Voluntary Self-tapping Induces Self-localization Shift

Masahiro Furukawa[1], Kouta Minamizawa[2] and Susumu Tachi[2]

***Abstract*— Rubber Hand Illusion (RHI) is known to provide a proprioceptive drift toward the direction where the rubber hand is tapped. On the other hand, Out-of-Body Experiences (OBEs) induce an entire body shift from a third-person Point of View (PoV) . These experiences are known to trigger external passive tactile cues. Telexistence allows an entire body shift from a first-person PoV, compared to RHI and OBE. However, the precise origin of the entire localization is not revealed when we actively provide the internal voluntary tactile cue. Therefore, in this paper, we focus on the effects of tactile cues to determine self-localization during the action of self-tapping. Participants viewed and tapped their own body on the back, and evaluated where on their body they perceived the tapping. The experiments show that the localized position tends to shift forward when an individual is tapped by a third-person; in contrast, the localized position tends to shift backward when an individual is tapping his own back. The subjective report indicates that participants perceived themselves as leaving their own bodies, or that someone appeared in front of them suddenly. Thus, we consider that self-produced tactile cue induces telexistence experience.**

I. INTRODUCTION

Synchronized visual and tactile cues can dramatically induce localization shifting, such as the Rubber Hand Illusion (RHI) [1] and Out-of-Body Experiences (OBEs) [2]. RHI is usually measured as the amount of proprioceptive drift toward the location where an individual can see he is touched from the First-Person View (FPV). In contrast, OBE is known to induce an entire body shifting experience when individuals can see where they are touched from a Third-Person View (TPV). In addition, both experiences require the experimenter to provide tactile cues as an extraneous stimulus. Compared to RHI and OBE, telexistence requires FPV and an entire body shift. In such a case, the question becomes one of determining where individuals perceive themselves when the individuals touch themselves while seeing themselves from TPV.

Body localization is divided into several groups in terms of experimental conditions: partial body or entire body, body appearance, point of view (PoV), and passive or voluntary stimulus. The following sections describe our perspective in terms of these four points.

[1]Masahiro Furukawa is with the Faculty of Graduate School of Information Science and Technology, Osaka University, 2-1 Yamadaoka, Suita, Osaka, Japan `m.furukawa@ist.osaka-u.ac.jp` [2]Kouta Minamizawa and Susumu Tachi are with the Faculty of Graduate School of Media Design, Keio University, 4-1-1 Hiyoshi, Kohoku-ku, Yokohama, Kanagawa, Japan `{kouta, tachi}@tachilab.org`

II. RELATED WORK

A. Rubber Hand Illusion

RHI is one of the most famous illusions induced by multisensory integration, such as synchronized visual and tactile cues. Botvinick et al. indicated three-way interaction between vision, tactile, and proprioception [1]. Stroking a rubber hand and a participant's hand with a paintbrush for an extended period results in a dramatic proprioceptive shift. That is, the perception of touch on the human hand shifts towards the rubber hand. For this study, the experimenter provided the tactile stimuli and the participants did not move, but saw the rubber hand. That is, the stimuli were provided passively.

It is known that individuals can experience ownership even when the appearance and size of the body is relatively different. Slater et al. showed that a computer-rendered arm and an entire body in virtual space provide ownership [3]. In addition, Armel reported that individuals can experience ownership of artificial external objects [4]. Such ownership to external objects is expressed as sensory projection. The virtual arm and hand have the advantage that an experimenter can change their appearance in terms of size. Interestingly, individuals can maintain body ownership and consciousness even when the arm appears to be extremely long [5].

B. Body Ownership

The RHI procedure is used sometimes to study entire body ownership. Petkova et al. showed that ownership towards a life-sized mannequin can be obtained; moreover, they succeeded in demonstrating body swapping experience [6]. Recently, BeAnotherLab by Bertrand et al. sensationally published artwork regarding entire body swaps [7]. For the artwork, two participants wore Head-Mounted Displays (HMDs) that provided one another's field of view, and the participants were asked to perform identical behavior, such as viewing and stroking their body.

Proprioception has an important role in controlling our posture, similar to strong visual cues. Petkova et al. reported that proprioception is much more dominant in blind individuals [8]. In their study, Petkova et al. defined somatic rubber hand illusion without vision, which uses somatosensory cues instead of vision on sighted individuals. They also used a self-touch procedure to compare dominance between vision and proprioception, similar to Davies et al. in a previous study [9]. Rohde et al. indicated that frequent stimulation and measurements result in proprioceptive drift even under asynchronous conditions [10]. Therefore, Rohde et al. concluded that proprioceptive drift can be used for discussions regarding only visual-proprioceptive integration.

C. Agency

Traditional RHI experimental procedures usually include passive tactile stimuli. This means that, not only participants, but also experimenters provide tactile stimuli. In other words, the tactile stimuli is not produced as voluntary behavior. Several works have attempted to use voluntary behavior to produce not only afferent tactile sense, but also efferent voluntary motor command.

Agency is another important topic in multisensory integration. Agency is obtained when executing body movements with intention. Agency involves efferent motor command; in contrast, ownership is obtained through external sensations, in other words, afferent nerve signals. The related works described in the previous sections focused on ownership using *passive* touch, such as an experimenter stroking a participant. In contrast, recent agency studies have used the voluntary behavior of moving fingers, which we consider as *active* touch. For instance, Tsakiris et al. [11] reported that proprioceptive drift significantly decreases under active movement conditions compared to passive conditions. Therefore, Tsakiris et al. concluded that agency is considered as self-consciousness that arises from action, not from sensation. Kalckert et al. carefully investigated the interaction between ownership and agency [12]. They indicated that action that involves efferent motor commands contributes to producing agency. Their study also demonstrated that afferent sensation represents fragmented body parts, but voluntary action provides coherent body self-consciousness.

D. Out of Body Experience

OBEs are known to provide dramatic proprioceptive shifting, although the proprioceptive drift is relatively small. That is, individuals perceive as though they existed outside of their bodies.

Ehrsson succeeded in producing this sensation using an HMD to provide an FPV and a video camera located behind the participants [2]. Thus, the participants saw themselves from behind. Ehrsson indicated that the synchronized visual-tactile stimulation induced OBEs. Note that Ehrsson provided a passive sensation to the participants under the condition of FPV. In addition, Lenggenhager et al. requested participants to walk where they felt in order to reveal a quantitative amount of localization shifting [13]. Unlike Ehrsson's first OBE work [2], Lenggenhager used a computer-rendered virtual body as well as a virtual object with the appearance of a human-sized flat box as visual cue to disrupt spatial congruency. Similar to Ehrsson, Lenggenhager provided visual-tactile stimuli such as stroking the participants' back, and concluded that synchronized stimuli reproduced OBEs even towards a virtual body.

Watanabe et al. investigated OBEs under a self-tapping condition using a long rod [14]. They used a questionnaire similar to Ehrsson's to obtain a qualitative impression in terms of OBEs. In this study, a video camera embedded in a robot head was placed 1.5 m behind the participants, and the participants saw their backs in a manner similar to Ehrsson's study. After the passive tap condition, an active tap condition was performed where the participants tapped their back from behind. As a result of this experiment, the authors concluded that the voluntary movement appears to contribute in obtaining localization. However, qualitative studies on where the participants perceive themselves or how frequently they perceive them have not been conducted.

E. Telexistence

Telexistence refers to the concept and technology that enables us to experience the real-time sensation of being at a place other than where we actually exist, as well as being able to interact with the remote environment, which can be real, virtual, or a combination of both [15]. Tachi et al. reported the design method of a visual display that allowed users to view their surroundings through stereoscopy, thus representing a proper distant sensation [16]. A robot head followed the users' head movement in real time, thus allowing the users to move their head voluntarily. Consequently, telexistence appears on the premise of voluntary behavior [17].

For telexistence, HMDs should be designed to provide natural visual sensations. The visual ability to focus and to converge are popular parameters for providing proper stereoscopic vision. It is important to design HMD optics with less discrepancy to focus and for convergence [16] [18]. Therefore, the HMD focal length is usually designed approximately 1 m from the view position.

Telexistence systems usually consist of master-slave systems, which include a master cockpit to apply a user's body behavior to a virtual or real avatar robot. The first telexistence vision system with one Degree of Freedom (DoF) [19][20] tracked a user's head and followed the user's voluntary movement through a robot head. Tachi et al. mounted the one DoF telexistence robot head onto a vehicle in order to investigate the relationship between the direction the head was facing and the direction the vehicle was following [21]. In their paper, Tachi et al. proposed construction of a telexistence system with the ability to explore, and compared feasibility in terms of smoothness and elapsed time through the exploration of corrosion avoidance.

The DoF of the telexistence avatar robot can be one of the key indicators of the sense of immersion. The first DoF is head movement. The head, including a binocular camera unit, can have a maximum of six DoFs to determine the position and orientation required to follow a user's head movement. Tachi et al. proposed a telexistence avatar with three DoFs in the head DoF [16]. It is important to consider latency as well as frequency width to be able to reproduce a user's head movement. Watanabe et al. constructed a six DoF robot head designed with a minimum of weight [18]. As a result, the robot head achieves much less latency and wide frequency width when realizing a user's voluntary head behavior. The objective of this work is to be able to view a target object from the front and from the side because of wide translational movements.

The second DoF is limb, which is imperative in order to consider manipulation in a remote place. When individuals

TABLE I

Comparison between RHI, OBEs, and Telexistence

Experience	Target	PoV	Agency
RHI	Partial Body	FPV	Not required
OBEs	Entire Body	TPV	Not required
Telexistence	Entire Body	FPV	Required

view their hand in a telexistence system, the hand should appear in the exact position where expected. Moreover, the hand should be voluntarily controllable in order to obtain agency. Tachi et al. were able to successfully prove the feasibility of manipulating limbs in remote places using a seven DoF arm and one DoF gripper hand [16]. Their findings indicate that strong agency is obtained even when it appears that a robot as long as an arm represents a user's voluntary movements in real-time. The latest work on a telexistence anthropomorphic robot is TELESAR V, and it achieved dexterous manipulation by transferring the haptic sense using a full upper body, including a three DoF head, a six DoF body, both 15 DoF arms, and both seven DoF hands [22]. Therefore, TELESAR V has 53 DoFs in total. This higher DoF design was developed to investigate active touch on telexistence, including dexterous behavior such as stroking, tapping, and pouring. Thus, the fingertips have pressure, vibration, and thermal sensors to transfer the haptic sense based on the factorial sensations of pressure-sense, vibration-sense, and thermal sense. A user wears gloves to obtain finger movement, which reproduces the haptic sensation with a fingertip mounted haptic display.

F. Our Focus

In short, the question posed in the Introduction remains open, where do individuals localize their entire body in self-touching situations? Unlike RHI, we focus on entire body localization, such as OBEs and telexistence (see Table I). That is, OBEs need to be investigated as the *telexistence* setup, which can include OBE situations. In other words, a telexistence setup requires that the PoV be located at the same position where an individual perceives his body (FPV). In contrast, an OBE setup requires TPV. Self-touch comprehends afferent somatosensory feedback and efferent motor command as *voluntary* behaviors. Moreover, voluntary behavior requires *agency* towards the artificial object, instead of the actual body.

III. Experiment

A. Experiment Setup

The experiment requires switching the tactile cues on the participants' back (provided *passively*) or hand (obtained *voluntarily*) in a similar manner to a previous method [14]. In addition, it is necessary to follow a quantitative approach to describe the body localization shift. Finally, a telexistence setup is required.

Thus, we developed a self-tapping machine as shown in Figure 1, 2 (see Appendix A, B for details). Our self-tapping machine has a master-slave structure. That is, the stick placed behind the participants follow the movement of the stick placed in front of the participants when they move it.

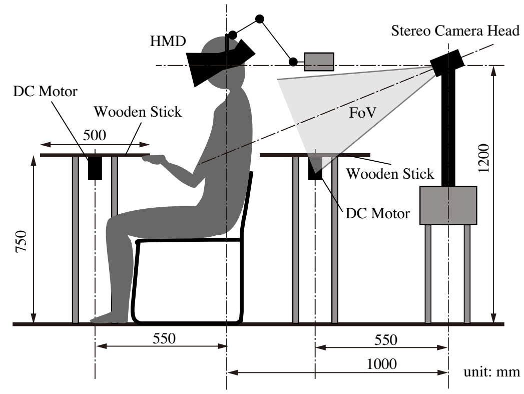

Fig. 1. Experiment setup dimension

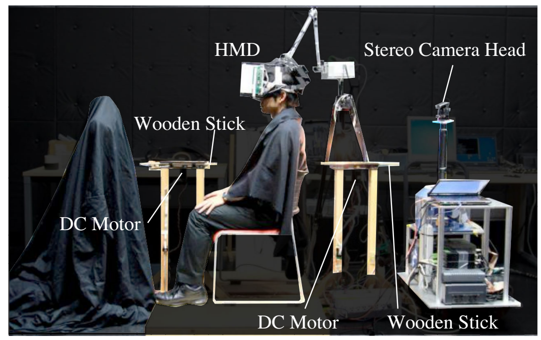

Fig. 2. Participants observe their back through HMD in real time, and tap their back on their own.

The experiment setup of this study consists of an HMD and a charge-coupled device (CCD) camera. The participants wear an HMD and sit on a chair. The HMD has two 7.1-inch LCDs, one for each eye, with a resolution of 1,024 $\times$ 768 pixels. The horizontal field of view (FOV) is 42 degrees. The pupillary distance is 65 mm. This setup is similar to the previous research [18]. A black soft form shield is attached to the HMD to cover all peripheral areas of the lens so that participants cannot see their hand even when looking down. To obtain FPV, we use a robot camera head. The robot head called TORSO has two small binocular cameras at a regular pupillary distance of 65 mm, which is 7 mm in diameter [18]. The horizontal FOV is 46 degrees and its resolution is 768 $\times$ 494 pixels. Note that these cameras can be replaced with two simple regular cameras because we used TORSO at a fixed position without allowing any joint movements in order to maintain the view direction. These cameras capture real-time video and send it to the HMD so that the participants can view themselves from behind. Their view is controlled carefully so they can only see the stick.

B. Experiment Design

We designed a two-factor within-subject experiment to obtain quantitative data when judging relative position. The first factor is the *passive* tactile cue provided on the participants' back: it is provided or not (see Table II). The red triangle indicates presence and position of tactile cue. The second

TABLE II

Passive Tap Condition

	**No response on the back** Even though participants move the stick back and forth, they do not receive any taps on their back.
	**Response on the Back** Participants perceive tapping on their back as though the stick tapped them on the back.

TABLE III

Active Tap Condition

	**No response on the Hand** Even though participants move the stick back and forth, they do not receive any responses from the stick.
	**Response on the Hand** Participants feel a response as though the stick struck an object.

factor is the *active* tactile cue provided on the participants' hand with voluntary movement; similar to the first factor, the conditions are : provided or not (see Table III).

The following paragraphs detail the participants' experience during the experiment. When the participants pushed the stick forward to tap, they perceived a force feedback as though the stick tip had touched an object. The participants might believe that someone was sitting in front of them, and that they had tapped that individual's back. In contrast, if the participants perceived a tap on their back at the same time, they might believe that their body had moved suddenly from their perceived position, or that their body had shifted slightly or not at all.

The participants could observe the stick in the HMD FOV during all experiment sequences. Thus, we consider that the master-slave structure realized agency because both sticks demonstrated identical behavior.

Under the no feedback condition, tactile feedback was not provided to the back or to the hand. In this case, the stick behind the participants was stopped to prevent contact with the participants' back, although the stick in front of the participants moved further.

When feedback to the participants' back was indicated, the stick behind the participants continued to move based on the movement of the front stick, until contact with the back occurred. Similar to the no feedback condition, the participants did not perceive any feedback to their hand. As a result, they only perceived passive tapping to the back. We used a unilateral control to isolate haptic feedback from the tapping to the back.

In contrast, when feedback only to the participants' hand was indicated, the front stick provided the sensation of tapping an object located in front of the participants. On the other hand, the stick behind the participants was stopped before contact with the back occurred. At this time, the stick that the participants can see *looks* tapping an object in front them simply stops without tapping anything. The front stick provided force feedback when the back stick was supposed to reach the participants' back, although the back stick did not actually reach the participants' back. To provide force feedback to the hand, we placed a virtual invisible wall where the stick stopped. We used the penalty method to determine the contact force. The PD gain was tuned to provide the impression of contact against an object that was neither considerably hard nor soft, such as a human body.

Another control condition was to provide tactile cues to the participants' hand and back simultaneously. We considered that this condition is expected to reveal dominance of tactile stimuli between the *passive* and the *active* tactile cues in terms of agency. Needless to say, the stimuli appeared extremely confusing because agency remained while moving the stick voluntarily because of somatosensory cues combined with visual cues. In addition, the participants perceived tapping feedback from the back simultaneously as though they had tapped themselves on the back as described before. This condition was implemented using a bilateral control system that established a link between the two sticks.

C. Procedure

The experimenter requested participants to sit on a chair and place a black cloth over their shoulders to cover their back. The experimenter explained the purpose of the experiment as such: "I'd like to ask you to indicate the position where you felt you were seated." After that, the experimenter described the experiment flow: "Here is a stick in front of you, and you can move it."

Then, the participants wore the HMD and were able to see the experimenter's hand in front of TORSO, which simply consisted of fixed video cameras; the participants confirmed that they could see TORSO. The experimenter also moved his hand away from the participants' back, and the participants confirmed that the hand was not visible, but that the tip of the stick was visible. He continued to explain the next condition and moved the stick forward to demonstrate such condition. The experimenter asked the participants to hold the stick and move it forward and then back to its initial position; the participants were also instructed to remove their hand from the stick after one tap. After the participants experienced all four condition combinations, the experimenter verified that the participants could perceive the feedback to their hand and back. The difference between each condition was noticeable to the participants.

We employed a two-alternative force choice to obtain quantitative results. Therefore, the experimenter asked the participants to evaluate where they felt situated compared to the standard condition described in the next paragraph, and whether they perceived their position as shifting backward or forward.

The participants were trained to perform the experimental sequence shown in Figure 3. The standard condition does not provide any feedback to the hand or to the back. The

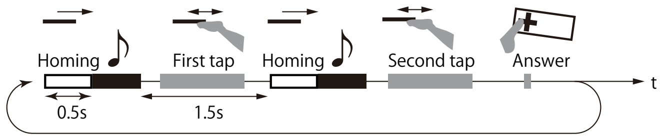

Fig. 3. Experiment procedure in a trial

experimenter explained that the standard condition is the baseline condition to compare with the target condition. He asked participants to tap once after hearing a beeping sound, and to indicate whether they perceived their location as shifting forward or backward during the second (target) condition compared to the first (standard) condition.

The stick returned to its home position within 0.5 s before every trial, and a 0.5 s beep (triangle wave at 1 kHz) was sounded. During this term, the participants were asked not to touch the stick. In addition, the experimenter instructed the participants to move the stick within 5 cm when allowed to move the stick. After the first beep, the participants tapped once to perform the standard condition. After the second beep sounded for 1.5 s, the participants tapped again to perform the target condition. After these two taps, they judged the shifting direction to push the "Top" or "Bottom" button to choose "Forward" or "Backward" with the keypad placed on their left hand. After pushing the button, the next trial started immediately.

The participants learned to move the stick by attempting several trials with the beep. After the training session, the experimenter provided earphones to allow the participants to hear white noise.

The main session consisted of 80 trials that included a factor of $2 \times 2 = 4$ conditions in total as described previously. A short rest was provided after every 20 trials. The participants heard white noise from earphones during all trials, with the exception of the resting periods. Each rest period lasted from approximately 30 s to a maximum of 2 min. The main session lasted approximately 20 min. The condition order was counter-balanced in randomized order for each person. After all trials, the experimenter interviewed the participants to obtain their subjective impression.

Six participants participated in the experiment (one female and five males, average age 24.3 years, standard deviation 1.80). They were healthy and did not experience any difficulty viewing real time video through HMD. Five of the participants had previous experienced using HMD. All participants were well trained so that they could continue the task through all the trials.

IV. Results

A. Quantitative Result

As described before, each participant collaborated 80 times, which included 20 times per condition for all four conditions. The focus is on the probability of localization shifting. Therefore, we calculated the representative probability from each condition, including the 20 trials. This means that each participant provided four representative probability values. Moreover, we hypothesized that the haptic cue affects the values.

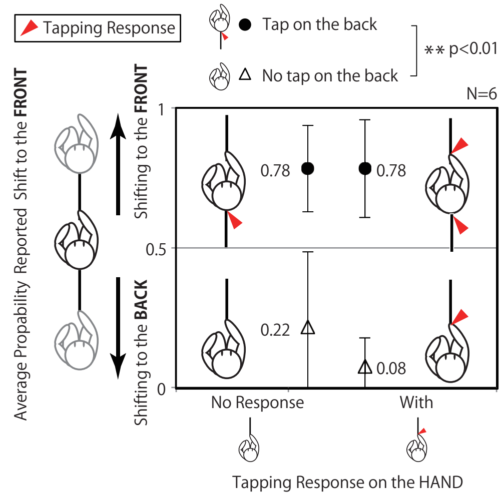

Fig. 4. Experimental results - probability distribution

The quantitative results are shown in Figure 4. The red triangle indicates the presence and position of tactile cues similar to Tables II and III. The horizontal axis shows the feedback condition for the hand; that is, whether the tapping response is provided to the hand. "No response" means that the feedback is not provided, and "With" means that feedback is provided. The plot of blank triangles and filled circles show feedback conditions for the back; that is, whether tapping occurred on the back. The vertical axis shows the probabilities when the participants reported that they perceived as though their body shifted towards the back. That is, if the participants indicated that they perceived as though their body shifted towards the front, the probability decreases and the plot is lowered in the graph, and vice versa. The plots indicates the average probability of the report on each condition. The error bar shows standard deviations.

We conducted statistical analysis by performing two-way repeated measured analysis of variance (ANOVA). As a result, the main effect of the feedback condition for the back is significant ($F(1, 5) = 113.75, p < 0.01$). In contrast, the main effect of the feedback condition for the hand is not significant ($F(1, 5) = 0.65, n.s.$). Moreover, interaction between the two factors is not significant ($F(1, 5) = 1.43, n.s.$). Note that the plot height does not indicate position, but the probability of answering.

B. Subjective Report

We obtained some subjective reports through an interview. The representative reports are as follows. Participant *A* indicated that he perceived tapping someone sitting behind him when he perceived that there was an object in front of him. He explained that it seemed that someone had suddenly appeared around him. He continued to say that there were occasions he perceived himself to be tapped, although he actually tapped the person sitting in front of him; moreover, he expressed that this was unfamiliar and strange. He added that he perceived himself to be tapped from a long distance when the tap was late. In addition, he expressed that the two sticks, connected with something rigid, had pinched his body from front and back. Participant *B* indicated that she perceived clearly to be tapping someone when she obtained a response (from the stick), rather than perceiving herself to be tapped. Participant *B* also said that she perceived her position to be uncertain ("fuzzy") when she obtained no response from either the hand or back. Participant *C* reported that it was easy to determine the answer and chose based on the taps, not on what she saw.

V. Discussion

Localization significantly tends to shift towards the back for the condition of no feedback to the hand or back (see the bottom left of Figure 4). During this condition, the participants moved the stick back and forth once to compare exactly to the condition. This means that the probability ratio is 50 %. Therefore, it is feasible that the standard deviation is relatively high. However, the result tends to go towards the back. As Kalckert indicated, voluntary behavior obtained from artificial objects can provide agency [12]. This indicates that *agency* was strongly reproduced when the participants saw their voluntary movements on the stick, which was realized exactly as their movement.

For the *passive* stimuli on the back condition (see the top left of Figure 4), the answer significantly shifts towards the front. Note that this passive stimuli is not provided from an external person such as the experimenter [2]. It is interesting that the tactile cue provided to the participants' back appears to work as external *passive* stimuli even though *agency* appears to be established according to the result described previously. This estimation is supported by Lenggenhager's results [13] as well as Ehrsson's results. According to the subjective report, the participants perceived that they were sitting 1 m in front of their actual sitting position. It is important to consider that the participants perceived to be viewing themselves *from outside of* their body's consciousness. This experience is a typical subjective report of RHI [2].

Passive stimuli with self-touch appears to induce OBEs. The participants indicated that they experienced a relatively large jump in terms of localization. Such a jump was considerably large to consider proprioceptive drift [10]. We consider that passive stimuli dominate voluntary active touch. This result seems feasible because the internal forward model predicts self-produced sensory inputs to be negated, as Blakemore reported [23]. In other words, the external sensory input of tapping on the back seems to have been clearly distinguished from the voluntarily movement, including motor commands.

This localization shift is different from proprioceptive drift, as Tsakiris et al. described [11]. Such shift is obtained in terms of the entire body, rather than a part of the body (see Table I). Needless to say, the tactile stimuli was provided *with* the stick, not *onto* it, so voluntary movement provides *agency* only, and does not provide any *ownership*; in other words, sensation is not projected onto the stick, as Armel et al. described [4]. Above of all, the unilateral sensory loop that includes *voluntary* behavior seems to indicate that tactile sensation dominates *agency*. As a result, voluntary behavior triggers OBEs. Thus, PoV also occurs out-of-body. However, the participants perceived the body to be in front of them. No participant reported that the body was swapped or faced a reversed direction. It appears that nobody perceived a body-swapping experience [6].

The top right plot in Figure 4 was obtained for the condition of feedback to both the hand and back. Similar to the condition with tactile feedback only to the back, the result significantly tends towards the front. In contrast, the localization significantly tends toward the front when compared to the feedback only to the hand. Note that *tapping* means self-tapping under this condition. That is, the tap on the back must be understood as self-generated sensory input, and feedback to the hand must be considered as a result of voluntary tapping. Therefore, we expected the answer to be distributed around the probability rate of 50 % because we assumed no dominance between the tap on the back and feedback to the hand. However, the result is as described previously. Thus, the tap on the back seems to dominate the feedback to the hand. This result can be explained similar to sensory suppression based on the prediction of self-generated sensory input [23].

The last plot at the right bottom in Figure 4 is obtained for the condition of feedback to the hand only. The plot shows significant localization shifting compared to the condition obtained by tapping on the back. In contrast, there is no significant difference from the standard condition without any feedback. According to the subjective report, the participants seemed to perceive as though someone were sitting in front of them. This indicates that *agency* of the stick remained for the conditions; moreover, *ownership* toward the artificial object is not obtained similarly to the other conditions. The PoV coincides with body consciousness because of stick *agency*. In other words, the participants perceived simply tapping something in front of them with the stick as the usual voluntary behavior from FPV. This indicates that the experience is *telexistence* [19] because there is significant localization shifting compared to proprioceptive drift in terms of entire body localization, rather than simply part of the body [10].

Above all, tactile feedback during voluntary self-tapping movement induces OBEs as well as telexistence as shown in Figure 5. As mentioned previously, the PoV is discordant to where the body is perceived during OBEs. In contrast, PoV matches exactly where the body is perceived for the duration of the telexistence experience. Therefore, in this paper, we can conclude that tactile feedback as sensory loop when self-tapping voluntarily can induce these two OBEs in addition to a telexistence experience. Thus, tactile feedback during *active* touch enhances the localization of body consciousness on telexistence [22], although the DoF is much diminished in this paper.

Surprisingly, self-localization shifting is dynamically accepted. In many previous studies, adaptation requires as long as 30 min to obtain proprioceptive drift [10]. In contrast, in this study, the participants were required to experience the set of two conditions and judge within several seconds. It is noteworthy that sudden PoV shifting occurs triggered

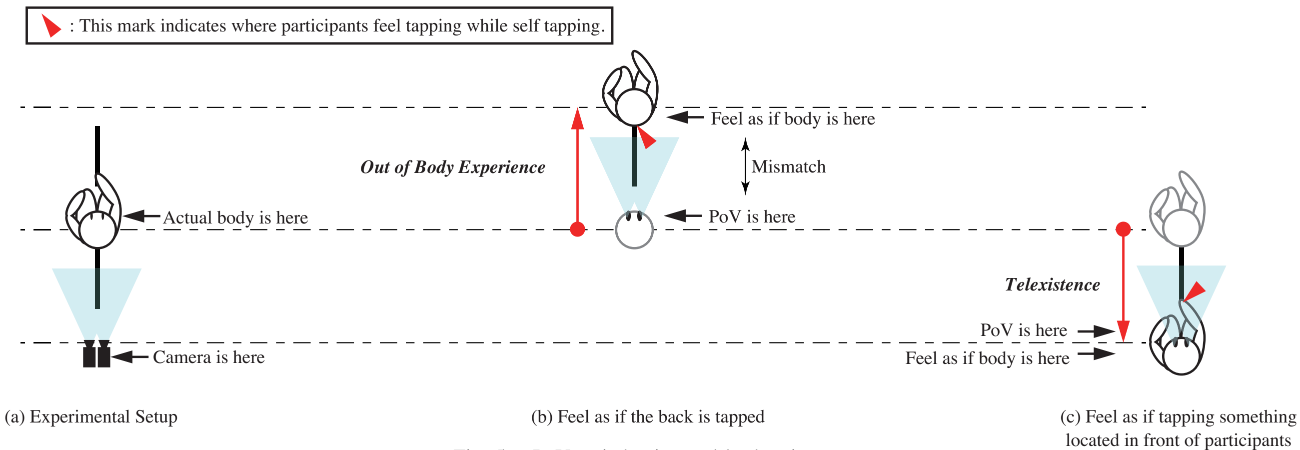

Fig. 5. PoV switch triggered by haptic cue

by haptic cue, although there is a large difference from the previous PoV such that the visual cue is eliminated. This finding strongly supports the significance of haptic feedback in telexistence because it can be considered that haptic cue enhances the existence.

Previous research indicated that synchronized movement provides the sensation of existence [16]. In this experiment, the movement of the stick is well synchronized, as described previously. In addition, all the participants reported that they could not see their back. These facts indicate that the visual cue did not work to localize. Therefore, it seems that the second case, including out-of-body situations, rarely occur, even for the standard condition. Thus, it seems valid to consider that the haptic cue provided on an individual's hand can allow the individual to perceive himself pushed back from their body.

The persons that seemed to appear to the participants should be the participants themselves, but the fact that they are not sounds feasible because their own back disappears, thus becoming extremely difficult for the participants to confirm whether the back was their own. This indicates that visual consistency maintains ownership, and it seems to be the reason the participants perceived an existence different from themselves. In addition, sensory feedback such as being tapped is more dominant; in other words, sensory feedback is the only feedback that can allow the participants to obtain ownership when visual cues relative to their body are lacking. In order to understand such a strange situation, the participants appear to have attempted to provide the previous explanation. Note that they obtained some knowledge about the experiment setup before the trials; moreover, the experimenter requested the participants to answer one of the two; thus, the participants tended to understand that there was no "somewhere," but simply forward movement. Nevertheless, it also seems valid to understand that the haptic cue provided to the participants' back caused them to perceive as though they were outside their own body.

VI. CONCLUSION

In this study, we focused on the effect of haptic cues to determine self-localization in telexistence. To reveal the effect, we constructed a self-tapping device that allowed participants to tap themselves on the back. The participants wore an HMD and tapped their back using a stick to evaluate where they perceived themselves to be. Unlike previous studies, we designed a fast repetition sequence to measure quantitative psychological data. We determined that the method validated the result; moreover, the measurements were valid. It was revealed that an individual's localized position tends to shift backward when the individual is tapped; in contrast, the position tends to shift forward when the individual is performing the tapping. This quantitative result was also supported by a subjective report that included statements to indicate that the participants perceived themselves to be out of their body, or that someone had appear suddenly. Thus, it was determined that haptic cue switches the PoV depending on active and passive states. For the next step, it is necessary to consider balancing the visual cue and haptic cue to reveal the dominant condition to obtain localization.

APPENDIX

A. Tapping Instrument

Each wooden stick is 50 cm in length and 9 mm in diameter, and is placed on a linear slider on a 20 cm rack gear in front of the seated participant. The rack is driven by a pinion gear (the diameter of the reference circle is 30 mm) and is directly connected to a DC motor (maxon DC motor RE40 series, 40 mm, Graphite Brushes, 150 W, 148866 / Encoder MR, 500 CPT, 228452) without any other gear. The motor driver TITECH Driver PC-0121-2 has high power output at a maximum of 450 W. This direct drive mechanism provides force feedback through the stick to the participants' hand and allows us to move the slider with minimal force as well as measure the distance travelled when the participant moves the stick. The main mechanism around the linear slider, the rack gear, and the pinion gear are covered.

The direct drive unit is placed 55 cm in front of TORSO to produce the same view from the TORSO unit as from the participants' position. The two units are located 1 m apart so that the tip of the stick reaches the participants' back. To avoid propagating the tactile cue to the chair on which the participants sit, the direct drive units and the chair do not touch. In fact, the units stand on the ground directly, and other ground plates are installed under the chair. The chair has a backrest to maintain the participants' back at a constant distance from the tip of the stick behind them.

B. Visual Transfer System

The visual transfer system TORSO [18] is placed 1 m behind the participants to provide visual feedback when they look at themselves from behind. This distance was determined based on several factors: the HMD FOV, the distance of the virtual screen, and the length of the stick. When the participants look at their back from 1 m behind using the HMD, the FOV height extends from the participants' neck to half of the stick. The FOV is sufficiently wide to allow the participants to see their back. To tap their back, the ideal length of the stick is approximately 50 cm. Several meters is too long to tap, and 10 cm is too close for the participants to see their entire back.

TORSO has two small video cameras installed 65 mm apart on a lightweight head, which is designed to make fast head movements. It has six DOFs with two rotational joints and one translational joint for the torso, and with three rotational joints for the head. The top axis acts as the panning axis to minimize the mechanical latency between operator and TORSO.

In this study, the TORSO head was fixed at approximately 30 degrees so that the participants could see the tip of the stick at the bottom part of the FOV through the HMD.

C. Condition of Surrounding Environment

The room is an acoustic room with black walls. All lights are off with the exception of a 40 W light bulb positioned next to TORSO. A black cloth is placed on the participants' shoulder to cover their entire back and neck. The shutter speed of the binocular camera embedded in TORSO is set to 1/250 s to decrease brightness. The HMD parameters, such as brightness, contrast, and color temperature, are adjusted before the trial.

D. Control Parameters

The two motors are under master-slave control. The control frequency is maintained at 10 kHz.

To maintain visual consistency, we use the same coefficient value of 0.6 to diminish the moving distance of the back stick compared to the front stick. The sticks are controlled with PD control. The PD gains are sufficiently high to make contact noticeable, but sufficiently low to avoid pain. In addition, the control block limited its torque at a low level.

We multiplied the displacement by a coefficient value of 0.6 in order to maintain visual congruency, as well as to maintain the same movement with the back stick as the front stick. That is, if the front stick travels approximately 10 cm, the back stick only travels 0.6 m simultaneously. The coefficient value was determined through a preliminary study that determined that different displacements between an individual and the target cause a pseudo force sensation [24]. However, this sensation seems less than other parameters because of changing inertia and because of the reset when conditions are changed after every trial.

During the condition of feedback to both the back and hand, we employ a position-based symmetrical bilateral control to link the two sticks in terms of vision and haptic feedback so that the participants can perceive the contact force on the hand, as well as the tap on their back, simultaneously. Both sticks move the same distance, and the PD parameters are tuned sufficiently high to allow the participants to perceive the force feedback and to allow the sticks to maintain the same movement distance.

ACKNOWLEDGMENT

This work was supported by JSPS Grant-in-Aid for Scientific Research A (23240017).

REFERENCES

[1] J. C. Matthew Botvinick, "Rubber hands "feel" touch that eyes see," *Nature*, no. 6669, p. 756, 1998.

[2] H. H. Ehrsson, "The experimental induction of out-of-body experiences," *Science*, vol. 317, no. 5841, p. 1048, 2007.

[3] M. Slater, D. Pérez Marcos, H. Ehrsson, and M. V. Sanchez-Vives, "Inducing illusory ownership of a virtual body," *Frontiers in Neuroscience*, vol. 3, no. 29, 2009.

[4] K. C. Armel and V. S. Ramachandran, "Projecting sensations to external objects: evidence from skin conductance response," *Proceedings of the Royal Society of London. Series B: Biological Sciences*, vol. 270, no. 1523, pp. 1499–1506, 2003.

[5] K. Kilteni, J.-M. Normand, M. Sanchez-Vives, and M. Slater, "Extending body space in immersive virtual reality: A very long arm illusion." *PLoS ONE*, vol. 7, no. 7, p. e40867, 2012.

[6] V. I. Petkova and H. H. Ehrsson, "If i were you: Perceptual illusion of body swapping," *PLoS ONE*, vol. 12, no. 3, p. 223, 2008.

[7] P. Bertrand, D. G. Franco, C. Cherene, and A. Pointeau, "Gender swap - experiment with the machine to be another," themachinetobeanother.org, 2014.

[8] V. I. Petkova, H. Zetterberg, and H. H. Ehrsson, "Rubber hands feel touch, but not in blind individuals," *PLoS ONE*, vol. 7, no. 4, p. e35912, 2012.

[9] A. M. Aimola Davies, R. C. White, G. Thew, N. M. V. Aimola, and M. Davies, "Visual capture of action, experience of ownership, and the illusion of self-touch: A new rubber hand paradigm," *Perception*, vol. 39, no. 6, pp. 830–838, 2010.

[10] M. Rohde, M. Di Luca, and M. O. Ernst, "The rubber hand illusion: Feeling of ownership and proprioceptive drift do not go hand in hand," *PLoS ONE*, vol. 6, no. 6, p. e21659, 2011.

[11] M. Tsakiris, G. Prabhu, and P. Haggard, "Having a body versus moving your body: How agency structures body-ownership," *Consciousness and Cognition*, vol. 15, no. 2, pp. 423–432, 2006.

[12] A. Kalckert and H. H. Ehrsson, "Moving a rubber hand that feels like your own: A dissociation of ownership and agency," *Front Hum Neurosci.*, vol. 6, no. 40, pp. 830–838, 2012.

[13] B. Lenggenhager, T. Tadi, T. Metzinger, and O. Blanke, "Video ergo sum: Manipulating bodily self-consciousness," *Science*, vol. 317, no. 5841, pp. 1096–1099, 2007.

[14] K. Watanabe and S. Tachi, "Verification of out of body sensations, attribution and localization by interaction with oneself," in *IEEE International Symposium on VR Innovation (ISVRI) 2011*, 2011, pp. 111–118.

[15] S. Tachi, *Telexistence*. World Scientific Pub Co Inc, 2009.

[16] S. Tachi, H. Arai, and T. Maeda, "Tele-existence visual display for remote manipulation with a real-time sensation of presence," in *International Syposium on Industrial Robots*, 1989, pp. 427–434.

[17] S. Tachi, K. Minamizawa, M. Furukawa, and C. Fernando, "Telexistence - from 1980 to 2012," in *Intelligent Robots and Systems (IROS), 2012 IEEE/RSJ International Conference on*, 2012, pp. 5440–5441.

[18] K. Watanabe, I. Kawabuchi, N. Kawakami, T. Maeda, and S. Tachi, "Torso: Development of a telexistence visual system using a 6-d.o.f. robot head," *Advanced Robotics*, vol. 22, no. 10, pp. 1053–1073, 2008.

[19] S. Tachi, K. Tanie, K. Komiyama, and M. Kaneko, "Tele-existence (i) -design and evaluation of a visual display with sensation of presence-," in *the 5th Symposium on Theory and Practice of Robots and Manipulators (RoManSy84)*, 1984, pp. 245–254.

[20] S. Tachi and H. Arai, "Tele-existence (ii) -three dimensional color display with sensation of presence-," in *the International Conference on Adavnced Robotics ('85 ICAR)*, 1985, pp. 345–352.

[21] S. Tachi, H. Arai, I. Morimoto, and G. Seet, "Feasibility experiments on a mobile tele-existence system," in *The International Symposium and Exposition on Robotics (19th ISIR)*, 1988.

[22] C. Fernando, M. Furukawa, T. Kurogi, S. Kamuro, K. Sato, K. Minamizawa, and S. Tachi, "Design of telesar v for transferring bodily consciousness in telexistence," in *Intelligent Robots and Systems (IROS), 2012 IEEE/RSJ International Conference on*, 2012, pp. 5112–5118.

[23] S. J. Blakemore, D. Wolpert, and C. Frith, "Why can't you tickle yourself?" *Neuroreport*, vol. 11, no. 11, pp. R11–R16, 2000.

[24] A. Lécuyer, "Simulating haptic feedback using vision: A survey of research and applications of pseudo-haptic feedback," *Presence: Teleoper. Virtual Environ.*, vol. 18, no. 1, pp. 39–53, 2009.