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TacPoint: Influence of Partial Visuo-Tactile Feedback on Sense of Embodiment in Virtual Reality

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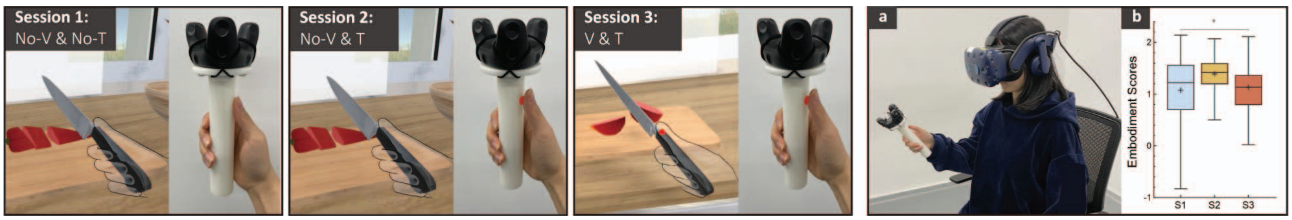

Figure 1: Left: Three experimental sessions about different combinations of visual (V) and tactile (T) feedback. Right: (a) Participants use one tangible handle to complete the virtual cooking task (e.g., vegetable chopping as an example). (b) The data of total embodiment score.

Abstract

The employment of Virtual Reality (VR) in medical rehabilitation has been broadened to incorporate visual and tactile feedback, while how people use tangible objects to induce better perceptions in VR remains unexplored. We investigated how partial visuo-tactile feedback influences users' embodiment and proposed a design idea named TacPoint (a red point mark) that connects to the physical and virtual worlds. The results reported that higher embodiment illusions could be induced in the *TacPoint* session than in others without feedback during virtual interactions. It is proposed that *TacPoint* could help people induce the embodiment easily to increase their positive experience in VR rehabilitation training.

Keywords: Virtual reality, Embodiment, Body ownership, Agency, Self-location, Tactile sensation, Rehabilitation.

Index Terms: H.1.2 [Human-centered computing]: Human-computer interaction (HCI) — HCI design and evaluation methods — User studies

1 Introduction

Virtual Reality (VR) has found applications across various fields, including medical rehabilitation [1, 2]. It offers immersive environments that engage patients in essential training, such as upper limb exercises, in a more engaging manner [2]. Moreover, one significant advantage of VR in occupational therapy is its ability to simulate activities of daily living (ADL) that may be hazardous or impractical to carry out in reality, such as cooking [2].

The effectiveness of VR could be amplified by multi-sensory stimuli, and visual and tactile stimuli are vital for user interaction within virtual settings [3-5]. Several research studies are investigating advanced haptic feedback through tangible objects equipped with VR trackers (e.g., HTC Vive Tracker) to enhance the realism of such interactions, particularly for tasks related to daily activities [4, 6]. While considering the grasping ability of patients and the training tasks for ADL, the designs of tangible handles as tactile stimuli also play an essential role in upper limb training.

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Experiencing a virtual avatar from a first-person viewpoint can offer an alternative form of bodily presence for patients in VR rehabilitation, and they can perform interactive tasks in a virtual world by having the virtual avatar. The sense of embodiment is induced when they perceive the avatar as a convincing stand-in for their physical body [7]. Importantly, research has demonstrated that stroke, which is a primary source of motor disabilities and causes alterations in the perception of one's body, could modulate the embodiment [8]. The embodiment is one of the critical user perceptions in VR rehabilitation, characterised by feelings of body ownership, agency, self-location, and tactile sensation [7]. Besides, it has been established that the disparity between virtual changes and physical reality can affect user interactions [3]. Despite many studies on enhancing user experiences with synchronised visual and tactile feedback utilising complicated electronic devices, limited research addresses partial haptic responses and interactions by tangible objects without reliance on vibration [6].

The research aims to evaluate the impact of partial visuo-tactile feedback on users' embodiment during virtual interactions. The contribution of this study is to propose a design concept named *TacPoint* (i.e., a red virtual point stimulus corresponding to a red tactile point stimulus) on the tangible handle to help users induce better embodiment perceptions in VR.

2 User Study

The experiment of the user study was designed with three sessions about different combinations of partial visual and haptic stimuli for upper limb exercises in VR. The user's perceived embodiment was evaluated via the self-reported results. The experimental apparatus included an HTC Vive Pro Eye, an HTC Vive tracker, and two types of tangible handles (Figure 1). Sixteen right-handed healthy participants (ten males and six females; 24.38 ± 2.06 years old) as volunteers were involved, and all of them had signed the informed consent form before the experiment.

Tangible Handle Design The tangible handle was built, as shown in Figure 1a, which was composed of two parts: a 3D printed cylinder with a 3cm diameter and an HTC Vive tracker installed on the top. *TacPoint* was designed to be a half-sphere stimulus approximately 1cm in diameter, located on the cylindrical handle's upper part and allowed users to touch this tactile point stimulus with their right thumb fingers. Two types of handles were used in this study: a tangible handle without *TacPoint* (in Session 1) and a tangible handle with *TacPoint* (in Session 2 and Session 3).

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Virtual Environment Design A virtual cooking scenario was designed where participants were required to complete a virtual soup-making task. The tangible handle could be transformed into four kinds of kitchenware in VR, and participants needed to complete the four steps of cutting vegetables (as shown in Figure 1), adding water, pouring spices, and stirring the soup. These interactive processes correspond to the traditional cooking training of upper limb rehabilitation in occupational therapy. A virtual red point of kitchenware as a visual stimulus was added in Session 3, while no partial visual stimulus existed in Session 1 and Session 2.

Experimental Procedure The experiment included a tutorial phase and a task phase. The tutorial phase was designed to allow participants to familiarise themselves with tangible handles and virtual environments. In the task phase, participants engaged in the soup-making task with the four steps mentioned above using the tangible handle. There are three sessions in the task phase: ***Session 1*** (without tactile and visual feedback), ***Session 2*** (without tactile but with visual feedback), and ***Session 3*** (with both tactile and visual feedback). These sessions were conducted in random order for participants. Upon completion of each task, they were required to complete a standardised embodiment questionnaire [7]. After completing all tasks, they were invited to an interview.

3 Results And Discussion

The ANOVA analysis of embodiment questionnaire items was tested for normality using Shapiro–Wilk test, and *post-hoc* comparisons for significant interaction effects were based on two-tailed paired t-tests. Figure 1b shows the boxplot graph of the total embodiment, and Figure 2 presents the results of its components.

Tactile sensation The t-test was conducted to compare average tactile sensation values in three sessions, and there were significant differences between Session 1 (M=3.08, SD=3.53) and Session 3 (M=5.44, SD=2.01) (t(15)=-2.59, p=0.020), and Session 2 (M=1.44, SD=3.37) and Session 3 (t(15)=-3.64, p=0.002). **Body ownership** Comparing the body ownership in Session 1 (M=3.63, SD=2.92) and Session 3 (M=5.25, SD=1.88), the t-test result indicated statistical significance (t(15)=-3.01, p=0.009). **Agency** The agency results showed no significant effects. The highest mean value of agency was shown in Session 3 (M=6.50, SD=2.00), and the lowest mean value was in Session 1 (M=4.94, SD=3.57). **Self-location** No significant results about location perception were found. There was the lowest mean value of the self-location in Session 3 (M=2.44, SD=2.10), and similar mean values were shown in Session 1 (M=2.81, SD=2.64) and Session 2 (M=2.81, SD=2.97). **Total Embodiment** The t-tests confirmed that Session 3 (M=1.39, SD=0.43) rated higher embodiment values than Session 1 (M=1.08, SD=0.73), t(15)=-2.385, p=0.031.

Several users reported in the interview that the virtual red point representation would quickly attract their attention due to the red mark and the virtual kitchenware with more noticeable differences. Users' thumb fingers then touch the physical point (i.e., *TacPoint*), and haptic feedback also provides perceptual input consistent with the vision. Hence, users could exhibit heightened tactile perceptions in Session 3, as opposed to Session 1 and Session 2. It may be interpreted that users are more sensitive to tactile stimuli

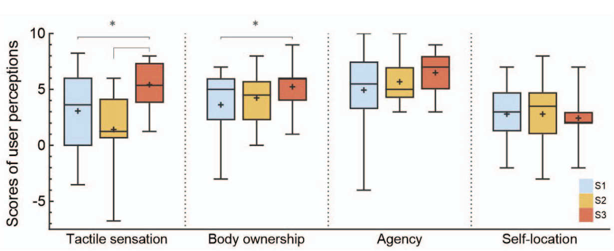

Figure 2: The data of user perceptions scores (S1-3: Session1-3).

when the visual cues in virtual environments correspond with the tactile markers they physically encounter, mainly when there is a consistent visuo-tactile alignment. Moreover, users reported the significantly strongest body ownership on a virtual hand in Session 3 over Session 1 from the questionnaire results. The interpretive reason may be that when users grasped a specific location of an object (i.e., right thumb finger touching the *TacPoint*) and observed the virtual hand executing an identical grasp, there was a significant enhancement in the feeling of owning the virtual hand. The agency is defined as the control over the movements of the virtual hand, and the definition of self-location is the perception of the virtual hands' position. The results revealed no significant differences in the agency and self-location within the three experimental sessions, indicating that users did not perceive a significant enhancement in discerning these two items using the *TacPoint*. Overall, the interaction with TacPoint in Session 3 is shown to enhance positive user perceptions, and the consistent alignment of visual and tactile stimuli notably improves users' embodiment.

4 Conclusion And Future Work

This study investigated the influence of partial visuo-tactile feedback on the sense of embodiment. Our results showed when participants used the tangible handle with *TacPoint* that as a correspondence between visual and tactile stimuli (i.e., a virtual and physical red point mark), they significantly rated higher users' embodiment than in the absence of any partial visuo-tactile stimuli. Taking advantage of this simple sign of consistency mark, *TacPoint* has the potential to help patients with no prior VR experience induce higher embodiment to complete interactive tasks and enhance the virtual experience in further therapeutic contexts. In future work, we plan to conduct further tests with patients in a hospital setting to validate our findings in a clinical context.

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