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(Not My) Self-Haptics: Reducing the Sense of Ownership and Agency toward a Virtual Keypad due to Visual Misalignment and Invisibility of the Self-Haptic Hand

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***Abstract*—Self-Haptics is a tactile feedback technique where users utilize their own body to generate tactile sensations. This method allows the body to act purely as a prop, making it useful for virtual objects and user interfaces not directly related to the body. However, a method for maintaining the sense of ownership (SoO) and agency (SoA) of the user's body and interaction targets that aligns with the perceptual interaction by visual cues does not established. To address this, we present the concept of "(Not My) Self-Haptics," which aims to resolve these inconsistencies, leveraging vision's dominance in sensory integration. Our study proved how the task performance and the user's experience, including SoO and SoA toward a virtual keypad (VPad) displayed at the position of the real hand (RHand), changes based on the visual appearance of the VHand during the interaction with the VPad. The results show that displaying the VHand in a position different from the RHand or hiding the VHand significantly reduces SoO and SoA toward the VPad, with this effect more pronounced when the RHand faces downward. These findings contribute to the understanding of the interaction between visual and tactile sensations in Self-Haptics and the realization of "(Not My) Self-Haptics".**

***Index Terms*—Virtual Reality, Haptics, Perception and psychophysics.**

I. Introduction

Self-Haptics is a kind of tactile techniques, where one's body is used as a medium for tactile feedback. The use of the body provides several advantages. First, it offers high convenience, as it is truly wearable [1]. Second, its different anatomical characteristics allow for a diverse range of inputs [2], [3]. Finally, it has the potential to provide both tactile sensation and proprioception, enabling users to roughly perceive the location and shape of physically associated objects [4].

On the one hand, due to the advantages, Self-Haptics is widely applied as a tactile feedback in body-extended user interfaces (UIs) such as on-body interfaces and on-skin interfaces in the fields of Mixed Reality and Virtual Reality (VR) [4]–[9]. On the other hand, similar to passive haptics in which types of haptic devices [10]–[14], by treating the body merely as a prop, it can also be applied to virtual objects and UIs that are unrelated to the body [9], [15]–[17]. The advantage of this approach is that high convenience of Self-Haptics allows tactile feedback function to be added without limiting the target. Kohli et al. proposed the "Haptic Hand," which overlays UI screens onto a Virtual Hand (VHand) and evaluated its usability [9]. Marichal et al. developed an environment where a VHand transforms into a virtual object for interaction [15]. They found that using one's real hand (RHand) was preferred to using someone else's RHand in the interactions. Fang et al. proposed a system that displays the VHand in a position naturally shifted from the RHand, creating three different interaction types [16]. Their results indicated that users preferred the interaction using both Rhands. Pei et al. proposed an interaction method where the user's RHands and the virtual objects are related in terms of shape similarity, demonstrating that their proposed method was varied and enjoyable to use [17].

However, in Self-Haptics that merely treat a body as a prop, the consistency between visual and tactile sensations becomes an issue. For example, consider a scenario where a user interacts with a virtual object using one's right hand. To provide tactile feedback of the virtual object touching the right hand, the user's left hand is positioned behind the virtual object as a physical prop. In this case, due to the tactile sensation and proprioception from the left hand, the user may perceive the interaction target not as the virtual object but as the left hand or as something that shares sensory feedback with the left hand. Although Self-Haptics successfully delivers tactile feedback to the right hand, the user's perception of the interaction base on visual cues is disrupted, leading to a breakdown in the consistency between visual and tactile sensations.

Fang et al. reported that the inconsistency affects the sense of ownership (SoO) and the sense of agency (SoA) [16]. In interactions where the touched body part is visually perceived as incapable of generating tactile sensations, SoA over the corresponding VHand, displayed separately, was reduced. This decreased SoO of the VHand is an undesirable perceptual

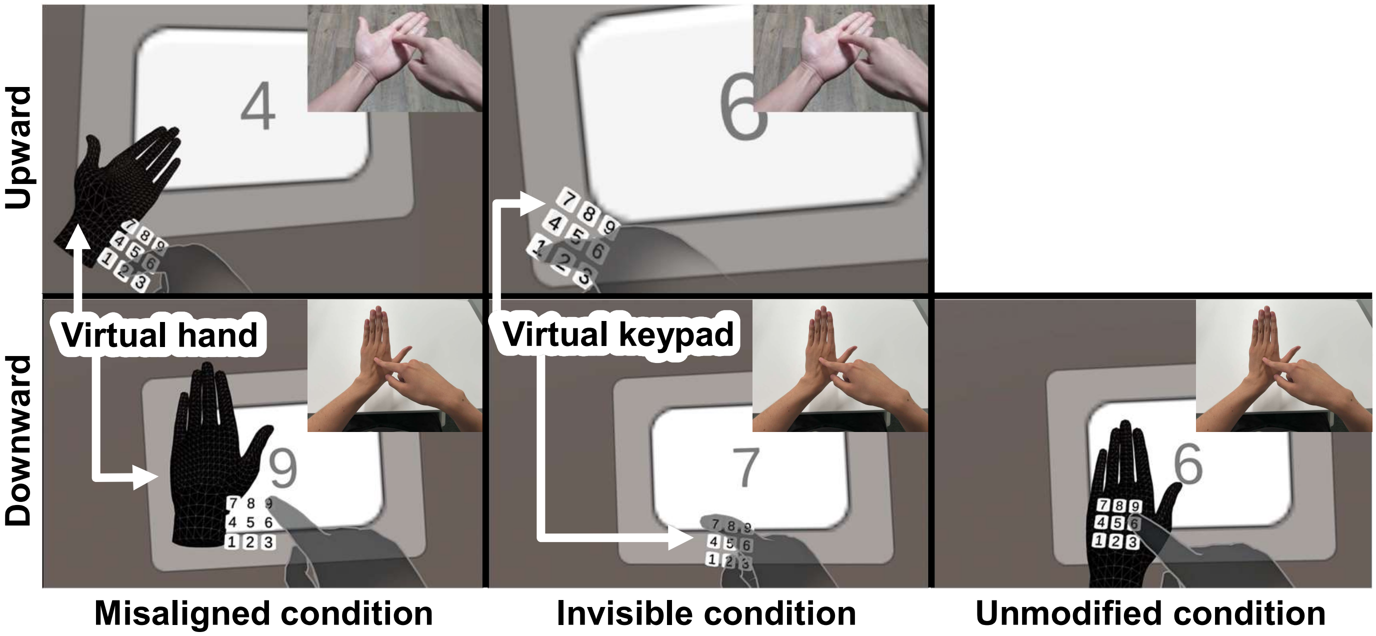

Fig. 1. Self-Haptics is generated by pressing the virtual keypad superimposed on the left hand with the right hand. User experience, including the sense of ownership and agency, and task performance are compared across three conditions: misaligned virtual hand, invisible virtual hand, and unmodified virtual hand.

state when visual cues are considered the primary basis for perception in a VR experience. The decrease in SoO of the VHand is likely due to a sensory mismatch: while both visual input and the active hand' s tactile sensation indicate that the UI is providing tactile feedback, the passive hand' s tactile sensation suggests that the feedback originates from a misaligned and invisible touched hand. The relationship between SoO and SoA, and the consistency has been extensively demonstrated by studies such as the rubber hand illusion [18], the virtual hand illusion [19], the arm movement [20], and the telexistence [21]. Thus, when designing an ideal perceptual state for a VR experience primarily based on visual cues, it is necessary to control the consistency between visual and tactile sensations so that the VHand maintains a high SoO and SoA, while the interaction target has a lower SoO and SoA. We consider that this issue should be addressed even if the interaction target is a UI functioning as a bodily extension, as long as the design does not treat the body itself as the UI. This misperception may lead to more significant obstacles for the user, such as pain or anxiety [22]. However, to the best of our knowledge, no existing research on Self-Haptics has directly addressed this issue.

To address this issue, we introduce "(Not My) Self-Haptics," state of Self-Haptics that resolves this issue, conveying the idea of being self-generated yet not felt as one's own touch, and we aim to achieve this through visual stimuli. This paper investigates the effectiveness of visual modifications to VHands in addressing of this issue focusing on UI screens overlaid on a RHand, a common application of Self-Haptics. We clarify that the user experience, including SoO and SoA toward a virtual keypad (VPad) displayed at the position of the RHand, changes based on the appearance of the VHand, through two experiments with different hand orientations (see Figure 1). We expect that displaying a misaligned VHand reduces SoO and SoA for the VPad, with this effect more pronounced when the RHand is facing downward. Additionally, from the perspective of the applicability of "(Not My) Self-Haptics", we focus on changes in task performance during interaction with the VPad, expecting an improvement in the performance. These results are anticipated to be beneficial for "(Not My) Self-Haptics". This study contributes to the understanding of the interaction between visual and tactile sensations in Self-Haptics, expanding the potential applications of Self-Haptics that merely treat a body as a prop in VR.

II. Related Works

A. Self-Haptics and User Interfaces

Self-Haptics is used in on-body interfaces and on-skin interfaces, which are UI systems that involve the body due to provide simple, fast, accurate, and versatile interaction capabilities [4], [9]. Moreover, Hands and arms are commonly used as body parts in UIs with Self-Haptics. This is likely because input and output of UIs do not significantly reduce the immersion and the presence in VR experiences, combined with advancements in sensing technology [23]. For example, Harrison et al. developed Skinput, which captures skin displacement caused by contact with hands or arms and converts it into sound waves for input [1].

However, Lediaeva et al. report that the hand is more suitable than the arm for displaying UI elements [24]. They evaluated graphical menus based on the body in terms of different placements (space, arm, hand, waist), menu shapes (linear, radial), and selection methods (ray-cast, head, gaze). The results indicated that menu input on the hand, space, and waist was significantly faster than on the arm, and spatial menus were preferred the most. Furthermore, the way hands are used is also considered to influence compatibility with the UI. Perella-Holfeld et al. established design guidelines for Hand-Proximate User Interfaces based on the anatomical characteristics of hands and user feedback, where UI screens are displayed around hands [25].

The generation of tactile sensation and proprioception from the touched hand is likely to contribute to the perception of the RHand, making it often unsuitable for achieving "(Not My) Self-Haptics". Therefore, the less sensitive back of the hand is considered more effective. This is because the palm is so sensitive that thermal stimuli are difficult to distinguish from tactile stimuli [26]. However, since the back of the hand has surface irregularities and hardness, and differs anatomically from the palm, its effect on SoO and SoA toward a UI overlaid on the hand should also be considered in terms of tactile reproducibility. Our study focuses on the hand, a body part with high applicability for UIs with Self-Haptics, and conducts experiments on both the palm and back of the hand.

B. Virtual Key Input

The design methods for UIs enabling users to operate keys floating in Virtual environments using their hands have been studied [27], [28]. Applying the configuration of real keyboards and screens directly to virtual environments may degrade the user experience [29], [30]. Dudley et al. evaluated the impact of the virtual keyboard' s position and the number of fingers used for input on the input and error rate [31]. Their results suggest that using two fingers to operate a virtual keyboard overlaid on a flat surface in the real environment is recommended.

Tactile feedback improves user experience and input rates for key input in Virtual environments [31], [32]. Bermejo et al. evaluated the changes in task performance when combining 2D and 3D displays of real and virtual keyboards with audio and vibration feedback [33]. Their findings revealed that adding vibration improved the input speed of the virtual keyboard, regardless of the display format. Ma et al. investigated the effects of audio and vibration feedback on task performance in flat and 3D real keyboards [34], concluding that tactile feedback is effective in improving input speeds and reducing error rates.

We adopt a VPad as the UI and measure the input speed and the error rate as indicators of task performance. The VPad, consisting of nine digits as developed by Bermejo et al., can be displayed on the hand [33]. Furthermore, these indicators are widely used for evaluating virtual key input.

C. Effect of Sensory Modality on Ownership and Agency

Synchronous visual-tactile stimulation can alter SoO and SoA toward virtual objects [35], [36]. SoO is well known from the study of the rubber hand illusion by Botvinick and Cohen [18]. Slater et al. demonstrated that the principle of the rubber hand illusion where synchronous visual and tactile stimulation between a RHand and a rubber hand induces SoO also applies when using a VHand instead of a rubber hand, thereby inducing SoO over the VHand [19].

On the other hand, SoA is known to depend heavily on the synchrony of movement, which is perceived through proprioception [37]. Argelaguet et al. introduced visually distinct virtual objects synchronized with a RHand movements and imposed an active movement task that visually involved pain [38]. Their results showed that SoA was determined by movement synchrony regardless of appearance, while SoO was primarily influenced by appearance.

However, the determination of SoO and SoA is based on sensory integration, and the degree of reliance on each sensory modality changes [39], [40]. Medina et al. showed that increasing the asynchrony of visual-tactile stimulation using a mirror box led to a greater reliance on vision over touch, as evidenced by drift measurements and changes in SoA [40]. They also suggested that an increased SoO could further enhance visual dependency. Guterstam et al. demonstrated that SoO can emerge even for invisible hands or bodies, as evidenced by responses to questionnaires and changes in skin conductance in a rubber hand illusion experiment [41], [42]. They suggested that showing a brush stroking empty space, rather than stroking a visible wooden block, more strongly induces the perception that something, including a hand, exists at the location being stroked and enhances SoO.

Based on these findings, this study introduces two types of visual stimuli: modifying the VHand's position relative to the RHand and making the VHand invisible. This is because vision is fundamentally dominant over other sensory modalities [43]–[45]. Furthermore, the effect of changing the positional relationship between the VHand and the RHand on SoO and SoA during interaction with a UI has not been fully clarified.

D. Haptics Retargeting

Haptic retargeting is a method that allows one real object to correspond to multiple virtual objects for tactile feedback [46]. The visual methods used in haptic retargeting alter the entire Virtual environment [47], [48] and the user' s perceived motion, taking advantage of the dominance of vision over touch in sensory integration [44], [45].

For methods that alter the user' s perceived motion, it is essential to select the optimal approach for each interaction. On one hand, Azmandian et al. used wrist rotation gain to reduce sensory mismatch [46]. Zenner et al. and Esmaeili et al. measured gain variation thresholds along the three axes of height, width, and depth [49], [50].

On the other hand, Fang et al. applied a modified gain adjustment based on Azmandian' s method to create different interaction modalities [16]. Our study follows Fang's approach and applies gain adjustments based on the VHand's position, with the gain magnitude referencing the depth values from Zenner and Esmaeili.

III. Experiment 1: Hand Facing Upward

A. Objective

In Experiment 1, we investigated the effect of the presence and absence of the left VHand on user experience and task performance with the left VHand displayed in a different position from the left RHand as users press the VPad located on the left RHand facing upward. Unless otherwise specified, VHand and RHand refer to the left hand. Specifically, we hypothesized the following as two major findings.

H1 The presence of the VHand decreases SoO and SoA toward the VPad.

H2 The presence of the VHand improves task performance on the VPad.

B. Methods

1) Experimental Design: Experiment 1 was a within-subjects design with one factor, the presence or absence of the VHand, with two levels. User experience and task performance were compared at the two levels. This experiment consisted of a sub task, which involves modifying the positional relationship between the VHand and the RHand, and a main task, which involves key input using the VPad. These two tasks are collectively referred to as the task set.

The sub task was divided into two phases: calibration and transition. In the calibration phase, participants first position their left hand in a predefined posture, aligning the direction between the thumb and index finger with the front of the body, and aligning the palm with the ground (see Fig. 2 (top)). Next, participants touch their wrist to the center of their abdomen while maintaining the hand's orientation. Finally, participants extend their hand forward as far as possible while maintaining the same orientation. In the transition phase, participants first align their hand with the virtual box closest to the body, maintaining the hand's orientation (see Fig. 2 (bottom)). This virtual box was located 10% of the hand's length in front of the initial point from the calibration phase. Next, participants extend their hand forward to align it with the virtual box farther from the body. This virtual box was located 90% of the extended distance away from the other virtual box, based on the extension in the calibration phase. During the extension motion in the transition phase, the position of the VHand shifts to differ from that of the RHand. The amount of this difference was equal to the width of the RHand when the VHand aligns with the virtual box farther from the body. The length and width of the hand were defined based on the predefined posture.

The main task was performed immediately after the sub task. Participants was able to see the VPad displayed on their left hand, the right hand that operates the VPad, and the virtual display that indicates the key to press. The virtual display showed a single-digit number from the sequence. The sequence consisted of 10 random non-consecutive digits from one to nine. Participants pressed the key on the VPad, which matches the number displayed on the virtual display using the index finger of their right hand. If the correct key was pressed,

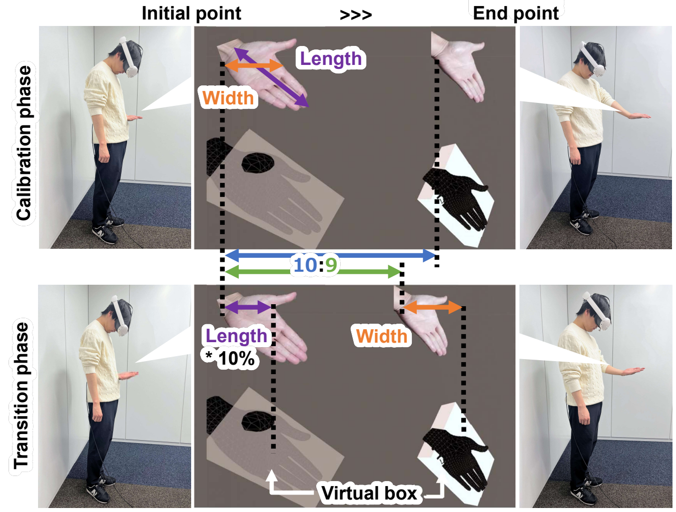

Fig. 2. (Top) Hand positions during the calibration phase of the sub task. The predefined posture of the hand. (Bottom) Hand positions during the transition phase.

the virtual display showed the next number in the sequence. If an incorrect key was pressed, the virtual display continued to show the same number until the correct key was pressed. Each time a sequence was completed, the virtual display showed the remaining number of sequences for one second. The main task ended after three sequences were completed. Participants were instructed to keep the position and orientation of their left hand as still as possible during the main task.

2) Measurements: User experience in the main task was measured through a questionnaire. Task performance in the main task was measured using a score.

For the user experience questionnaire, we chose a modified version of Q1–24 by Fang et al. [16] aimed at evaluating UIs and by Gonzalez-Franco et al. aimed at measuring the body ownership [51], and the Q25–27 by Bermejo et al. for evaluating the key input [33], modified for this study (see Table I). Responses were based on a seven-point Likert scale: (+3: strongly agree, +2: agree, +1: slightly agree, 0: neutral, -1: slightly disagree, -2: disagree, -3: strongly disagree). The order of the questions follows the ascending order of the question numbers and is the same for all VHand conditions. Additionally, SoO and SoA of the VHand were measured using Q1–7, replacing VPad with VHand, after the completion of practice tasks designed to familiarize participants with the task set.

Task performance scores were based on the number of key inputs and the input error rate, following Bermejo et al. [33]. The number of key inputs was calculated as the number of keys pressed per minute using the following equation (1). n represents the number of sequences. T_k represents the time elapsed for each sequence from when the first correct key was pressed.

$$\text{Number of key inputs} = \frac{n(10-1)}{\sum_{k=1}^{n} T_k} \cdot 60 \tag{1}$$

The input error rate was the rate of key input errors across the entire main task.

TABLE I
THE QUESTIONNAIRE ON USER EXPERIENCE. Q1–7 ARE RELATED TO THE VHAND DURING THE PRACTICE TASK. RESPONSES ARE BASED ON A SEVEN-POINT LIKERT SCALE.

Q1.	I felt as if the virtual keypad was a part of my body.
Q2.	It felt as if the virtual keypad I saw was someone else.
Q3.	It seemed as if I might have more than two hands.
Q4.	It felt like I could control the virtual keypad as if it was a part of my own body.
Q5.	The movements of the virtual keypad were caused by my movements.
Q6.	I felt as if the movements of the virtual keypad were influencing my own movement.
Q7.	I felt as if the virtual keypad was moving by itself.
Q8.	It seemed as if I felt the touch of the keypad in the location where I saw the virtual keypad touched.
Q9.	It seemed as if the touch I felt was located somewhere between my virtual left hand and the virtual keypad.
Q10.	It seemed as if the touch I felt was caused by the virtual right hand touching the virtual keypad.
Q11.	It seemed as if my real right hand was touching the virtual keypad.
Q12.	I felt the virtual keypad.
Q13.	The virtual keypad felt like it was there.
Q14.	The virtual keypad felt real.
Q15.	I did not feel anything when my right hand touched the keypad.
Q16.	I felt as if my real left hand was located where I saw the virtual keypad.
Q17.	I felt as if my real hand were drifting toward the virtual keypad or as if the virtual keypad were drifting toward my real hand.
Q18.	It felt as if my real hand were turning into an ”avatar” virtual keypad.
Q19.	At some point it felt as if my real hand was starting to take on the posture or shape of the virtual keypad that I saw.
Q20.	At some point it felt that the virtual keypad resembled my own real hand, in terms of shape, skin tone or other visual features.
Q21.	The main task felt realistic in the case where the virtual left hand was misaligned/invisible.
Q22.	The effect of the misaligned/invisible virtual hand made me feel more immersed in the main task.
Q23.	The main task was fun in the case where the virtual left hand was misaligned/invisible.
Q24.	I preferred the experience with the virtual left hand to without it.
Q25.	How comfortable was it to use the system in the case where the virtual left hand was misaligned/invisible?
Q26.	How reliable was the system in the case where the virtual left hand was misaligned/invisible?
Q27.	How fast was the system operate where the virtual left hand was misaligned/invisible?

3) Conditions: The VHand condition consisted of two states: the presence or absence of the VHand (see Fig. 1). When it is present, as the misaligned condition, and when it is absent, as the invisible condition. In the invisible condition, the VHand is no longer rendered after the subtask is completed. The position of the VPad is synchronized with the real left hand regardless of the VHand condition.

A preliminary task was set to help participants understand the virtual environment and the key input. In the preliminary task, the positions of the VHand and the RHand were the same. Participants were free to press the keys of the VPad while adjusting the position and orientation of their hands. The position and orientation of the VPad, as well as the position of the virtual display, were adjusted and fixed for each participant in this task.

A practice task was set to help participants become familiar with the task set. In the practice task, the participants performed the task set twice under the misaligned condition.

4) Apparatus: The virtual environment was implemented using the game engine Unity3D and an HMD: Head Mounted Display (Meta, Quest3). The position and orientation of the participant's RHands were detected using the hand-tracking feature of the HMD.

5) Procedure: Each participant completed the task by following the five steps. The order of the VHand conditions was counterbalanced across the experiment. The total experiment time was within one hour.

1) Adjusted the orientation of the virtual display and VPad during the preliminary task.
2) Performed the practice task and answer Q1–7 related to the VHand.
3) Completed the task set for the first VHand condition and answered Q1–20.
4) Completed the task set for the second VHand condition and answered Q1–20.
5) Answered Q21–27 and provided free-text responses.

6) Participants & Configurations: The participants were 12 healthy individuals (nine males, three females; ages 25 to 48; body measurements: mean (standard deviation), height 167.8 (7.6) cm, weight 61.3 (10.0) kg, hand width 9.4 (0.6) cm, hand length 18.3 (0.9) cm). All participants were right-handed. Three participants had little experience using VR with an HMD. All participants signed a consent after receiving a full explanation of the study and agreeing to participate. The instructions and consent forms for all the experiments conducted in this study were approved from an ethical perspective by the first author's institution.

7) Analysis: The responses of the questionnaire were treated as an ordinal scale based on a Likert scale. However, following previous study, we used aggregated calculated values for some questions [16]. SoO is calculated as $(Q1 - Q2 - Q3)/3$. SoA is calculated as $(Q4+Q5+Q6-Q7)/4$. Tactile is calculated as $(Q8-Q9+Q10+Q11)/4$ and $(Q12-Q13+Q14+Q15)/4$. Localization is calculated as $(Q16+Q17)/2$. Appearance is calculated as $(Q18 + Q19 + Q20)/3$. The number of key inputs and the input error rate were treated as proprtional scales based on user behaviors.

The Wilcoxon signed-rank test was conducted for the responses of the questionnaire. The paired t-test was conducted for the number of key inputs and the input error rate. Effect sizes were calculated using the rank-biserial correlation r and Cohen's d. The interpretation criteria for r follow the guidelines proposed by Funder et al. [52], while those for d are based on Cohen's standards [53]. The significance level was set at $\alpha = 0.05$. Normality tests were omitted in consideration of their potential impact on post hoc tests when used as preliminary tests [54]–[56]. Statistical analysis was performed using R software [57].

C. Results

The results of the user experience are shown in Fig. 3 and Tab. II. A significant difference in the median of the tactile sensation of the VPad was confirmed between the VHand conditions ($p = 0.021$). The medians of SoO and SoA for the VHand were significance different from zero ($p = 0.002$, $p = 0.013$). The results of task performance are shown in Fig. 4. The number of key inputs showed no significant difference between the VHand conditions (Misaligned condition: $M = 36.0, SD = 5.1$; Invisible condition: $M = 38.2, SD = 5.9$; $t(11) = 1.21$, $p = 0.253$, $d = 0.35$ $(-0.27,\ 0.96)$). The input error rate also showed no significant difference between the VHand conditions (Misaligned condition: $M = 0.09, SD = 0.06$; Invisible condition: $M = 0.07, SD = 0.09$; $t(11) = 0.57$, $p = 0.578$, $d = 0.17$ $(-0.44,\ 0.77)$).

D. Discussion

Tactile feedback for the VPad was significantly higher in the invisible condition. Thus, the absence of the VHand can make it easier to perceive the tactile feedback generated by the VPad. On the other hand, H1 was rejected, as SoO and SoA toward the VPad tended to decrease in the invisible condition. It is speculated that in the absence of the VHand, the lack of congruency between the visual and tactile feedback related to the VHand also led to a decrease in SoO and SoA associated with the VPad. First, the relationship between the congruency of the VHand' s visual and tactile feedback and SoO and SoA is supported by the findings of Bovet et al. [20]. Bovet et al. revealed that with no matching of visual feedback with tactile feedback related to one's own body during motion, SoO and SoA decreases. Next, similar to the report by Fang et al., SoO and SoA toward the VHand in this experiment likely decreased due to the tactile feedback related to one's own body [16]. Finally, two factors can be considered for the linkage between SoO and SoA of the VHand and the VPad. The first is the perception of the VHand's presence through the tactile feedback generated by interacting with the VPad. The second is the recall of the VHand's presence due to the synchronization between the RHand and the VPad' s position, regardless of the VHand condition. These are supported by the relatively high points for SoA, as well as the higher points for realism, immersion, and enjoyment in the invisible condition.

There were no significant differences in the number of key inputs and the input error rate, with better performance in the invisible condition. Therefore, H2 was rejected, and it can be said that the absence of the VHand did not reduce task performance. The results of this experiment align with studies showing that task performance differs more significantly with the presence or absence of tactile feedback, but less so with only visual conditions [33], [34]. On the other hand, Knierim et al. pointed out the reduction of visual influence due to cognitive load and proficiency [58]. In this experiment, since the VHand did not directly contribute to the task, it may have been unnecessary and possibly increased cognitive load. This is also supported by the results related to comfort, reliability, and responsiveness.

TABLE II
STATISTICAL MEASURES OF THE QUESTIONNAIRE RESULTS REGARDING EACH ELEMENT OF USER EXPERIENCE. 'VH' MEANS FOR VHAND.

Elements	Z	p	r (95%CI)
Ownership	0.40	0.719	0.14 (-0.51, 0.68)
Agency	1.38	0.174	0.49 (-0.13, 0.84)
Tactile	2.27	0.021	0.77 (0.34, 0.93)
Tactile_Local	0.89	0.432	0.38 (-0.23, 0.78)
Location	1.16	0.270	0.39 (-0.22, 0.78)
Appearance	1.81	0.073	0.59 (0.04, 0.87)
Realism	0.99	0.354	0.32 (-0.35, 0.77)
Immersion	1.54	0.138	0.50 (-0.12, 0.84)
Fun	0.16	0.879	0.05 (-0.55, 0.62)
Preference	0.25	0.836	0.08 (-0.51, 0.62)
Comfort	0.83	0.456	0.27 (-0.37, 0.74)
Reliability	0.58	0.576	0.20 (-0.44, 0.70)
Responsivity	0.12	0.940	0.04 (-0.58, 0.63)
Ownership_VH	2.83	0.002	0.92 (0.75, 0.98)
Agency_VH	2.40	0.013	0.78 (0.39, 0.93)

Moreover, both SoO and SoA toward the VHand during the preliminary task were significantly greater than zero, indicating that haptic retargeting was functioning properly. The gain of 1.44 (0.11) over 23 trials in the experiment, excluding the error of one trial, did not differ substantially compared to Zenner et al.'s 1.34 and Esmaeili et al.'s 1.38 [49], [50]. This is further supported by the fact that it was after haptic retargeting that all twelve participants realized for the first time that the positions of the VHand and the RHand were different, as revealed in the free responses.

IV. EXPERIMENT 2: HAND FACING DOWNWARD

A. Objective

In Experiment 2, we aimed to clarify the effect of the presence and position of the left VHand on user experience and task performance when users press the VPad located on the left RHand facing downward. Unless otherwise specified, VHand and RHand refer to the left hand. Specifically, we hypothesized the following as two major findings.

- H3 When the positions of the VHand and RHand differ, SoO and SoA toward the VPad decrease compared to the absence of the VHand. However, SoO and SoA further decrease when the positions of the VHand and RHand are the same.
- H4 The presence of the VHand improves VPad task performance compared to when the VHand is absent, but task performance further improves when the positions of the VHand and the RHand are the same.

B. Methods

1) Experimental Design: Experiment 2 was a within-subjects design with one factor, the VHand condition, which

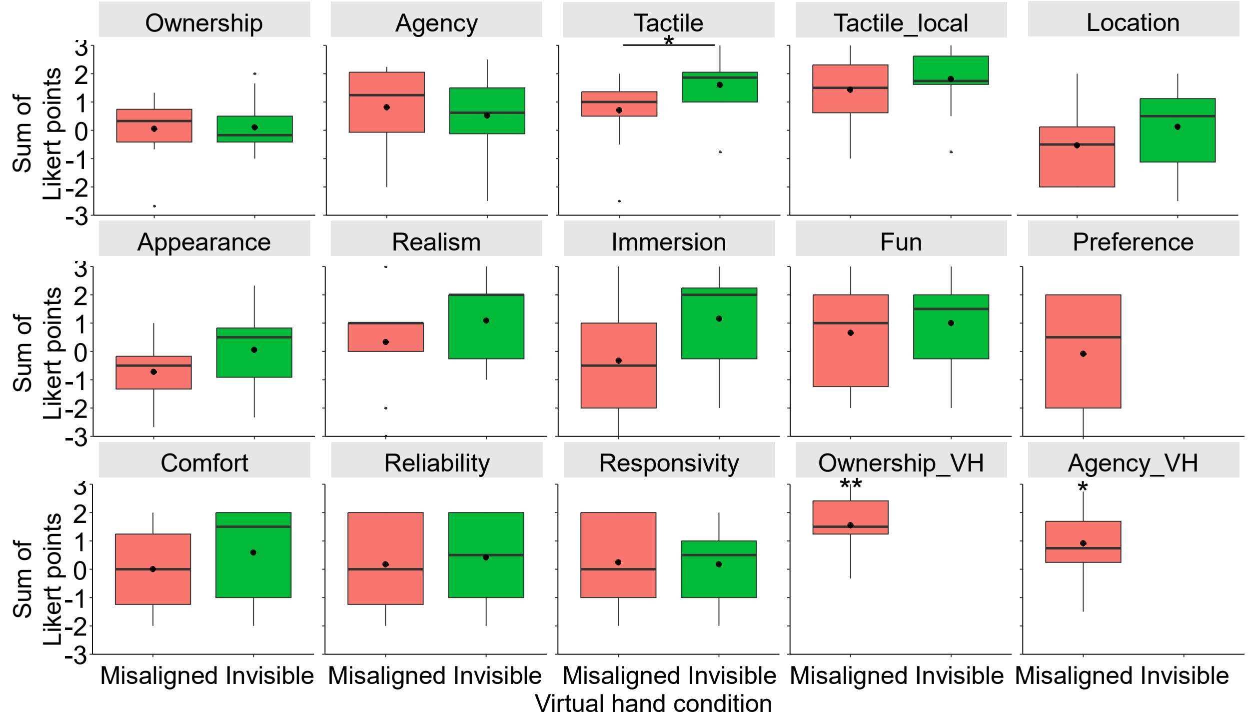

Fig. 3. The sum of Likert points of the questionnaire on user experience (n =12). Representative lines indicate the median, and representative points indicate the mean. SoO, SoA, tactile sensation, location, and appearance are calculated values. *: $p < 0.05$, **: $p < 0.01$.

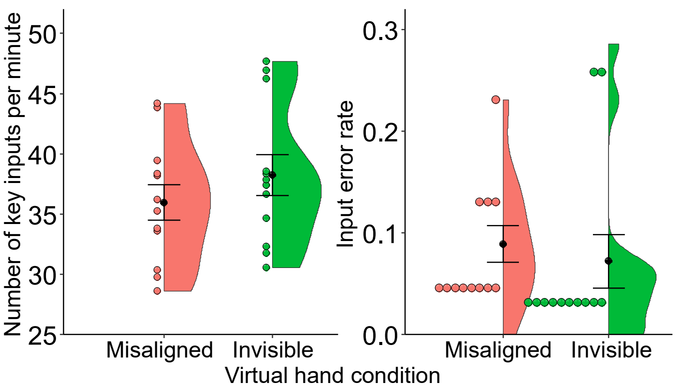

Fig. 4. The number of key inputs, and the input error rate (n =12). Representative points indicate the mean, and error bars indicate the standard error (SE).

combines the presence or absence of the positional relationship between the VHand and the RHand, across three levels. User experience and task performance were compared across the three levels. There were three major differences from Experiment 1, aside from the hand's two faces. First, the posture was set to a seated position to enable the execution of the real task described later. Second, the position and orientation of the RHand during the main task differed to reduce the unnaturalness of key input. Third, a real task was added, involving key input on a real keypad as one of effective UI using "(Not My) Self-Haptics".

Regarding the first difference, participants performed two setups in an experimental environment with an office desk and office chair (see Fig. 5 (right)). First, as in Experiment 1, the chair height was adjusted so that participants could extend their hand forward. The adjusted chair position remained fixed until the end of this experiment. Next, participants determined a natural position for pressing the VPad displayed on the back of the RHand. The hand's orientation was set with the fingertips pointing forward and the back of the hand level with the desk, tilted 45 degrees in the depth direction.

Fig. 5. A participant performing the real task. The orientation and position of the RHand are the same as the main task.

For the second difference, participants translated their hand to the natural pressing position determined during the setup at the end of the sub task (see Fig. 6). The natural pressing position was presented as a new virtual box after the RHand was aligned with the farthest virtual box from the body during the sub task. The length and width of the hand were defined

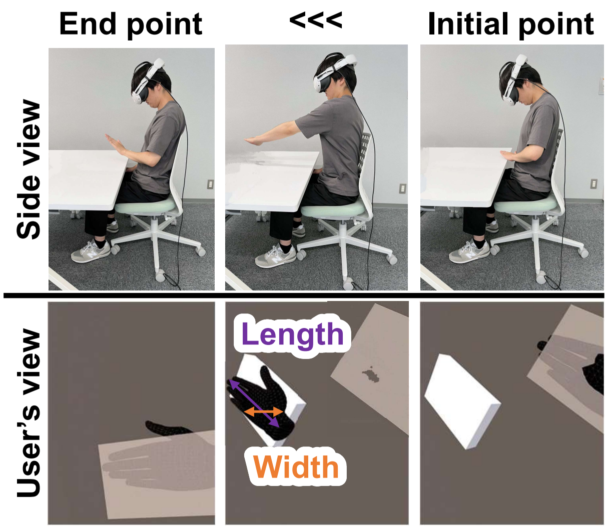

Fig. 6. Changes on the position of the RHand during the transition stage of the sub task. The predefined posture of the hand. The end point of the RHand are the natural pressing position where the VPad overlaid on it can be easily pressed by the right hand.

based on the predefined posture of the hand facing downward.

The third difference, the real task, was conducted after all VHand conditions are completed (see Fig. 5 (left)). In the real task, participants pressing keys of the real keypad, but the visual content remained the same as in the main task. First, participants sit and confirmed the virtual box indicating the natural pressing position and the VPad displayed through the HMD. Next, with the RHand aligned with the virtual box, participants performed the main task. Since the VPad was overlaid onto the real keypad, participants experienced tactile feedback from the real keypad when pressing the VPad. However, because the sub task was not performed, the postional relationship between the VHand and the RHand was not modified due to haptic retargeting. Thus, the positional relationship was the same between the unmodified condition and the real task.

2) Measurements: User experience in the main task was measured through a questionnaire using some of the indicators from Experiment 1. Additionally, some indicators were measured as relative values compared to the real task. Task performance in the main task was measured using a score.

User experience was measured using SoO, SoA, and tactile feedback based on Q1–15 from Experiment 1. SoO and SoA for the VHand were measured by replacing VPad with VHand in Q1–7, as in Experiment 1. However, unlike in Experiment 1, SoO and SoA for the VHand were measured after each VHand condition was completed. Responses were based on a seven-point Likert scale, as in Experiment 1.

Furthermore, SoO, SoA, tactile feedback, realism, comfort, reliability, and preference, as used in Experiment 1, were measured using relative expressions (see Tab. III). These indicators were selected based on their relevance in related studies [16], [33], [51]. Responses were given as arbitrary numerical values based on the magnitude estimation method [59], [60]. The magnitude estimation originates from psychophysics

TABLE III
THE QUESTIONNAIRE ON USER EXPERIENCE. ALL THE QUESTIONS COMPARE THE EXPERIENCE IN THE MISALIGNED, INVISIBLE, AND UNMODIFIED CONDITIONS TO THE REAL TASK. RESPONSES WERE PROVIDED AS ARBITRARY NUMERICAL VALUES BASED ON THE MAGNITUDE ESTIMATION.

Q1'.	How much did the left virtual hand like a part of your body?
Q2'.	How much did you feel your intention was reflected in the movement of the left virtual hand?
Q3'.	How much did the virtual keypad feel like a part of your body?
Q4'.	How much did you feel your intention was reflected in the movement of the virtual keypad?
Q5'.	How realistic was the tactile feedback?
Q6'.	How realistic did the virtual keypad feel?
Q7'.	How comfortable was the virtual keypad?
Q8'.	How reliable was the virtual keypad?
Q9'.	How much did you prefer this experience?

and allows participants to provide a number indicating the relative degree compared to a reference (standard stimulus). In this experiment, the standard stimulus was the real task, with a reference value of 100. The order of the questions follows the ascending order of the question numbers and remains the same for all VHand conditions.

Task performance was measured by the number of key inputs and input error rate, as in Experiment 1. However, task performance for the real task was not measured.

3) Conditions: The VHand condition consisted of three states: the combination of the presence or absence of the VHand and the position of the RHand (see Fig. 1). The first condition was where the position of the VHand differs from the RHand, and the VHand was visible (misaligned condition). The second condition was where the position of the VHand differs from the RHand, and the VHand was invisible (invisible condition). The third condition was where the position of the VHand was the same as the RHand, and the VHand was visible (unmodified condition).

The first and second conditions were the same as those in Experiment 1, except for the hand's orientation and the use of white noise. The third condition differed from the first only in that the position of the VHand and the RHand was the same. Specifically, in the third condition, the VPad was displayed on the back of the VHand, which was superimposed on the RHand. Additionally, the preliminary task to help participants understand the virtual environment and key input, as well as the practice task to familiarize them with key input, were the same as in Experiment 1.

4) Apparatus: In the real task, an adjustable stand (MOTTERU, MOT-PCSTD01S) and a real keypad (iClever, IC-KP10) were used (see Fig. 5 (left)). The stand allowed the real keypad to be placed adjacent to the participant's natural pressing position by adjusting the height and angle. The real keypad was located at a 45-degree angle, the same as the RHand, and this angle was achieved by temporarily placing a smartphone equipped with a gyroscope sensor (Apple, iPhone13) on the stand. To eliminate the effect of tactile feedback anticipation caused by recognizing the real keypad, both the stand and the real keypad are kept hidden from participants until the real task was performed.

To superimpose the VPad onto the real keypad, the position was adjusted by temporarily placing a controller (Meta, Meta Quest Touch Plus) on the stand. Since the controller' s position was calculated in the virtual environment by the HMD, the virtual keypad could be displayed at the corresponding position relative to the real keypad.

5) Procedure: Each participant completed the task by following the four steps. The order of the VHand conditions was counterbalanced across the experiment. The total experiment time was within one hour.

1) Adjusted the orientation of the virtual display and VPad, as well as the natural pressing position during the preliminary task, and completed the practice task.
2) Completed the task set and answered Q1–15.
3) Repeated step 2) for all VHand conditions.
4) Completed the real task and answered Q1'–9' and provide free-text responses.

6) Participants & Configurations: The participants were 24 healthy individuals (12 males, 12 females; ages 23 to 56; body measurements: height 165.5 (10.2) cm, weight 55.9 (10.8) kg, hand width 10.1 (0.6) cm, hand length 17.4 (1.0) cm). Among the participants, 23 were right-handed, and one was left-handed. Their prior VR experience was as follows [61]: The frequency of using VR with an HMD was once a month or more for two participants, once a week or more for one participant, and less than that for 21 participants. As for the years of experience using VR with an HMD, three participants had more than one year of experience, 12 had less than one year, and nine had no experience. Regarding experience with the equipment, 10 participants had experience using VR with both an HMD and hand-tracking functionality, six had experience using only an HMD, and nine had no experience.

7) Analysis: As in Experiment 1, the sum of Likert points of the questionnaire were treated as an ordinal scale based on a Likert scale, and calculated to aggregated values [16]. The Magnitude estimation values of the questionnaire were treated as a proportional scale. To use the geometric mean as a representative value, the obtained values were log-transformed. If the obtained values are zero, they were replaced with one to enable log transformation. The number of key inputs and the input error rate were treated as proprtional scales based on user behaviors. The analysis methods and statistical measures used for each scale are the same as those in Experiment 1. The Holm method was used to correct p-values for multiple comparisons. The results of the Friedman test and the repeated-measures ANOVA, and the descriptive statistics for each condition are presented in the appendix. As in Experiment 1, preliminary tests were omitted in the main analysis to avoid their potential impact on the significance level of post hoc comparisons [54]–[56]; however, given the varying perspectives on this matter [62], these results are included in the appendix for reference.

C. Results

The sum of the Likert points and the magnitude estimation value for user experience are shown in Fig. 7, 8. In the Likert scale, significant differences were found between the misaligned condition and the unmodified condition in SoO for the VPad ($p = 0.031$), SoO for the VHand ($p < 0.001$), and tactile feedback ($p = 0.029$). In the magnitude estimation, significant differences were found between the misaligned condition and the unmodified condition for all indicators (SoO for the VPad: $p < 0.001$, SoA for the VPad: $p = 0.001$, tactile feedback: $p = 0.001$, realism: $p = 0.001$, comfort: $p < 0.001$, reliability: $p < 0.001$, preference: $p = 0.003$). Additionally, significant differences were found between the invisible condition and the unmodified condition in SoO for the VPad ($p = 0.028$) and SoA ($p = 0.006$). All statistical measures are shown in Tab. IV, V.

The results for task performance are shown in Fig. 9. A significant difference in the number of key inputs was found between the misaligned condition and the invisible condition, and between the misaligned condition and the unmodified condition (misaligned vs. invisible: $t(23) = 2.72$, $p = 0.025$, $d = 0.55\ (0.11,\ 1.00)$; invisible vs. unmodified: $t(23) = 0.03$, $p = 0.763$, $d = 0.06\ (-0.35,\ 0.47)$; misaligned vs. unmodified: $t(23) = 2.89$, $p = 0.025$, $d = 0.59\ (0.14,\ 1.03)$). A significant difference in the input error rate was found between the misaligned condition and the invisible condition (misaligned vs. invisible: $t(23) = 3.04$, $p = 0.018$, $d = 0.62\ (0.17,\ 1.07)$; invisible vs. unmodified: $t(23) = 1.08$, $p = 0.338$, $d = 0.22\ (-0.20,\ 0.64)$; misaligned vs. unmodified: $t(23) = 1.42$, $p = 0.338$, $d = 0.29\ (-0.13,\ 0.71)$).

D. Discussion

SoO and tactile feedback toward the VPad were significantly higher in the unmodified condition compared to the misaligned condition in both the Likert scale and the magnitude estimation. Thus, part of H3 was supported, showing that displaying the VHand in a position different from the RHand decreases SoO and tactile feedback toward the VPad. The SoO results align with Fang et al.'s findings on SoO toward the VHand, but the tactile feedback differed, as it was lower in the 2T2F interaction type, where the congruency between visual and tactile sensations was higher [16]. However, considering that Fang et al.'s results did not show a significant difference and that SoO and tactile sensation, which form the sense of body ownership, are correlated [51], these findings may be more appropriate.

SoA toward the VPad was significantly higher in the unmodified condition compared to the misaligned condition in the magnitude estimation only. Moreover, SoO and SoA toward the VPad were significantly higher in the unmodified condition compared to the invisible condition, but only in the magnitude estimation. The trend in SoA between the unmodified and misaligned conditions is consistent with Fang et al.'s findings on SoA toward the VHand. Although Fang et al. did not examine the invisible condition, this outcome is supported

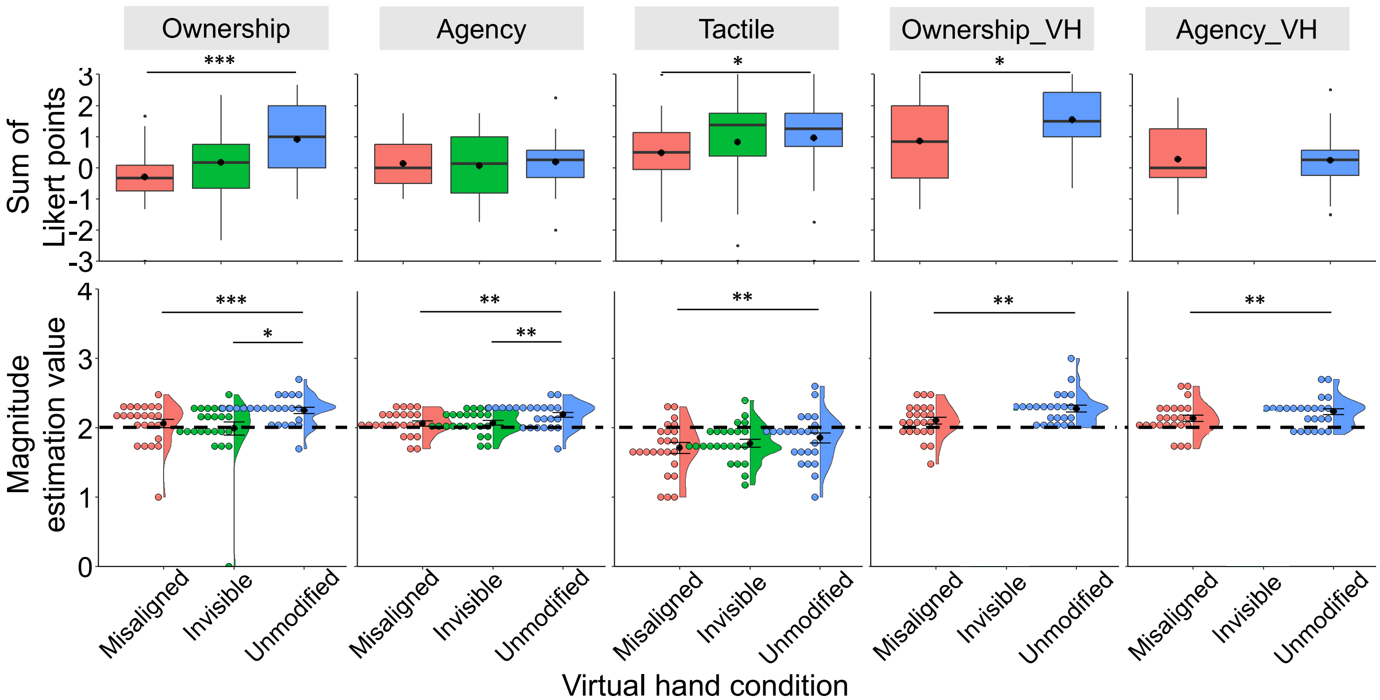

Fig. 7. The responses of the questionnaire on SoO, SoA and tactile (n =24). (Top) Sum of Likert points. Representative lines indicate the median, and representative points indicate the mean. (Buttom) Magnitude estimation values. Representative points indicate the mean, and error bars indicate SE. Horizontal dotted lines indicate the reference value under the standard stimulus. 'VH' means for VHand. *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

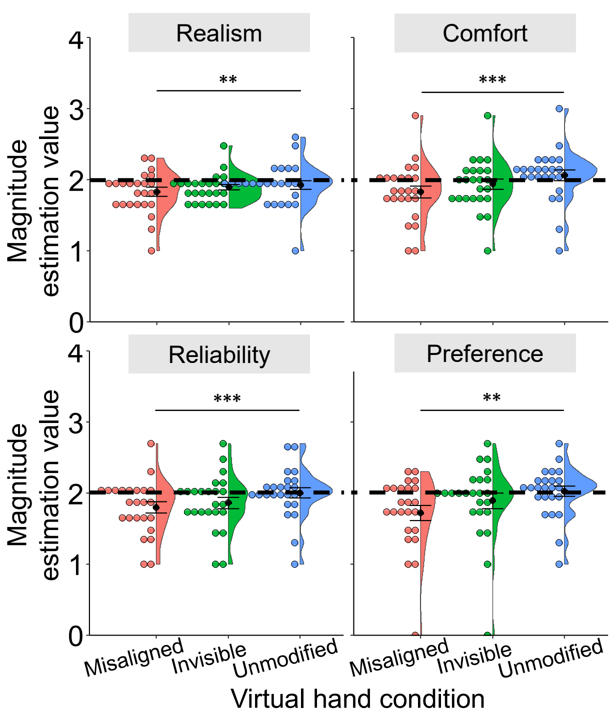

Fig. 8. The Magnitude estimation values of the questionnaire on realism, comfort, reliability, and preference (n =24). Representative points indicate the mean, and error bars indicate SE. Horizontal dotted lines indicate the reference value for the standard stimulus. **: $p < 0.01$, ***: $p < 0.001$.

by Argelaguet et al., who reported that SoA varies based on the perception of movement [38]. Therefore, participants may have perceived the VPad as a differently shaped part of their own hand.

Realism, comfort, reliability, and preference were significantly higher in the unmodified condition compared to the misaligned condition according to the magnitude estimation. Thus, displaying the VHand in a position different from the RHand decreases the realism, comfort, reliability, and preference toward the VPad. The results for realism and preference align with those of Fang et al. and Marichal et al. [15], [16]. The results for comfort and reliability can be explained by Bermejo et al. [33]. In their study, comfort and reliability were slightly higher when operating a 2D virtual keypad with vibration compared to when vibration was absent. Furthermore, in the free responses from this experiment, two participants stated that the invisible condition was easier to perform key input, and there were many opinions expressing discomfort toward the misaligned condition. Thus,

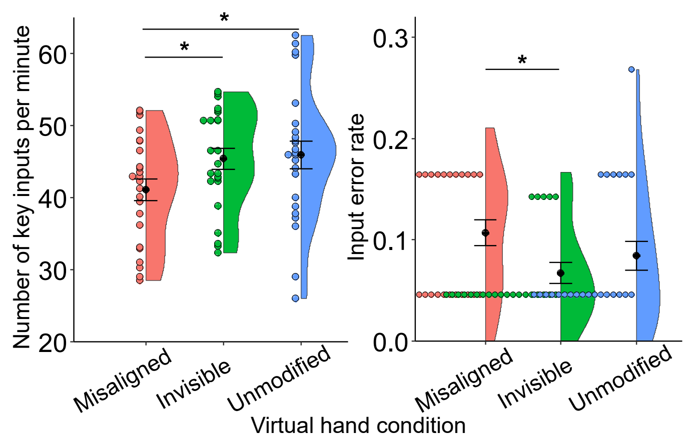

Fig. 9. The number of key inputs, and the input error rate (n =24). Representative points indicate the mean, and error bars indicate SE. *: $p < 0.05$.

TABLE IV
STATISTICAL MEASURES OF THE QUESTIONNAIRE RESULTS REGARDING EACH ELEMENT OF USER EXPERIENCE. COMP. MEANS THE COMPARISON BETWEEN THE VHAND CONDITIONS (MIS.: MISALIGNED, INV.: INVISIBLE, UNM.: UNMODIFIED).

Elements	Comp.	Z	p	r (95%CI)
Ownership	Mis. vs. Inv.	1.62	0.107	0.41 (-0.03, 0.72)
Ownership	Inv. vs. Unm.	2.09	0.072	0.52 (0.10, 0.78)
Ownership	Mis. vs. Unm.	3.32	< 0.001	0.85 (0.65, 0.94)
Agency	Mis. vs. Inv.	0.07	1.000	0.02 (-0.44, 0.47)
Agency	Inv. vs. Unm.	0.59	1.000	0.15 (-0.32, 0.55)
Agency	Mis. vs. Unm.	0.49	1.000	0.12 (-0.34, 0.54)
Tactile	Mis. vs. Inv.	1.87	0.124	0.48 (0.05, 0.76)
Tactile	Inv. vs. Unm.	0.70	0.509	0.19 (-0.28, 0.58)
Tactile	Mis. vs. Unm.	2.51	0.029	0.67 (0.33, 0.86)
Ownership_VH	Mis. vs. Unm.	2.13	0.031	0.56 (0.17, 0.80)
Agency_VH	Mis. vs. Unm.	0.20	0.854	0.05 (-0.40, 0.49)

TABLE V
STATISTICAL MEASURES OF THE MAGNITUDE ESTIMATION RESULTS REGARDING EACH ELEMENT OF USER EXPERIENCE. THE DEGREE OF FREEDOM WAS 23. COMP. MEANS THE COMPARISON BETWEEN THE VHAND CONDITIONS (MIS.: MISALIGNED, INV.: INVISIBLE, UNM.: UNMODIFIED).

Elements	Comp.	t	p	d (95%CI)
Ownership	Mis. vs. Inv.	0.72	0.478	0.15 (-0.27, 0.56)
Ownership	Inv. vs. Unm.	2.66	0.028	0.54 (0.10, 0.98)
Ownership	Mis. vs. Unm.	5.18	< 0.001	1.06 (0.54, 1.57)
Agency	Mis. vs. Inv.	0.48	0.637	0.10 (-0.31, 0.51)
Agency	Inv. vs. Unm.	3.29	0.006	0.67 (0.22, 1.13)
Agency	Mis. vs. Unm.	4.14	0.001	0.84 (0.37, 1.32)
Tactile	Mis. vs. Inv.	1.24	0.306	0.25 (-0.16, 0.67)
Tactile	Inv. vs. Unm.	1.48	0.306	0.30 (-0.12, 0.72)
Tactile	Mis. vs. Unm.	4.19	0.001	0.86 (0.38, 1.34)
Realism	Mis. vs. Inv.	1.28	0.423	0.26 (-0.16, 0.68)
Realism	Inv. vs. Unm.	0.64	0.528	0.13 (-0.28, 0.54)
Realism	Mis. vs. Unm.	3.28	0.001	0.67 (0.21, 1.12)
Comfort	Mis. vs. Inv.	1.86	0.153	0.38 (-0.05, 0.80)
Comfort	Inv. vs. Unm.	1.81	0.153	0.37 (-0.05, 0.79)
Comfort	Mis. vs. Unm.	5.76	< 0.001	1.18 (0.64, 1.71)
Reliability	Mis. vs. Inv.	1.13	0.271	0.23 (-0.19, 0.65)
Reliability	Inv. vs. Unm.	2.17	0.081	0.44 (0.01, 0.87)
Reliability	Mis. vs. Unm.	4.71	< 0.001	0.96 (0.46, 1.46)
Preference	Mis. vs. Inv.	1.38	0.361	0.28 (-0.14, 0.70)
Preference	Inv. vs. Unm.	1.36	0.361	0.28 (-0.14, 0.70)
Preference	Mis. vs. Unm.	3.75	0.003	0.77 (0.30, 1.23)

it is considered that the unmodified condition, which provides more reliable and trustworthy tactile feedback when pressing keys, offered higher comfort and reliability compared to the misaligned condition.

The number of key inputs was significantly higher in both the invisible and unmodified conditions compared to the misaligned condition. The input error rate was significantly lower in the invisible condition compared to the misaligned condition. Thus, part of H4 was rejected, showing that the misaligned condition decreased UI performance. This can be attributed to cognitive load and the effects of proficiency, as suggested by previous study [58], along with the negative opinions toward the misaligned condition and positive opinions toward the invisible condition in the free responses from this experiment. SoO toward the VHand was significantly higher in the unmodified condition compared to the misaligned condition in both the Likert scale and the magnitude estimation, and SoA was significantly higher only in the magnitude estimation. This aligns with Fang et al.'s results [16] and is well supported by findings from RHI and VHI studies [18], [19]. Furthermore, haptic retargeting was considered to function correctly. The average of gain for the 24 participants across 48 trials in the misaligned and invisible condition was 1.39 (0.01), which was similar to Zenner et al.'s 1.34 and Esmaeili et al.'s 1.38 [49], [50]. In the free responses, 17 participants first realized during VPad operation after haptic retargeting that the positions of the VHand and the RHand were different, and two participants did not notice the difference until the end of this experiment, supporting the fact that approximately 80% of participants were unaware of the discrepancy.

V. GENERAL DISCUSSION

Experiments 1 and 2 showed almost identical results. Furthermore, the Likert scale results for SoO and SoA toward the VPad in the misaligned condition tended to be lower in Experiment 2, where the RHand faces downward. This is likely related to the anatomical characteristics of the hand's orientation. First, the palm contains a higher number of tactile receptors [63]. Thus, since the back of the hand is less sensitive to touch compared to the palm, SoO and SoA may have been lower. Second, the back of the hand has more prominent bones and cartilages. Therefore, the sensation obtained from the back of the hand might have felt more similar to the inorganic tactile sensation from the VPad contact, leading to lower SoO and SoA. This is supported by reports suggesting that changes in SoO and SoA are influenced by the preference of tactile feedback [64].

When considering the main task as Fang et al.'s 2T1F interaction modality, SoO and SoA of the VHand in the misaligned condition in Experiment 2 showed higher values than those reported by Fang et al. Thus, it can be said that the potential for applying Self-Haptics as a UI prop has been expanded. However, the decline in user experience and task performance was evident in the results of both Experiments 1 and 2. Various perspectives for evaluating UIs are not simply correlated, as also indicated by Bailey et al.'s proposal to separate preference from performance in UI evaluation [65].

Several limitations must be noted in this study. First, the participants' experiential characteristics related to VR were not taken into account. Since prior VR experience can influence various aspects of user experience, Experiment 2 reported a preliminary survey of this [61]. However, as some studies have suggested that imaginative suggestions can have a stronger effect on SoO and SoA than basic sensory integration such as the consistency between visual and tactile sensations [66], it may be preferable to conduct experiments with participants matched for experiential characteristics. More importantly, handedness was not accounted for, which plays an important role in UI operation [67], [68]. Kohli et al. pointed out that UI operation superimposed on the non-dominant hand is significant [9]. In Experiment 2, one participant actually was left-handed. Second, the experimental design does not strictly compare the front and back of the hand. There was merely a difference in the scores of the respective results. Third, the misaligned condition did not demonstrate an advantage over the invisible condition in terms of reducing SoO and SoA toward the VPad. This is because the invisible condition is suggested to promote the affirmation of the existence of one's invisible body [42]. However, when accurate perception of one' s own body is required, the misaligned condition remains worth further investigation. Fourth, the differences in SoO and SoA, which are the primary outcomes in this study, were very small, indicating that the sample size warrants reconsideration. In Experiment 1, the difference in SoO for the VPad was not statistically significant and had only a "small" effect size, suggesting that increasing the sample size could potentially alter the conclusions. In Experiment 2, the differences in SoO and SoA between the misaligned and invisible conditions using the magnitude estimation values for the VPad were also not significant, with "small" effect sizes and a statistical power of only 0.1. Therefore, increasing the number of participants may lead to further discussion. Finally, the evaluation of user experience should be conducted in more practical experimental settings. In particular, participants may not have expected the tactile feedback of a real keypad from the VPad. The real task was based on the assumption that the tactile feedback from pressing a real keypad is what users most expect from a VPad, using it as the reference for the magnitude estimation. However, some participants preferred simpler and more intuitive tactile feedback. Other limitations include the lack of long-term evaluations, such as usage over several hours, and the absence of assessments that engage sensory modalities beyond visual and tactile sensations. In this study, white noise was used to focus on visual and tactile modalities; however, incorporating auditory feedback which is an important cue for UI operation could potentially enhance user experience.

VI. Conclusion

In this study, we clarified that the task performance and the user experience changes based on the representation of the virtual hand, including the sense of ownership and agency toward a virtual keypad displayed at the position of the real hand, through two experiments with different hand orientations. As a result, we confirmed that displaying the virtual hand at a position different from the real hand or hiding it reduces task performance but effectively lowers the sense of ownership and agency toward the virtual keypad, with this effect being more pronounced when the hand is facing downward. These findings support most of our main hypothesis, demonstrating that visual modifications are effective for "(Not My) Self-Haptics".

We expect that "(Not My) Self-Haptics" can enhance haptic functions in existing real and virtual UIs. In the future, we plan to clarify the changes in the sense of ownership and agency caused by time-delayed stimuli and on other body parts. Additionally, we will investigate the potential applications of "(Not My) Self-Haptics" beyond UIs, such as simulating a handshake with another person using only one's own hands.

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APPENDIX

TABLE VI
STATISTICAL MEASURES OF A FRIEDMAN TEST ON THE QUESTIONNAIRE RESULTS REGARDING EACH ELEMENT OF USER EXPERIENCE. THE DEGREE OF FREEDOM WAS TWO. THE EFFECT SIZE IS KENDALL'S W.

Elements	χ^2	p	W (95%CI)
Ownership	11.3	0.004	0.24 (0.08, 0.47)
Agency	0.31	0.857	0.01 (0, 0.19)
Tactile	7.34	0.026	0.15 (0.02, 0.44)

TABLE VII
STATISTICAL MEASURES OF A ONE-WAY REPEATED MEASURES ANOVA ON THE MAGNITUDE ESTIMATION RESULTS REGARDING EACH ELEMENT OF USER EXPERIENCE. THE DEGREES OF FREEDOM WERE TWO AND 46. THE EFFECT SIZE IS PARTIAL ETA-SQUARED.

Elements	F	p	η^2 (95%CI)
Ownership	5.43	0.008	0.19 (0.03, 0.33)
Agency	11.2	< 0.001	0.33 (0.13, 0.46)
Tactile	4.57	0.015	0.17 (0.02, 0.30)
Realism	2.38	0.104	0.09 (0, 0.22)
Comfort	8.36	< 0.001	0.27 (0.08, 0.40)
Reliability	7.14	0.002	0.24 (0.06, 0.37)
Preference	4.42	0.018	0.16 (0.02, 0.30)

TABLE VIII
THE MEAN AND STANDARD DEVIATION OF THE MAGNITUDE ESTIMATION VALUES FOR USER EXPERIENCE FOR EACH COMBINATION OF ELEMENT AND CONDITION. 'VH' MEANS FOR VHAND. MIS.: MISALIGNED, INV.: INVISIBLE, UNM.: UNMODIFIED.

Elements	Conditions	M	SD
Ownership	Mis.	2.06	0.31
Ownership	Inv.	1.99	0.47
Ownership	Unm.	2.25	0.21
Agency	Mis.	2.06	0.18
Agency	Inv.	2.07	0.17
Agency	Unm.	2.19	0.18
Tactile	Mis.	1.71	0.38
Tactile	Inv.	1.78	0.28
Tactile	Unm.	1.85	0.36
Realism	Mis.	1.83	0.30
Realism	Inv.	1.89	0.19
Realism	Unm.	1.93	0.31
Comfort	Mis.	1.83	0.41
Comfort	Inv.	1.94	0.36
Comfort	Unm.	2.06	0.38
Reliability	Mis.	1.80	0.39
Reliability	Inv.	1.86	0.39
Reliability	Unm.	2.00	0.35
Preference	Mis.	1.72	0.52
Preference	Inv.	1.89	0.54
Preference	Unm.	2.03	0.36
Ownership_VH	Mis.	2.11	0.24
Ownership_VH	Unm.	2.28	0.23
Agency_VH	Mis.	2.14	0.23
Agency_VH	Unm.	2.23	0.21

TABLE IX
STATISTICAL MEASURES OF A ONE-WAY REPEATED MEASURES ANOVA ON THE NUMBER OF KEY INPUTS AND THE INPUT ERROR RATE. THE DEGREES OF FREEDOM WERE TWO AND 46. THE EFFECT SIZE IS PARTIAL ETA-SQUARED.

Scores	F	p	η^2 (95%CI)
Key input	5.10	0.010	0.18 (0.03, 0.32)
Input error rate	3.52	0.038	0.13 (0, 0.26)

TABLE X
THE MEAN AND STANDARD DEVIATION OF THE NUMBER OF KEY INPUTS AND THE INPUT ERROR RATE FOR EACH CONDITION. MIS.: MISALIGNED, INV.: INVISIBLE, UNM.: UNMODIFIED.

Scores	Conditions	M	SD
Key input	Mis.	41.1	7.41
Key input	Inv.	45.4	7.05
Key input	Unm.	45.9	9.39
Input error rate	Mis.	0.11	0.06
Input error rate	Inv.	0.07	0.05
Input error rate	Unm.	0.08	0.07