where I saw the virtual hands touched.
Q8	It seemed as if my hand was touching the virtual cube.
Q9	It seems as if I had more than one right hand.
Q10	It seemed as though the touch I felt on my neck was caused by the object touching the virtual hand.
Q11	It seemed as if the touch I was feeling came from somewhere between my own neck and the virtual hand.

participants removed the HMD and answered the questionnaire. We randomized the condition order for each participant.

User Study 2. User study 2 investigated whether HR based on finger locations led higher SoBO than HR based on the fingers themselves or not. We evaluated SoBO under three conditions without HR (C1), with part-based HR (C2) (Fig. 1 Left), and with location-based HR (C3) (Fig. 1 Right). The participants put an HMD, sat on a chair, and put their right hand on a cushion with their palms facing up. The participants observed cube dropping on each finger 30 times for 60 seconds. Then, we instructed the participants to turn their palms down. The virtual hand was also turned over. The participants observed cube dropping on each finger 30 times for 60 seconds without moving their hands. Then, the participants removed an HMD and answered the questionnaire. The condition order was randomized for each participants.

Result of User Study 1. Figure 1 Right Top shows the result of User Study 1 and the statistical analysis results with Wilcoxon signed rank tests.

Result of User Study 2. Figure 1 Right Bottom indicates the result of User Study 2 and the statistical analysis results using pairwise Wilcoxon signed rank tests with Holm correction.

3. Discussion and Conclusion

Regarding RQ1, the result of User Study 1 shows that finger-to-neck HR induced SoBO. The scores of Q5 and Q8 under the condition with HR was significantly higher than that without HR. Therefore, SoBO over a virtual hand occurred by remapping thumb, middle, and pinky fingers to three locations of the back of the neck.

Regarding RQ2, the result of User Study 2 found that location-based HR induced stronger SoBO than part-based HR. The location-based HR achieved significantly higher Q5 score than the part-based HR. However, we found no significant difference in Q8 score between location-based and part-based HR. Therefore, our results indicate that both HR let the participants feel a sensation of touching virtual objects, while location-based HR enhances SoBO over a virtual hand in addition to the touching sensation. Through this study, we revealed a potential that dynamically HR based on specific finger location enhances SoBO. We will further study the impact of location-based HR using a scale with more gradation and explore whether sensory adaptation to haptic stimuli affect SoBO.

Acknowledgment

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