The Rubber Tool Illusion Reveals How Body Image Modifies Body Schema

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Abstract

Rubber hand illusion and tool-use paradigms have been employed extensively in the literature to investigate how the brain processes bodily information. Resulting perceptual and motor changes indicate that both paradigms involve multisensory integration of visual, tactile, and proprioceptive signals and incorporation of extraneous objects, be it rubber hands or tools, into body representation. Despite such common ground, studies of these paradigms have only run in parallel, following separate research programs with little empirical work to bridge the gap. Here, we present a novel behavioral procedure that combines the rubber hand illusion and tool-use in a single experimental setup to investigate whether perceptual modifications to body representation could lead to motor changes and vice versa, providing solicited empirical work towards uncovering the nature of the relationship between body image and body schema. Following this procedure, participants first completed a tool-use task, actively using either a short or long grabber tool to move cubes. As a result, we observed an increase in the motor representation of the forearm length only if the long tool is used, confirming previous findings. Subsequently, participants experienced the "rubber tool illusion," where they observed an identical-looking tool grasped by a rubber hand while passively grasping the same tool they just used, as the experimenter stroked the tips of both tools to induce the illusion. As a novel finding, when the participants used a short tool for tool-use but observed a long tool during the illusion, the motor representation of forearm length significantly increased after the illusion. Follow-up experiments revealed that this elongation effect depended on prior active use of the tool, embodiment of the observed rubber hand and tool induced via synchronous stroking, and a length disparity between the grasped and observed tools during the illusion. Overall, these results reveal for the first time that motor representation of forearm length, a core component of body schema, can be modified by altering body image.

Keywords: rubber hand illusion, tool-use, body representation, body schema, body image

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Abstract

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that motor representation of forearm length, a core component of body schema, can be modified by altering body image.

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1. Introduction

The capacity for voluntary action depends on the neural models of self and the environment. Throughout the development of an infant, motor systems gradually learn to control the limbs for specific actions, which allows the infant to manipulate objects in the environment. Sensory networks continuously monitor such actions by integrating signals from various sensory modalities and identifying the resulting environmental changes. This interplay between action and perception delineates our physical connection with the environment. For instance, the match between the proprioceptive and visual signals from a moving arm generates a sense of ownership of that arm (Ehrsson, 2012). Concurrently, when the intention to move the arm matches the sensory information received during the execution of the action, it results in a sense of agency over that arm (Tsakiris et al., 2006). These senses of ownership and agency have been argued to be the fundamental components of self-experience, defining the boundary between the self and the environment (Gallagher, 2000).

For the last twenty-five years, the study of bodily signals that define this boundary has been deeply divided into two distinct approaches. One experimental practice has investigated the factors that comprise the sense of agency and examined how actions, perceptions, and neural processes change as the participants extend the proficient control of their limbs to an extraneous object, e.g., a tool (Iriki et al., 1996; Maravita et al., 2002; Cardinali, Frassinetti, et al., 2009). These changes have been theorized to modify the "body schema": an unconscious, action-oriented, and sensorimotor representation of the position, size, and posture of body parts (Martel et al., 2016) that derives information mainly from bottom-up proprioceptive, tactile, and kinesthetic senses (Cardinali, Brozzoli, et al., 2009).

A separate experimental program, on the other hand, has inclined to manipulate the sense of ownership by introducing conflicts to multisensory integration and inspecting the resulting changes as participants experience an illusion of embodying rubber hands (Botvinick & Cohen, 1998; Costantini & Haggard, 2007; Tsakiris et al., 2008). Such embodiment has been argued to be reflected in the "body image": a conscious representation of the body used for perception (Kammers et al., 2010), grounded on previous sensory experiences and semantic/lexical body knowledge (Schwoebel & Coslett, 2005) and visual, auditory and tactile signals (de Vignemont, 2010; Martel et al., 2016).

While the scientific approach and the jargon differed between these two bodies of literature, studied notions were, in fact, very similar: How does the brain represent the bodily self? Specifically, when a subject observes an artificial hand being stroked synchronously with the out-of-sight real hand in the case of the rubber hand illusion (RHI), or when they use tools to extend their reach in the case of a tool-use, how are these extraneous objects integrated into a coherent body representation?

1.1. Rubber Hand Illusion

In 1998, the seminal article from Botvinick and Cohen defined a novel paradigm, RHI, for studying bodily perception, where participants placed their arm behind a vertical screen that occluded its view while they observed a rubber hand placed in front of them being stroked synchronously or asynchronously with their hidden hand. As a result, participants who experienced synchronous stimulation during the RHI (compared to the asynchronous condition) reported that the location of their index finger had drifted towards the rubber hand. The proprioceptive drift was also accompanied by a sense of ownership, such that the subjects felt as if the rubber hand was their own hand. Later studies revealed certain temporal, spatial, and anatomical constraints of the illusion. Notably, the illusion worked only if the stroked object viewed by the participant was hand-shaped (Tsakiris et al., 2010) and had identical laterality (Tsakiris & Haggard, 2005), suggesting a modulation from a top-down template-matching process. These findings led to the interpretation of RHI as a task that mainly influences perceptual mechanisms–and the body image conjointly–since many studies had also concluded that motor responses were unaffected by the illusion (Holmes et al., 2006; Kammers, de Vignemont, et al., 2009; Kammers et al., 2010; Heed et al., 2011).

Over the years, there have been many modifications to the methods used for inducing RHI. Perceptual induction methods (e.g., tactile stimulation of fingers with a brush or passive movement of fingers through a mechanism controlled by the experimenter) led to changes in the perceptual responses, i.e., verbal reports of the position of the affected hand or ownership over the rubber hand (Tsakiris & Haggard, 2005; Kalckert & Ehrsson, 2012), but when it was a motor measure (e.g. pointing/grasping movements towards the other hand or an object) that was employed to quantify the effect of the illusion, studies revealed somewhat conflicting findings. In some studies, authors could not detect a difference between the synchronous and asynchronous conditions and argued that the motor effect was solely due to the visual information, independent of the embodiment of the rubber hand (Holmes et al., 2006; Kammers et al., 2010; Heed et al., 2011), while others attributed the effect to the motor induction of the illusion, as participants actively moved their index finger and observed an identical motion in the rubber hand (Kalckert & Ehrsson, 2012, 2014; Riemer et al., 2013). Although several studies failed to demonstrate the effect of perceptual induction on motor responses (Holmes et al., 2006; Kammers, de Vignemont, et al., 2009; Kammers et al., 2010; Heed et al., 2011), two of them did (Riemer et al., 2013; Kalckert & Ehrsson, 2014). While these disagreements most likely resulted from the differences in the methodological and analytical approaches (for a more detailed discussion of such differences, see Riemer et al., 2013), they nonetheless underscored the need for further investigation concerning the effect of perceptual processes on motor responses.

1.2. Tool-use

In an influential single-cell recording study, Iriki et al. (1996) trained monkeys to use a rake-shaped tool to retrieve food located outside their arm reach, revealing enlargement in the visual receptive fields of parietal bimodal cells after using the tool. Following this discovery, tool-use became a frequent experimental paradigm to inspect body-related changes in sensorimotor processing. More than a decade later, Cardinali et al. (2009) established that such changes also occurred in humans. Following a ten-minute tool-use task with a mechanical grabber, participants were instructed to execute unsighted, ballistic pointing movements towards specific anatomical locations on the tool-using arm, which revealed a change in body schema, i.e., an elongation in the motor representation of the forearm.

Later studies employing tool-use tasks revealed certain constraints on this elongation effect. Sposito et al. (2012) showed that the arm-lengthening effect, as measured by a forearm bisection task, depended on functional gains in reachable space, as it occurred only with a 60-cm-long tool and not a 20-cm-long one. Garbarini et al. (2015) investigated four brain-damaged hemiplegic subjects as they observed the experimenter's arm carry out a tool-use task in a position that coincided with where their contralesional arm would be, leading to the embodiment of the experimenter's arm as their own. This condition was later compared to another where the experimenter's arm was more distal and did not evoke such an embodiment. Forearm bisection measurements revealed that the embodiment of the tool-using arm was necessary to induce the elongation effect. Lastly, Baccarini et al. (2014) discovered that imagining the use of the tool was sufficient to trigger this effect. They asked participants to execute free-hand reach-to-grasp movements before and after two mental imagery tasks, where participants were instructed to imagine performing the same movements either with their bare hands or with a grabber tool. Kinematic recordings of the movements after the imagery tasks demonstrated the elongation effect only for the tool imagery condition. All in all, these findings indicate that tool-use is not an isolated motor task, as the resulting changes are also affected by non-motor factors, such as functionality, embodiment, and imagination.

1.3. Joint Experimentation

Over the last decade, there have been numerous calls for systematic examination of these paradigms and related body representations (de Vignemont & Farne, 2010; Martel et al., 2016; Pitron et al., 2018) and several attempts to provide empirical answers to these calls (Weser et al., 2017; Weser & Proffitt, 2019; Cardinali et al., 2021). As an intriguing finding, Weser and colleagues successfully induced the illusion by having the participant and the rubber hand hold identical tools and by stroking the tools' tips rather than the hands grasping them. They also demonstrated that the strength of the illusion, as measured by a proprioceptive drift task and a questionnaire, increased when the tool-use preceded the illusion or when participants had better skill for using the tool, implying the role of embodiment (Weser et al., 2017). However, while the illusion was successfully elicited through tactile stimulation of chopsticks, pliers, and tweezers, there was no effect of synchronicity when participants grasped a teacup, indicating that a morpho-functional (concerning the tool's output) and sensorimotor (concerning the tool's input) match is necessary for embodiment to occur (Weser et al., 2017; Weser & Proffitt, 2019). In the Cardinali et al. (2021) study, participants were able to embody a grabber tool while their fingers and the tool's prongs were brushed by the experimenter synchronously, as shown by proprioceptive drift measurements and skin conductance responses. Interestingly, their results indicated that prior tool use did not affect the perceptual responses, which conflicted with Weser and colleagues' findings. In sum, these studies revealed that the embodiment of a tool through the induction of RHI was possible. However, evaluations in these experiments only measured perceptual changes; motor measures were not employed at all. This omission, combined with the aforementioned contradictory results on the effect of tool use, warranted our investigation.

1.4. Aims of the Study

The present study empirically examined the changes in body representations in a procedure that combines tool-use and RHI paradigms. Modifying the tool-integrated RHI setup introduced by Weser et al. (2017), this study intended to bridge the gap between these dissonant experimental practices by unveiling the nature of the interaction between body schema and body image, i.e., motor judgments of limb size and perceptual judgments of limb position and ownership.

At the beginning of the procedure, participants used a grabber tool to complete several tasks of moving cubes closer to or away from their bodies in order to embody the tool motorically. Then, while still grasping the same tool, they experienced the "rubber tool illusion" (abbreviated as RTI from now on to prevent confusion with the classical RHI), where they observed the experimenter brush the tip of an identical-looking tool grasped by a rubber hand, either synchronously or asynchronously. We measured the perceptual changes, i.e., changes in body image, through the implicit proprioceptive drift measures before and after RTI and the explicit subjective experience questionnaire at the end of each block. In turn, motor changes, i.e., changes in body schema, were measured via forearm bisection tasks in three instances: baseline (before tool-use), after tool-use (before RTI), and after RTI. Altogether, we conducted three different experiments by modifying this general procedure (see Figure 1). As a result, we were able to investigate how observing a same- or different-length tool during RTI would affect body schema, and how prior tool-use or its absence (implemented as a "tool-hold" task where participants merely held the tool and completed the same task with their other hand) would affect body image.

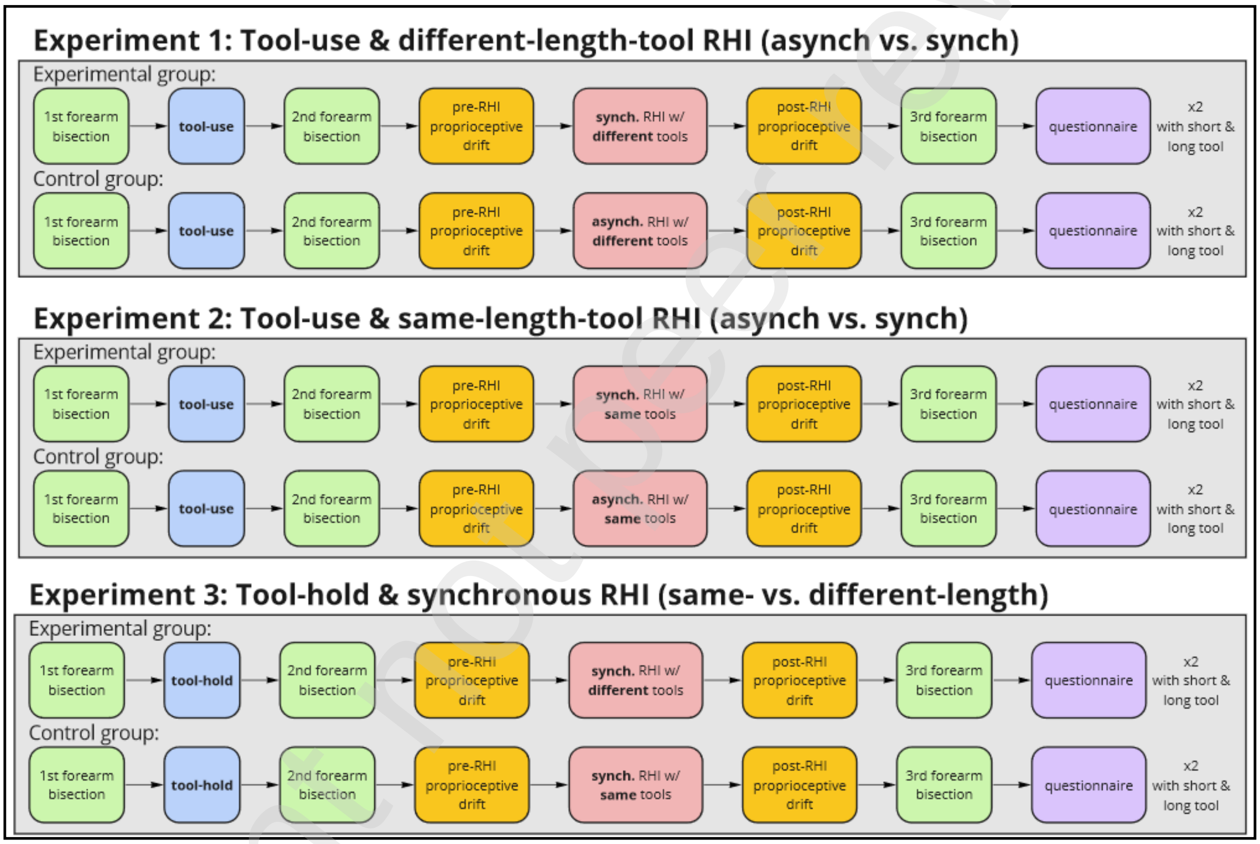

Figure 1: Procedures of all three experiments. Experiments followed a similar order: In each experiment, the measures of forearm bisection, proprioceptive drift, and questionnaire were conducted identically, and each participant completed the experimental block twice, once with a short and once with a long tool. However, the tool tasks, RTI conditions, and between-subjects variables differed between experiments. In *Experiment 1*, participants performed the tool-use task and experienced the RTI while observing a different-length tool, where the between-subjects variable was RTI synchronicity. In *Experiment 2*, participants again performed the tool-use task, but this time, they experienced RTI while observing a

same-length tool, where the between-subjects variable was again RTI synchronicity. In *Experiment 3*, participants performed the tool-hold task instead and experienced only synchronous RTI, where the between-subjects variable was observed tool identity (same- or different-length).

Colored.

We hypothesized that (i) using the long tool in the tool-use task would increase the motor measure of forearm length, while the short tool would not (replicating previous findings and validating the tool-use part of our procedure); (ii) proprioceptive drift and embodiment scores of the questionnaire would be higher in the synchronous RTI conditions than the asynchronous ones (replicating previous findings and validating the RTI part of our procedure); (iii) the motor representation of forearm length would increase only if the participants observed a longer tool during synchronous RTI following tool-use (a novel finding, indicating that body image can modify body schema); and (iv) this modification would not take place if participants did not actively use the tool (i.e., experienced the tool-hold task instead) prior to RTI (a novel finding, suggesting motor embodiment of the tool is necessary to qualify a modification of body schema through body image).

1.5. Our Contributions

In three experiments, we established that a change in the perceptual (visuotactile) information regarding the length of a tool could influence a motor (pointing) response regarding the length of the forearm. Notably, we showed that this influence was unidirectional, only permitting an increase in the length of the forearm, and it was contingent on prior tool-use and the embodiment of the observed hand and tool during RTI. Overall, our results support the theoretical approach that motor and perceptual processes encoding bodily information are not isolated; on the contrary, they reciprocally affect each other. In the context of the dyadic taxonomy of body representation (Dijkerman & de Haan, 2007), we demonstrate that body schema can be modified via the perceptual changes introduced to the body image.

2. Experiment 1

It has previously been shown that RHI can alter motor responses (measurement of the end target of a pointing movement) towards the presumed position of body parts (Riemer et al., 2013; Kalckert & Ehrsson, 2014). However, to our knowledge, no prior work has examined whether RHI could also affect the perceived body metrics through motor responses. For this purpose, we designed a procedure enabling the manipulation of the perceived forearm length during RTI (see Figure 1). In this procedure, participants first use either a long or short grabber tool during the tool-use task, integrating the tool into the body schema. Then, we aimed to modify the tool-integrated representation of forearm length by having participants experience the ownership of a rubber hand grasping a longer or shorter tool during RTI. Our initial goal was to replicate the classical findings of these paradigms with our experimental setup by demonstrating an elongated forearm representation after tool-use with a reach-enhancing (long) tool, and a proprioceptive drift towards the tool-grasping rubber hand after RTI. After establishing the validity of the tasks, we predicted that participants, having used a short tool in the tool-use task and observed a long tool grasped by the rubber hand during synchronous RTI, would exhibit an elongation effect when we compared the forearm bisection results before and after RTI. Thus, we intended to modify the motor response regarding the forearm length through the perceptual induction of RTI. We did not expect to see any shortening effect in the reverse condition, where participants would observe a short tool during the synchronous RTI after using a long tool during the tool-use task since contraction effects have rarely been observed in previous studies (Martel et al., 2016).

2.1. Methods

2.1.1. Participants

Twenty-four right-handed participants (11 females, mean age 24.00, ranging between 19 and 38) participated in Experiment 1. All participants had normal or corrected vision, reported no injury or neurological disorder, were naïve to the purpose of the study, and gave informed consent. Participants were recruited either through the psychology department's student recruitment system or by direct contact. Psychology students were compensated with course credits, while the rest volunteered. The study was approved by the university ethics committee and conducted according to the guidelines of the Declaration of Helsinki.

A statistical power analysis was conducted with G*Power version 3.1 (Faul et al., 2009). A preliminary study conducted among lab members resulted in a medium effect size of $d = .62$, according to Cohen's criteria. With a two-tailed alpha of 0.05 and power of 0.95, the required sample size was 23. Thus, a sample size of 24 was deemed to be adequate.

2.1.2. Experimental Design

Experiment 1 had a 2 x 2 mixed design, where *tool length of participant* (long or short) was the within-subjects factor and *RTI synchronicity* (synchronous or asynchronous) was the between-subjects factor. RTI synchronicity was designated as the between-subjects factor to alleviate the effect of perceived task requirements on illusion outcomes, as recent findings suggested that expectancies arising from task demands might be an unsought contributor to RHI (Lush et al., 2020). Participants completed the experimental block twice, once with the long and once with the short tool, where they grasped the same tool during the tool-use and RTI tasks. There was a 15-minute break between the two blocks, during which participants were encouraged to move and engage in other activities to negate any carryover effects from the first block. The order of the blocks was counterbalanced. Overall, there were four mixed conditions in Experiment 1: (i) using long tool and observing short tool during synchronous RTI; (ii) using long tool and observing short tool during asynchronous RTI; (iii) using short tool and observing long tool during synchronous RTI; and (iv) using short tool and observing long tool during asynchronous RTI.

2.1.3. Tasks and Procedure

Each experimental block consisted of a tool-use task followed by an RTI task (see Figure 1). There were three forearm bisection measurements during a session: at baseline (before the tool-use task), after the tool-use task (before RTI), and after RTI. Proprioceptive drift measurements were taken immediately prior to and following RTI. Finally, subjects completed the session by filling out the subjective experience questionnaire. Throughout the sessions, participants wore a black nitrile glove on their right hand, similar to that worn by the rubber hand, to augment the strength of the illusion.

2.1.3.1. Forearm Bisection

A similar measurement to the one described by Sposito et al. (2012) was adopted. Participants were seated on a chair and asked to keep their backs straight with their abdomen touching the table in front. They placed both of their forearms on the table, parallel and 20 cm lateral to the midsagittal plane, with their palms facing down and fingers extended. Their elbows were positioned at the edge of the table, and the length of the segment from the right elbow (olecranon) to the tip of the right middle finger was recorded. Following the instructions, participants were blindfolded, and a platform was placed about 4 cm above their right forearm to prevent tactile feedback during the task. Then, the tip of the right middle finger and the right elbow were stimulated tactually as the participants were asked to point to the midpoint of this limb segment with their left index finger in a ballistic movement without halting or changing the trajectory. Several practice trials were performed until the participants correctly executed the pointing movement. At each measurement, the position along the right parasagittal axis where the left index finger's tip touched the platform's top surface was recorded to the precision of 5 mm. If another part of the limb made contact with the platform before the left index finger, that trial was repeated. After the experimenter recorded the position of the left index finger, participants returned their left hand to the initial position, and the subsequent trial started. A total of three measurements were collected.

2.1.3.2. Tool-use Task

In previous studies, the specific motor pattern employed by arm joints (actions that require mostly proximal or distal joint movement) during a tool-use task was shown to affect forearm bisection measurements (Romano et al., 2019). Also, a tool that brought about an extension in reaching space (e.g., using a 60-cm-long vs. 20-cm-long tool) was imperative for observing an increase in the representation of forearm length (Sposito et al., 2012). Additionally, a tool that provided morphological and functional correspondence to how one would typically perform a task was also critical for tool embodiment (Miller et al., 2014; Cardinali et al., 2016).

As a result, we designed a task involving identical-looking short or long mechanical grabber tools that resulted in a net increase of 30 or 60 cm in arm reach, respectively. An additional weight was placed towards the tip of the short tool to match the perceived torque and weight while wielding the tools. To account for any fatigue difference that persisted despite this modification, participants were asked to indicate the level of discomfort they felt during the tool-use task on a 0 to 10 VAS measure (0: no pain/numbness/tingling sensation, 10: intolerable pain/numbness/tingling sensation) at the end of each experimental block. To prevent proximal or distal bias in motor patterns, execution of the task required simultaneous movement in every arm joint (shoulder, elbow, wrist, and hand). To enhance the morpho-functional resemblance, participants were instructed to wield the tools in a grip akin to a palmar grasp.

Tool-use task consisted of four blocks. During each block, participants placed and retrieved eighteen numbered cubes on and from targets marked on a sheet containing three rows of six targets each (see Figure 2). The furthest row of targets was placed 10 cm proximal to participants' maximum reach with the tool to provide an extension in reaching space. The task began after several practice trials to ensure correct grasp and movement. Participants picked up a particular cube from the baskets on the side of the table using their left hands, placed it on the designated spot on the table (at 30 cm from their torso), and operated the tool with their right hand to grab the cube and place it on the corresponding target. After all eighteen cubes were placed on their respective targets, subjects recollected them one by one by picking up a cube with the tool, placing it on the designated spot, grabbing it with their left hand, and placing it in the particular basket, thus ending the block. All participants performed the same task. The complexity of the task increased with every block (i.e., changing the order of placement/retrieval, randomizing the order of targets, stacking cubes in groups of three on the middle row) to incur cognitive load and keep participants focused on the task. The task ended when all four blocks were completed, and participants were timed to account for any effect of task duration on the results.

Figure 2: A snapshot of the tool-use task. In this instance, the participant uses the long tool to pick up or place cubes on the random-target sheet.

2.1.3.3. Proprioceptive Drift

In the literature, the proprioceptive drift measurement has been differentiated as either a perceptual or motor task. In perceptual tasks, participants are asked to indicate the position of their affected hand verbally, without any movement (Tsakiris & Haggard, 2005; Riemer et al., 2013); while in motor tasks, participants are asked to point at the position of their affected hand in a ballistic movement (Kammers, de Vignemont, et al., 2009; Kammers, Longo, et al., 2009; Riemer et al., 2013). We intended to measure the perceptual changes in body image; therefore, we adopted a perceptual task.

After completing the second forearm bisection measurement, participants were moved to the other end of the table, where the RTI setup was hidden under a wooden panel. They were comfortably seated and blindfolded as the experimenter placed the participants' right hand 15 cm distal to the rubber hand, which, in turn, was also positioned 15 cm distal to their midsagittal plane. The rubber hand was not placed on the body midline due to a perceptual bias for limbs positioned towards the torso that might inflate the results (Preston, 2013). The same tool that participants wielded during the tool-use task was carefully placed in their right hand, and participants were informed that they were still grasping the same tool as before, with the prongs fixed in a closed position to prevent fatigue. After ensuring the proper arrangement of the setup and covering it with a black smock to prevent any visual cues of the right arm's location, the experimenter removed the blindfold and sat across the participants. Participants were briefed that the tool in their hand was placed parallel to the edge of the table and asked to verbally indicate the point on a ruler that coincided with the tip of the tool. The ruler was placed at a random position on the fronto-parallel axis along the edge of the box near the experimenter. Participants were asked to repeat this measurement five times, closing their eyes and readjusting their head orientation between measurements. At the same time, the experimenter changed their position and the position of the ruler to ensure that the participants did not rely on external cues. The results were recorded to a precision of 1 mm. The same measurement was repeated post-RTI.

2.1.3.4. Rubber Tool Illusion

In previous tool-integrated RHI setups, the illusion was successfully elicited by having the rubber hand and participants grasp chopsticks or pliers while synchronously stroking the tip of the tools instead of the hands (Weser et al., 2017; Weser & Proffitt, 2019). Similarly, we designed a setup where participants and the rubber hand grasped identical-looking grabber tools as the tactile stimuli were delivered to the distal end of the tools to induce the illusion. A wooden hand model wearing a black nitrile glove was employed as the "rubber hand" since its flexible finger joints allowed for switching the tool between blocks and adjusting the grip to imitate participants' hand configuration. The rubber hand and the proximal end of the tool it grasped were affixed to the table with clamps and rubber bands, enabling vertical movement of the tool as the experimenter stroked the distal tip with a paintbrush during RTI. Sponges were placed below the handle and the shaft of the tool to support its weight and provide collapsible space below the tool for the resulting motion from brush strokes.

After the first proprioceptive drift measurement, participants were blindfolded. The experimenter vertically repositioned the wooden panel midway between the rubber hand and participants' right hand and clamped the black smock to the vertical panel in a way that obstructed the view of participants' right hand and the mechanism that supported the rubber hand. After removing the blindfold, participants were asked to confirm that the rubber hand and the tool it grasped were clearly visible. They were instructed to focus on the distal end of the tool grasped by the rubber hand while the experimenter stroked the tip of both tools with a paintbrush for the next two minutes. This duration was adopted since a recent review indicated that it might take up to 110 seconds to induce the illusion in some participants (Riemer et al., 2019). The experimenter stroked the tip of both tools with enough pressure to ensure that the participant sensed the vertical movement of the tool on their hand at a rate of one stroke per 2-3 seconds, either synchronously or asynchronously. Asynchronous stimuli were administered with an unpredictable, random delay since recent findings suggest that the predictability of tactile stimuli has a strong effect on body representations (Clark, 2013). As the two-minute duration ended, the participant was again blindfolded, and the wooden panel was returned to its horizontal position to measure post-RTI proprioceptive drift.

2.1.3.5. Subjective Experience Questionnaire

The questionnaire from Longo and colleagues (2008) was translated into *Anonymized Language* and adapted to RTI to be employed in the experiment as an explicit measure of perceptual changes in body image (see Supplementary Material for the English translation). Each of the twenty-five statements was measured on a Likert scale from -3 to 3. Statements reflected five dimensions of the illusion (see Table 1 for example statements from each dimension): embodiment of rubber hand (eleven statements), loss of own hand (five statements), movement of either hand (three statements), affect (three statements), and deafference of own hand (three statements). After completing the third and final forearm bisection task, participants were instructed to fill out the questionnaire, reflecting on their experience of the illusion during that block.

Dimension	A sample statement from the questionnaire
Embodiment	It seemed like the rubber hand grasping the tool was a part of my body.
Loss of hand	It seemed like I could not really tell where my own hand was.
Movement	It seemed like my hand was moving towards the rubber hand grasping the tool.
Affect	The touch of the brush on the tool I grasped was pleasant.
Deafference	I had a tingling sensation in my own hand.

Table 1: Sample statements (translated from *Anonymized Language*) from each dimension of the questionnaire.

2.1.4. Data Analysis

Data were analyzed using SPSS Statistics for Windows, Version 27.0 (IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp). Forearm bisection results of pre- and post-tool tasks were compared using within-subjects ANOVA, while proprioceptive drift, questionnaire, and forearm bisection results of pre- and post-RTI tasks were compared using mixed ANOVA. Three Pearson correlation coefficients were computed: one between the proprioceptive drift and the change in forearm length pre- and post-tool-use, one between the proprioceptive drift and embodiment ratings, and the last one between the proprioceptive drift and the change in forearm length before and after synchronous RTI. Finally, between-subjects t-tests and within-subjects t-tests were conducted to control the effects of pain and tool task duration on the dependent variables (see Supplementary Material). All tests were two-tailed. Outliers were winsorized to match the closest value. Nonparametric alternatives were used if the violation of assumptions prevented the use of parametric tests.

2.2. Results and Discussion

2.2.1. Forearm Bisection pre-post Tool-use

Forearm bisection results were transformed to percentage measurements, calculated with the formula [(□/arm length)*100], where □ is the subjective midpoint. Since the 0-cm point was the tip of the right middle finger, a value less than 50% marked an overestimation of perceived forearm length, whereas a value more than %50 marked an underestimation.

A two-way within-subjects ANOVA was conducted on the first two forearm bisection results with *tool length of participant* (short or long) and *bisection* (pre-tool-use or post-tool-use) as within-subjects variables. There was no main effect of tool length, $F(1, 23) = .92$, $p > .34$, $\eta_p^2 = .039$, or bisection, $F(1, 23) = .93$, $p > .34$, $\eta_p^2 = .039$. On the other hand, there was an interaction effect, $F(1, 23) = 7.15$, $p = .014$, $\eta_p^2 = .24$, with a planned comparison revealing that the participants reported the midpoint of their forearm more distally post-tool-use ($M = 41.94$, $SD = 2.05$) compared to pre-tool-use ($M = 46.28$, $SD = 2.08$) in the long tool condition, $p = .036$ (see Figure 3). The same comparison was not significant for the short tool condition, $p > .21$.

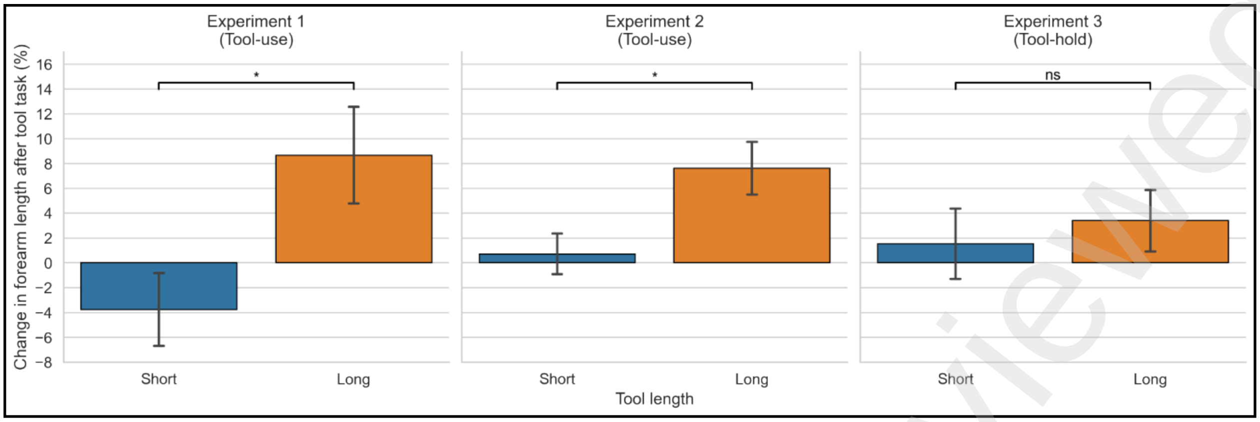

Figure 3: Change in forearm length representation after tool tasks in all three experiments. This value is calculated by subtracting the first (pre-tool-task) forearm bisection measurement from the second (post-tool-task) measurement and multiplying the result by 2. In Experiments 1 and 2, participants performed the tool-use task, using either a short or a long tool with their right hand to move cubes closer to or away from their bodies. In Experiment 3, the tool-hold task was performed, where participants merely held the tool with their right hand while they moved the cubes using their left hand instead. Results are averaged across subjects in each category. Error bars indicate ±1 SEM.

Colored.

These results indicated that while there was an elongation effect after the tool use task with the long tool, using the short tool did not induce any change in the internal representation of forearm length. Thus, we confirmed the first hypothesis and replicated the results in the literature regarding tool-use and forearm bisection tasks with our experimental setup.

2.2.2. Proprioceptive Drift

Perceptual judgments on the location of the tool's tip before and after RTI were subtracted [post-pre] to calculate the proprioceptive drift. A positive result marked a shift towards the rubber hand, while a negative result marked a shift away from it.

A mixed two-way ANOVA was conducted on proprioceptive drift results with *RTI synchronicity* (asynchronous or synchronous) as the between-subjects variable and *tool length of* *participant* (short or long) as the within-subjects variable. There was a significant main effect of the RTI synchronicity, $F(1, 22) = 7.27$, $p = .013$, $\eta_p^2 = .25$, with the participants that experienced synchronous RTI ($M = 4.79$, $SD = .80$) reporting more drift than those that experienced asynchronous RTI ($M = 1.74$, $SD = .80$). There was also a significant main effect of tool length, $F(1, 22) = 5.53$, $p = .028$, $\eta_p^2 = .20$ (see Figure 4), as participants that grasped the long tool (and observed the short tool during RTI; $M = 4.17$, $SD = .81$) reported more drift than participants that grasped the short tool (and observed the long tool during RTI; $M = 2.36$, $SD = .53$). The interaction between RTI synchronicity and tool length was not significant, $F(1, 22) = .86$, $p > .36$, $\eta_p^2 = .038$. Additionally, a Pearson correlation coefficient was computed to assess the linear relationship between proprioceptive drift and change in forearm length pre- and post-tool-use in the “grasping long tool & synchronous” condition. There was a negative non-significant correlation, $r(12) = -.14$, $p = .51$.

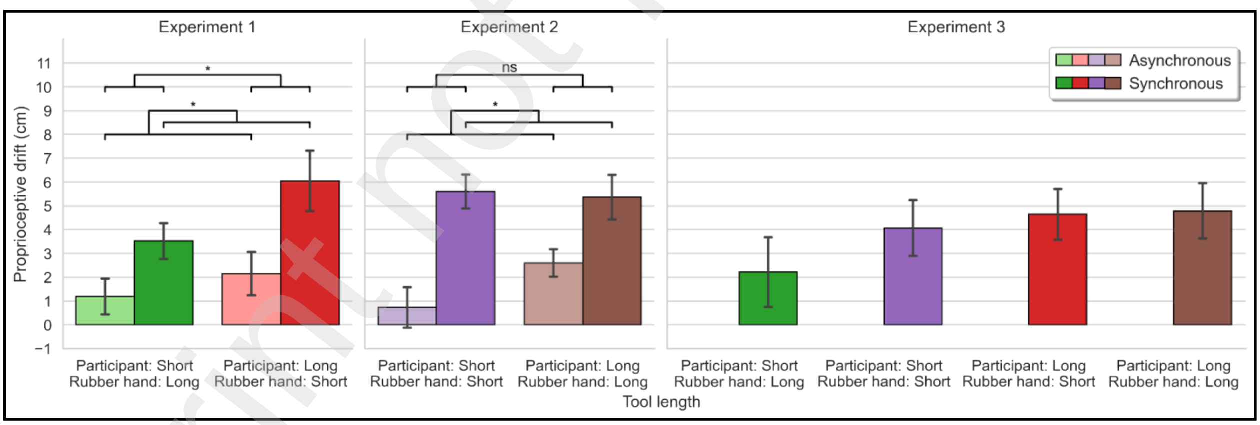

Figure 4: Proprioceptive drift in all three experiments. Note that in Experiment 3, there is no asynchronous condition. Results are averaged across subjects in each category. Error bars indicate ±1 SEM.

Colored.

These results suggested that synchronous RTI enabled implicit embodiment of the rubber hand and the tool it grasped. Thus, we partially confirmed the second hypothesis and replicated the classical RHI paradigm with our RTI setup. However, the effect of tool length on proprioceptive drift was unexpected. This result could mean that an extension of forearm length in the parasagittal axis might cause an extension of peripersonal space in the frontoparallel axis. However, the lack of a positive correlation between the proprioceptive drift measurement and the change in forearm length after long tool-use suggested otherwise. A reassessment of this effect in Experiment 2, where the observed and grasped tools are the same length, could be more insightful.

2.2.3. Subjective Experience Questionnaire

A mixed three-way ANOVA was conducted on the mean ratings of questionnaire components with *RTI synchronicity* (asynchronous or synchronous) as the between-subjects variable, and *tool length of participant* (short or long) and *components* (embodiment, loss of hand, movement, affect or deafference) as within-subjects variables. Since the homogeneity of variances assumption was violated for the "short tool & movement" group, the movement component was excluded from the analysis as there was no expected effect regarding this component. There was no significant main effect of RTI synchronicity, $F(1, 22) = 1.27$, $p > .27$, $\eta_p^2 = .055$. There was also no significant main effect of tool length, $F(1, 22) = .011$, $p > .91$, $\eta_p^2 < .001$. However, there was a significant main effect of components $F(2.54, 55.88) = 21.75$, $p < .001$, $\eta_p^2 = .50$. The interaction between RTI synchronicity and components was not significant, $F(2.54, 55.88) = 2.76$, $p = .072$, $\eta_p^2 = .11$, but a planned comparison revealed a significant effect for the embodiment component between the synchronous ($M = .40$, $SD = .48$) and asynchronous ($M = -1.15$, $SD = .48$) conditions, $p = .033$ (see Figure 5). None of the rest of the two- or three-way interactions were significant, all *ps* > .24. Additionally, a Pearson correlation coefficient was computed to assess the linear relationship between proprioceptive drift and embodiment. There was a positive significant correlation, $r(48) = .33$, $p = .024$.

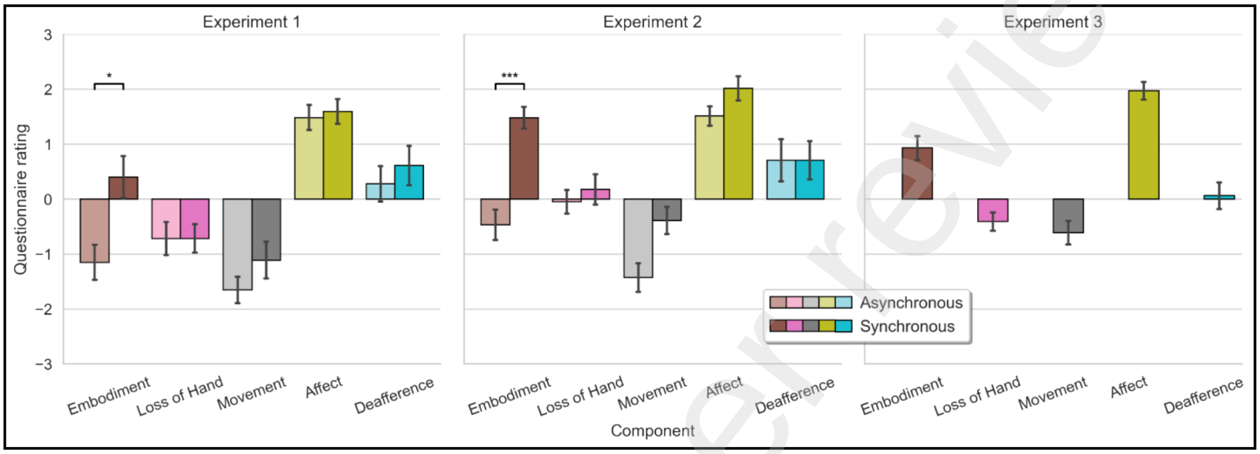

Figure 5: Questionnaire ratings in all three experiments. Note that in Experiment 3, there is no asynchronous condition. Results are averaged across subjects in each category. Error bars indicate ±1 SEM.

Colored.

Overall, low positive scores in the synchronous group were consistent with the previous tool-integrated RHI experiments that demonstrated a weaker illusion experience compared to the classical RHI (Weser et al., 2017; Weser & Proffitt, 2019; Cardinali et al., 2021). Since only the embodiment component was expected to differentiate the synchronous and asynchronous groups, and considering that participants observed different-length tools during the illusion, such low scores were expected. The lack of a main effect of RTI synchronicity was most likely due to comparable results in the other three components outweighing the significant difference in the embodiment component. However, the significant effect in the embodiment component reflected an explicit embodiment of the rubber hand and the tool it grasped, confirming our second hypothesis. Moreover, a significant positive correlation between the proprioceptive drift and embodiment results supported the established relationship between these measurements.

2.2.4. Forearm Bisection pre-post RTI

The change in forearm length after RTI was calculated with the formula [((bisection2-bisection3)/arm length)*100*2], where *bisection2* is the pre-RTI forearm midpoint, and *bisection3* is the post-RTI forearm midpoint. A positive result marked an elongation effect, while a negative result marked a contraction effect.

A mixed two-way ANOVA was conducted on the change in forearm length after RTI with *RTI synchronicity* (asynchronous or synchronous) as the between-subjects variable and *tool length of participant* (short or long) as the within-subjects variable. There was no significant main effect of RTI synchronicity, $F(1, 22) = 1.30$, $p > .26$, $\eta_p^2 = .056$. However, there was a significant main effect of tool length, $F(1, 22) = 11.02$, $p = .003$, $\eta_p^2 = .33$, with the participants that grasped the short tool (and observed the long tool during RTI; $M = -.53$, $SD = 1.92$) reporting less contraction in forearm length than those that grasped the long tool (and observed the short tool during RTI; $M = -8.79$, $SD = 2.54$). While the interaction between RTI synchronicity and tool length was not significant, $F(1, 22) = 2.86$, $p > .10$, $\eta_p^2 = .115$, a planned comparison revealed a significant effect for observing a longer tool during RTI between the synchronous ($M = 3.71$, $SD = 2.71$) and asynchronous ($M = -4.78$, $SD = 2.71$) conditions, $p = .038$ (see Figure 6). The same comparison for observing a shorter tool was not significant, $p > .98$. Additionally, a Pearson correlation coefficient was computed to assess the linear relationship between proprioceptive drift and change in forearm length pre- and post-RTI in the "holding short tool & synchronous" condition. There was a negative non-significant correlation, $r(12) = -.51$, $p = .093$.

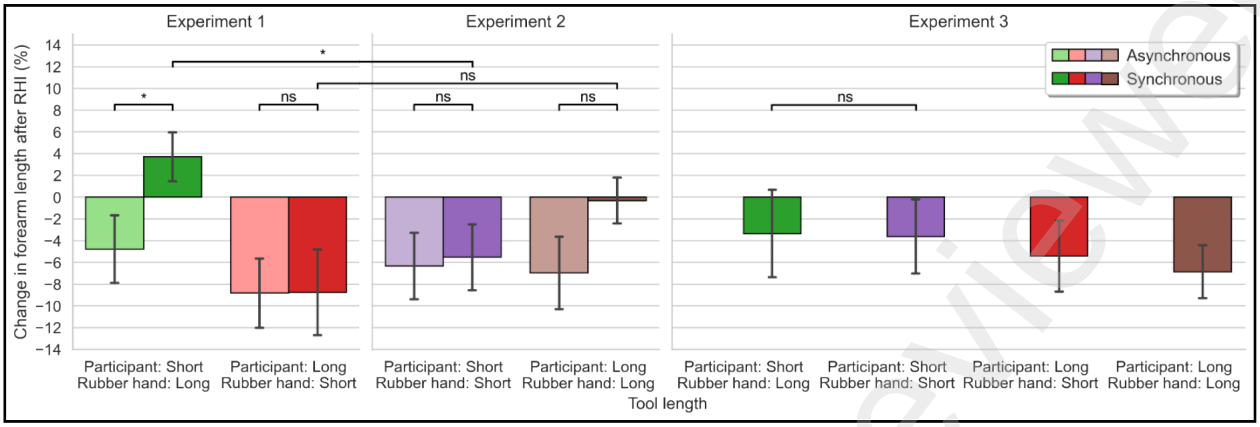

Figure 6: Change in forearm length representation after RTI in all three experiments. Note that in Experiment 3, there is no asynchronous condition. Results are averaged across subjects in each category. Error bars indicate ±1 SEM.

Colored.

These results indicated that after a tool-use task, observing a longer tool during synchronous RTI increased the motor measure of forearm length. While the significant main effect of tool length revealed that visual information regarding the tool length already affected the change in forearm length by itself, this effect was amplified when the illusion was synchronous, resulting in a significant elongation effect due to embodying the rubber hand and the longer tool it grasped. On the other hand, there was a contraction effect for observing a shorter tool during synchronous RTI. However, this effect was not significantly different from the contraction effects in asynchronous conditions. This general trend for forearm contraction could be attributed to the decay in the elongation effect for those who embodied the long tool prior to RTI. It is widely accepted in the literature that the extension of arm length that results from integrating a tool into body representation after tool-use is transient (de Vignemont & Farne, 2010). However, since there is also a contraction effect for those who used the short tool and showed no significant forearm elongation prior to asynchronous RTI, a decay of prior elongation is insufficient to explain this general effect. Alternatively, this effect might also originate from observing a different-length tool during RTI.

Finally, the lack of a significant correlation between the proprioceptive drift measurements and the change in forearm length pre- and post-RTI implied that these behavioral measures did not rely on the same processes of bodily information.

3. Experiment 2

To control for the factors unaccounted for in Experiment 1, a similar experiment was designed, with the only difference being that participants observed a same-length tool during RTI (see Figure 1). Through this control experiment, we aimed to show that observing a longer tool in synchronous RTI was sufficient to produce the elongation effect. To substantiate this aim, we planned to compare the condition where participants used a short tool during the tool-use task and observed a long tool during synchronous RTI in Experiment 1 with a condition where participants used a short tool during the tool-use task and observed a short tool during synchronous RTI in Experiment 2.

3.1. Methods

3.1.1. Participants

Twenty-four right-handed participants (11 females, mean age 21.29, ranging between 19 and 27) participated in Experiment 2. All participants had normal or corrected vision, reported no injury or neurological disorder, were naïve to the purpose of the study, and gave informed consent. Participants were recruited through the psychology department's student recruitment system and compensated with course credits. The study was approved by the university ethics committee and conducted according to the guidelines of the Declaration of Helsinki.

3.1.2. Experimental Design

Similarly to Experiment 1, a 2 x 2 mixed design was employed. *Tool length of participant* (long or short) was the within-subjects factor, while *RTI synchronicity* (synchronous or asynchronous) was the between-subjects factor. The only difference from Experiment 1 was that during RTI, participants grasped and observed tools of the same length. Overall, there were four different conditions in Experiment 2: (i) using long tool and observing long tool during synchronous RTI; (ii) using long tool and observing long tool during asynchronous RTI; (iii) using short tool and observing short tool during synchronous RTI; and (iv) using short tool and observing short tool during asynchronous RTI.

3.1.3. Tasks and Procedure

All tasks and procedures were identical to those in Experiment 1, except for the RTI task where participants observed a tool that had the same length as the one they grasped during the illusion in Experiment 2.

3.1.4. Data Analysis

All analyses in Experiment 1 were repeated for the results of Experiment 2, with an added mixed ANOVA on the pooled data of Experiments 1 and 2 to compare the forearm bisection results pre- and post-RTI.

3.2. Results and Discussion

3.2.1. Forearm Bisection pre-post Tool-use

A two-way within-subjects ANOVA was conducted on the first two forearm bisection results with *tool length of participant* (short or long) and *bisection* (pre-tool-use or post-tool-use) as within-subjects variables. There was no significant main effect of tool length, $F(1, 23) = .91$, $p > .35$, $\eta_p^2 = .038$. However, there was a main effect of bisection, $F(1, 23) = 8.98$, $p = .006$, $\eta_p^2 = .28$, as participants reported the midpoint of their forearm more distally post-tool-use ($M = 47.07$, $SD = 1.51$) compared to pre-tool-use ($M = 49.16$, $SD = 1.28$). Moreover, there was a significant interaction effect, $F(1, 23) = 7.28$, $p = .013$, $\eta_p^2 = .24$, with a planned comparison revealing that the participants reported the midpoint of their forearm more distally post-tool-use ($M = 45.66$, $SD = 1.58$) compared to pre-tool-use ($M = 49.47$, $SD = 1.53$) in the long tool condition, $p = .002$ (see Figure 3). The same comparison was not significant for the short tool condition, $p > .66$.

We have replicated the elongation effect with the long tool as in Experiment 1. Unexpectedly, there was a significant difference between pre- and post-tool-use bisection measurements regardless of tool length. This effect is best explained by the variation in short tool conditions between Experiments 1 and 2. There was a nonsignificant contraction effect for the short tool in Experiment 1, which resulted in no main effect of bisection. On the other hand, a nonsignificant elongation effect for the short tool (along with a large elongation effect for the long tool) in Experiment 2 resulted in a significant difference between pre- and post-tool-use bisection measurements.

3.2.2. Proprioceptive Drift

A mixed two-way ANOVA was conducted on proprioceptive drift results with *RTI synchronicity* (asynchronous or synchronous) as the between-subjects variable and *tool length of participant* (short or long) as the within-subjects variable. There was a significant main effect of the RTI synchronicity, $F(1, 22) = 16.14$, $p = .001$, $\eta_p^2 = .42$ (see Figure 4), with the participants that experienced synchronous RTI ($M = 5.48$, $SD = .67$) reporting more drift than those that experienced asynchronous RTI ($M = 1.67$, $SD = .67$). On the other hand, there was no significant main effect of tool length, $F(1, 22) = 2.07$, $p > .16$, $\eta_p^2 = .086$. The interaction between RTI synchronicity and tool length was also not significant, $F(1, 22) = 3.42$, $p = .078$, $\eta_p^2 = .135$. Additionally, a Pearson correlation coefficient was computed to assess the linear relationship between proprioceptive drift and change in forearm length pre- and post-tool-use in the "long tool & synchronous" condition. There was a negative non-significant correlation, $r(12) = -.24$, $p > .45$.

We have also replicated the implicit embodiment of the rubber hand and the tool it grasped as in the synchronous RTI condition of Experiment 1. On the other hand, we did not find a main effect of tool length on the drift measurements in Experiment 2. While asynchronous conditions showed a larger drift for the long tool, the amount of drift was comparable in synchronous conditions. Contrary to the findings in Experiment 1, an extension of forearm length prior to RTI did not eventuate in a larger proprioceptive drift in Experiment 2, while there was, again, no correlation between the two measures. Thus, the main effect of tool length in Experiment 1 was attributed to the attenuation of illusion strength as participants observed different-length tools during RTI.

3.2.3. Subjective Experience Questionnaire

A mixed three-way ANOVA was conducted on the mean ratings of questionnaire components with *RTI synchronicity* (asynchronous or synchronous) as the between-subjects variable, and *tool length of participant* (short or long) and *components* (embodiment, loss of hand, movement, affect or deafference) as within-subjects variables. There was a significant main effect of RTI synchronicity, $F(1, 22) = 5.00$, $p = .036$, $\eta_p^2 = .19$, as the participants that experienced synchronous RTI ($M = .80$, $SD = .24$) rated questionnaire statements more positively than those that experienced asynchronous RTI ($M = .055$, $SD = .24$). There was no significant main effect of tool length, $F(1, 22) = .004$, $p > .94$, $\eta_p^2 < .001$. However, there was a significant main effect of components $F(4, 88) = 20.68$, $p < .001$, $\eta_p^2 = .49$. The interaction between RTI synchronicity and components was significant, $F(4, 88) = 3.30$, $p = .014$, $\eta_p^2 = .13$, and a planned comparison revealed a significant effect for the embodiment component between the synchronous ($M = 1.48$, $SD = .34$) and asynchronous ($M = -.47$, $SD = .34$) conditions, $p < .001$ (see Figure 5). The interaction between tool length and components was also significant, $F(4, 88) = 3.38$, $p = .013$, $\eta_p^2 = .13$, as Bonferroni-adjusted post-hoc tests revealed a significant difference only in the affect component between the short tool ($M = 2.04$, $SD = .17$) and long tool ($M =$

1.49, *SD* = .23) conditions, $p = .001$. On the other hand, the interaction between tool length and RTI synchronicity was not significant, $F(1, 22) = .002$, $p > .96$, $\eta_p^2 < .001$. The three-way interaction was also not significant, $F(4, 88) = .66$, $p = .62$, $\eta_p^2 = .029$. Additionally, a Pearson correlation coefficient was computed to assess the linear relationship between proprioceptive drift and embodiment. There was a positive significant correlation, $r(48) = .51$, $p < .001$.

Paralleling the proprioceptive drift results, we have replicated the explicit embodiment of the rubber hand and the tool it grasped as in the synchronous RTI condition of Experiment 1. Additionally, there was a main effect of RTI synchronicity in Experiment 2 in contrast with Experiment 1, mainly due to the stronger effect in the embodiment component. As the incongruence of grasped and observed tool length was resolved in Experiment 2, participants rated the statements more positively overall, resulting in a larger effect in the synchronous condition compared to Experiment 1. The stronger positive correlation between the drift and embodiment ratings compared to Experiment 1 also complemented this effect. The interaction effect between tool length and components was most likely a false positive brought about by the winsorization of outliers in the "short tool & affect" groups, as revealed by the post-hoc tests.

3.2.4. Forearm Bisection pre-post RTI

A mixed two-way ANOVA was conducted on the change in forearm length after RTI with *RTI synchronicity* (asynchronous or synchronous) as the between-subjects variable and *tool length of participant* (short or long) as the within-subjects variable. There was no significant main effect of RTI synchronicity, $F(1, 22) = 1.68$, $p > .20$, $\eta_p^2 = .071$, and tool length, $F(1, 22) = .60$, $p > .44$, $\eta_p^2 = .026$, and no significant interaction between RTI synchronicity and tool length, $F(1, 22) = .98$, $p > .33$, $\eta_p^2 = .043$ (see Figure 6). A planned comparison did not result in a significant difference between the synchronous ($M = -5.52$, $SD = 3.05$) and asynchronous ($M = -$

6.33, *SD* = 3.05) conditions with the short tool, $p > .85$. The same comparison for the long tool condition was also not significant, $p > .10$. Additionally, a Pearson correlation coefficient was computed to assess the linear relationship between proprioceptive drift and change in forearm length pre- and post-RTI in the "short tool & synchronous" condition. There was a negative non-significant correlation, $r(12) = -.19$, $p > .55$.

These results revealed that the general trend towards forearm contraction observed in Experiment 1 was not due to observing different-length tools during RTI, as a similar effect was replicated here. Since there was no correlation between the proprioceptive drift results and the change in forearm length pre-and post-RTI, this effect could not be explained through the strength of the illusion either. Another possible explanation might be the difference in proprioceptive information concerning the position of the forearm midpoint between the tool-use task and RTI. In the tool-use task, the forearm midpoint of participants was often displaced distally as they extended their elbows to place or recollect the cubes. During the RTI, however, their forearm midpoint was always located proximally, as they placed their hand on the table and kept their elbow to their side. Contrasting the mean position of the forearm midpoint in the parasagittal axis between the two tasks, it could be the case that the forearm bisection task results might also reflect a moving average of recent forearm midpoint locations.

3.2.5. Forearm Bisection pre-post RTI on pooled (E1+E2) data

A mixed three-way ANOVA was conducted on the change in forearm length after RTI with pooled data of Experiments 1 and 2. *Tool length of participant* (short or long) was the within-subjects variable, while *RTI synchronicity* (asynchronous or synchronous) and *observed tool length* (same or different) were between-subjects variables. There was no significant main effect of RTI synchronicity, $F(1, 44) = 2.87$, $p = .097$, $\eta_p^2 = .061$, and observed tool length, F(1,

44) = .003, $p = .96$, $\eta_p^2 < .001$, and tool length, $F(1, 44) = 2.38$, $p = .13$, $\eta_p^2 = .051$. There was also no significant interaction between RTI synchronicity and tool length of participant, $F(1, 44) = .11$, $p > .74$, $\eta_p^2 = .002$, and between RTI synchronicity and observed tool length $F(1, 44) = .013$, $p > .90$, $\eta_p^2 < .001$. However, there was a significant interaction between grasped and observed tool length, $F(1, 44) = 7.44$, $p = .009$, $\eta_p^2 = .15$, as Bonferroni-adjusted post-hoc tests revealed a significant difference only between the conditions where participants grasped the short tool ($M = -.53$, $SD = 2.04$) or the long tool ($M = -8.79$, $SD = 2.27$) while observing different-length tools, $p = .004$. The three-way interaction between tool length of participant, observed tool length, and RTI synchronicity was not significant, $F(1, 44) = 3.41$, $p = .072$, $\eta_p^2 = .072$. However, a planned comparison revealed a significant difference between the conditions where the short-tool-grasping participants observed a long tool ($M = 3.71$, $SD = 2.89$) or a short tool ($M = -5.52$, $SD = 2.89$) during synchronous RTI, $p = .029$ (see Figure 6). The same comparison was not significant in synchronous long-tool-grasping conditions, $p = .070$, or in asynchronous short-tool-grasping conditions, $p > .70$.

These results indicated that the elongation effect observed in Experiment 1 resulted solely from observing a longer tool during synchronous RTI. Thus, we could conclude that we successfully modified motor responses through perceptual changes induced via RTI, confirming our third hypothesis. Additionally, a closer inspection of Figure 6 suggested that there might be a main effect of observing a long tool over a short one during RTI, regardless of the length of the tool grasped by the participants. While this effect was negligible in asynchronous conditions, it was amplified after synchronous RTI. However, due to our experiment's design, we could not investigate the possible significance of this effect, as the variable regarding the length of the observed tool changed both within and between subjects.

4. Experiment 3

A comparison of the first two experiments showed that after using a tool for a short period (~12 mins), it was possible to modify motor judgments of body metrics (of body schema) by observing a longer tool during RTI. Observing such an effect through RTI prompted us to investigate if prior tool use was a necessary condition to enable modification of motor responses via the perceptual induction of RTI. Previous works have shown that imagining an action with a tool is sufficient to increase corticospinal facilitation for relevant muscles (Fourkas et al., 2008) or integrate the tool into the body representation (Baccarini et al., 2014). Thus, we decided to modify the tool-use task into a tool-hold task, where participants conducted the task with their left hand while merely holding the tool in their right hand. Following the tool-hold task, all participants experienced synchronous RTI, where they observed a tool with either the same or different length (see Figure 1). As a result, since we did not instruct participants to actively imagine completing the task with the tool, we did not expect to see any effect of tool-use or RTI manipulations, unlike the results of previous experiments.

4.1. Methods

4.1.1. Participants

Twenty-four right-handed participants (18 females, mean age 20.50, ranging between 19 and 27) participated in Experiment 3. All participants had normal or corrected vision, reported no injury or neurological disorder, were naïve to the purpose of the study, and gave informed consent. Participants were recruited through the psychology department's student recruitment system and compensated with course credits. The study was approved by the university ethics committee and conducted according to the guidelines of the Declaration of Helsinki.

4.1.2. Experimental Design

Although this experiment also employed a 2 x 2 mixed design with *tool length of participant* (long or short) as the within-subjects factor, unlike previous experiments, the between-subjects factor was *observed tool identity* (same or different) during RTI. Another difference from earlier experiments was that all participants experienced synchronous RTI. Overall, there were four different conditions in Experiment 3: (i) holding long tool and observing long tool during synchronous RTI; (ii) holding long tool and observing short tool during synchronous RTI; (iii) holding short tool and observing long tool during synchronous RTI; and (iv) holding short tool and observing short tool during synchronous RTI.

4.1.3. Tasks and Procedure

4.1.3.1. Tool-hold Task

In Experiment 3, participants performed a very similar task to those in the previous two experiments; however, this time they executed the movements with their left hand while merely holding the tool in their right hand. In this task, the furthest row of targets was placed at participants' maximum arm reach. To imitate the two-step procedure of previous experiments, but without using the tool, participants were instructed to grab the cube from the baskets using the left thumb and index finger (similar to the prongs of the tools), place it on the designated spot on the table, touch the spot with their left index finger, then pick the cube back up and place it on the target sheet. After placing all eighteen cubes on targets in this manner, participants followed the reverse procedure to return the cubes to the baskets. Throughout the task, participants grasped the tool similarly to previous experiments as the tool rested on the table (see Figure 7). While participants moved the cubes with their left hand, they were instructed to also close the tool's prongs as if they were grabbing the cube without actually moving the tool. This was done to replicate the fatigue effect in participants' tool-grasping right hand that occurred in previous experiments. The task ended when all four blocks were completed (following the same procedure as previous experiments), and participants were timed to account for any effect of task duration on the results.

Figure 7: A snapshot of the tool-hold task. In this instance, the participant holds the long tool while picking up or placing cubes on the random-target sheet with their left hand.

4.1.3.2. Rubber Tool Illusion

In Experiment 3, contrary to previous experiments, there was no asynchronous stimulus condition. Both groups experienced synchronous RTI; however, while one group saw a same-length tool grasped by the rubber hand, the other group observed a different-length tool.

4.1.4. Data Analysis

Unlike Experiments 1 and 2, mixed ANOVA analyses on the proprioceptive drift, questionnaire, and forearm bisection results pre- and post-RTI were omitted in Experiment 3 since there was no asynchronous condition. Instead, three mixed ANOVAs were conducted on the pooled data of synchronous conditions in all three experiments to compare the questionnaire ratings, proprioceptive drift results, and forearm bisection results pre- and post-RTI.

4.2. Results and Discussion

4.2.1. Forearm Bisection pre-post Tool-use

A two-way within-subjects ANOVA was conducted on the first two forearm bisection results with *tool length of participant* (short or long) and *bisection* (pre-tool-hold or post-tool-hold) as within-subjects variables. There was no significant main effect of tool length, $F(1, 23) = .51$, $p > .48$, $\eta_p^2 = .022$, bisection, $F(1, 23) = 1.37$, $p > .25$, $\eta_p^2 = .056$, or interaction of tool length and bisection, $F(1, 23) = .33$, $p > 57$, $\eta_p^2 = .014$. A planned comparison showed no significant difference in the long tool condition between the post-tool-hold ($M = 48.89$, $SD = 2.04$) and the pre-tool-hold ($M = 50.59$, $SD = 1.59$), $p > .18$ (see Figure 3). The same comparison was non-significant for the short tool condition either, $p > .59$.

The tool-hold task did not result in an elongation effect in the long tool condition, contrary to Experiments 1 and 2. These results suggested that minor manipulations like asking participants to actively press on the lever to close the prongs of the tool while executing the task, to grab the cubes with their thumb and index finger (resembling the morphology of prongs), or placing and recollecting cubes to and from the maximum possible distance (as opposed to 10 cm more proximal targets in Experiments 1 and 2) were not sufficient to incur an effect akin to mental simulation of actions performed with a tool (Baccarini et al., 2014).

4.2.2. Proprioceptive Drift on Pooled (E1+E2+E3) Data

Since there was no asynchronous condition in Experiment 3, proprioceptive drift results were compared with the synchronous conditions of Experiments 1 and 2. A mixed three-way ANOVA was conducted on proprioceptive drift results with the pooled data of synchronous conditions of all experiments. *Observed tool identity* (same or different) and *tool task* (tool-use or tool-hold) were between-subjects variables, while *tool length of participant* (short or long) was the within-subjects variable. There was a significant main effect of tool length, $F(1, 44) = 4.53$, $p = .039$, $\eta_p^2 = .093$, with the participants that grasped the long tool ($M = 5.21$, $SD = .56$) reporting more drift than those that grasped the short tool ($M = 3.85$, $SD = .54$). However, there was no significant main effect of observed tool identity, $F(1, 44) = .91$, $p > .34$, $\eta_p^2 = .020$, and tool task, $F(1, 44) = 1.83$, $p > .18$, $\eta_p^2 = .040$. None of the two-way interactions were significant: tool length and observed tool identity, $F(1, 44) = 3.04$, $p = .088$, $\eta_p^2 = .065$; tool length and tool task, $F(1, 44) = .11$, $p > .73$, $\eta_p^2 = .003$; observed tool identity and tool task $F(1, 44) = .029$, $p > .86$, $\eta_p^2 = .001$. The three-way interaction was also non-significant, $F(1, 44) = .17$, $p > .68$, $\eta_p^2 = .004$, along with the non-significant planned comparison between the same-length tool ($M = 48.89$, $SD = 2.04$) and different-length tool ($M = 50.59$, $SD = 1.59$) conditions where participants grasped the short tool following tool-use, $p > .39$ (see Figure 4). The same comparison for the long tool condition following tool-use was also not significant, $p > .94$.

These results revealed that active tool-use prior to RTI did not affect the proprioceptive drift results. Additionally, planned comparisons showed that after tool-use, observing a longer or shorter tool during RTI did not change proprioceptive drift measurements either. So, we can conclude that the significant main effect of tool length was neither due to the observed tool length being different from the tool length of participant nor was it due to the elongation effect from prior tool-use. Additionally, the lack of interaction between the tool length of participant and the tool task means that this effect occurs independently of the motor embodiment of the tool acquired from active tool use. However, the absence of this effect in Experiment 2 suggests it is not robust.

4.2.3. Subjective Experience Questionnaire on Pooled (E1+E2+E3) Data

Since there was no asynchronous condition in Experiment 3, questionnaire ratings were compared with the synchronous conditions of Experiments 1 and 2. A mixed three-way ANOVA was conducted on questionnaire ratings with the pooled data of synchronous conditions of all experiments. *Observed tool identity* (same or different) and *tool task* (tool-use or tool-hold) were between-subjects variables, while *tool length of participant* (short or long) was the within-subjects variable. Since the only questionnaire component of interest was "embodiment" and the inclusion of other components violated the homogeneity of covariance assumption, they were excluded from the analysis. There was no significant main effect of tool length of participant, $F(1, 44) = .52$, $p > .47$, $\eta_p^2 = .012$, observed tool identity, $F(1, 44) = 2.69$, $p > .10$, $\eta_p^2 = .058$, and tool task, $F(1, 44) = .001$, $p > .98$, $\eta_p^2 < .001$. None of the two-way interactions were significant: tool length of participant and observed tool identity, $F(1, 44) = 1.44$, $p > .23$, $\eta_p^2 = .032$; tool length of participant and tool task, $F(1, 44) = .55$, $p > .46$, $\eta_p^2 = .012$; observed tool identity and tool task $F(1, 44) = .70$, $p > .40$, $\eta_p^2 = .016$. The three-way interaction was also non-significant, $F(1, 44) = 2.41$, $p > .12$, $\eta_p^2 = .052$, along with the non-significant planned comparison between the same-length tool ($M = 1.36$, $SD = .44$) and different-length tool ($M = .27$, $SD = .44$) conditions where participants grasped the short tool following tool-use, $p = .089$ (see Figure 5). The same comparison for the long tool condition following tool-use was also not significant, $p > .12$. In addition, a Pearson correlation coefficient was computed to assess the linear relationship between proprioceptive drift and the embodiment scores on the pooled data of all three experiments. There was a significant positive correlation, $r(144) = .40$, $p < .001$.

These results suggested that our tool-based manipulations did not affect the explicit measure of the illusion. The only factor differentiating the embodiment component ratings throughout these three experiments was synchronicity, which implies that questionnaire ratings are robust measures of the illusion. Moreover, as in previous analyses, embodiment ratings were positively correlated with proprioceptive drift measurements, further reinforcing the established relationship between these two measurements.

4.2.4. Forearm Bisection pre-post RTI on Pooled (E1+E2+E3) Data

Since there was no asynchronous condition in Experiment 3, forearm bisection results pre- and post-RTI were compared with the synchronous conditions of Experiments 1 and 2. A mixed three-way ANOVA was conducted on the change in forearm length after RTI with pooled data of synchronous conditions of all experiments. *Observed tool identity* (same or different) and *tool task* (tool-use or tool-hold) were between-subjects variables, while *tool length of participant* (short or long) was the within-subjects variable. There was no significant main effect of tool task, $F(1, 44) = .66$, $p > .42$, $\eta_p^2 = .015$, observed tool identity, $F(1, 44) = .058$, $p > .81$, $\eta_p^2 = .001$, or tool length of participant, $F(1, 44) = 3.14$, $p = .083$, $\eta_p^2 = .067$. There was also no significant interaction between tool task and tool length of participant, $F(1, 44) = .074$, $p > .78$, $\eta_p^2 = .002$, and between tool task and observed tool identity $F(1, 44) = .008$, $p > .92$, $\eta_p^2 < .001$. However, there was a significant interaction between tool length of participant and observed tool identity, $F(1, 44) = 5.41$, $p = .025$, $\eta_p^2 = .11$, as Bonferroni-adjusted post-hoc tests revealed a significant difference only between the conditions where participants grasped the short tool ($M = .18$, $SD = 2.29$) or the long tool ($M = -7.08$, $SD = 2.14$) while observing different-length tools, $p = .006$. Most importantly, the three-way interaction between tool length of participant, observed tool identity and tool task was significant, $F(1, 44) = 7.06$, $p = .011$, $\eta_p^2 = .138$; and a planned comparison revealed a significant effect between the conditions where the short-tool-grasping participants observed a different tool ($M = 3.71$, $SD = 3.24$) or the same tool ($M = -5.52$, $SD =$

3.24) following tool-use, $p = .001$ (see Figure 6). The same comparison for the tool-hold condition was not significant, $p > .56$.

These results indicated that prior active tool-use moderates the elongation effect that occurred while observing a longer tool during RTI. The three-way interaction shows that tool-use moderates the significant interaction between grasped and observed tool length. Thus, confirming our fourth hypothesis, we could conclude that modification of motor responses through perceptual changes induced via RTI depended on prior embodiment of the tool through active use.

Lastly, the general contraction effect continued in this experiment as well. Since the position and immobility of the forearm in the tool-hold task were very similar to that of RTI, this effect could not be explained with the forearm bisection task reflecting a moving average of the forearm midpoint position. In the end, we were unable to empirically reveal the underlying factor that resulted in the forearm contraction effect after RTI.

5. General Discussion

Investigations of tool-use and RHI paradigms in the last twenty-five years have produced abundant information on how the brain represents the body for action and perception, respectively. However, there has been a substantial disconnect in the field due to the lack of experimental work on the interaction of these paradigms. This study aimed to bridge the gap between the two bodies of literature by comparing the effect of these paradigms on body representation in a single experimental setup.

Initially, the experimental design was validated by replicating the classical effects of tool-use and RHI in the literature. Using the long tool resulted in elongation of the forearm in motor measures, while synchronous RTI resulted in an embodiment of and drift towards the tool-grasping rubber hand in perceptual measures. Thus, the experimental basis for the intended comparison was established.

Next, the influence of tool-use on RHI was investigated to discover how motor changes modified body image. Interestingly, tool-related factors did not influence RTI measures in any meaningful way. There was a slight tendency for increased proprioceptive drift while participants grasped a longer tool; however, this effect was inconsistent across experiments. These results concur with the previous findings that imply a weak effect: Weser et al. (2017) found that prior tool-use increased the proprioceptive drift, while Cardinali et al. (2021) did not. An important distinction between these results is that we compared the tool-use task to the tool-hold task in our experiment, while other works evaluated perceptual measures in the presence or absence of the task prior to RHI. Thus, our design constituted a more appropriate control condition. Altogether, the culmination of our results and previous findings indicate that as long as the tool has morpho-functional similarity to limbs, it is readily integrated into the body representation without the need for motor reinforcement. Preceding active use does not modify this "perceptual" embodiment, and this embodiment is strong enough to endure an incongruence in the length of the grasped and observed tools during the rubber tool illusion.

Most importantly, we inspected the influence of perceptual judgments on motor responses by examining how manipulation of observed tool's length during RTI changed the representational length of the forearm. After the short tool was embodied in the motor processing via active tool-use, observing a longer tool during synchronous RTI increased the motor representation of forearm length. Crucially, this effect was absent if the tool was not actively used prior to RTI or not embodied perceptually due to asynchronous stimulation. This finding was novel and notable for several reasons.

Foremost, this study was the first (to our knowledge) to investigate how motor measures of body part size were affected by tactually induced RHI. Previous studies that reported an effect on motor representation after tactile induction had measured changes in limb location (Riemer et al., 2013; Kalckert & Ehrsson, 2014). However, measurements that reflect a change in limb size have been one of the most common methods of studying motor responses in the tool-use paradigm and hence are more insightful for incorporating the findings of these literatures. Additionally, the neural mechanisms that process size information of body parts are most likely distinct from those that process location (Ehrsson et al., 2005; Blanke, 2012).

Furthermore, the experimental design of this study enabled the first empirical comparison of bodily judgments in perceptual and motor changes, i.e. body image and body schema, through the combined procedure of tool-use and RHI paradigms. While this design provides a novel framework for studying the interaction of body image and body schema, it also allows further inspection of factors that modify this interaction as a flexible experimental framework. We were able to control for the effects of fatigue and task duration (see Supplementary Material), but future studies might systematically introduce these factors into a modified experimental design to reveal novel factors that affect these representations and their relation.

Lastly, the proprioceptive drift results and questionnaire ratings were correlated, whereas proprioceptive drift and forearm bisection results were not. This finding further strengthens the theoretical attribution of these measures to different processes of bodily information.

5.1. Body Schema and Body Image

Considering the century-old distinction between a visual "image" and a postural "schema" of the body (Head & Holmes, 1911), it is imperative to also discuss the findings of the study in this context. Pitron and de Vignemont (2017) proposed a model to account for the interaction between body schema and body image. They argued that rather than a fusion model where a single representation encodes all bodily properties, or an independence model where body image and body schema work separately, the model best fitting to available evidence is a co-construction model, where body image and body schema can interact and modify each other. In a later article, they further specified this co-construction model into a serial model, where body schema has primacy over body image, as predicated by developmental, neuropsychological, and behavioral evidence (Pitron et al., 2018). Concurrently, they stated the need for empirical investigations of the interaction between these representations. A similar call had also been made by Martel et al. (2016), as they invited researchers to conduct a systematic examination of body representations via the tool-use paradigm.

The findings in this study are compatible with the serial model proposed by Pitron et al. (2018). The method of forearm bisection taps into the motor representation of body schema, while perceptual judgments of proprioceptive drift and subjective experience questionnaire are commonly regarded in the literature as components of body image. Thus, we argue that the results of forearm bisection measurements before and after tool tasks demonstrate that the tools were integrated into the body schema only after tool-use, but not in the case of tool-hold. On the other hand, we interpret the results of proprioceptive drift and questionnaire in Experiment 3 as the successful integration of the tools into body image since there was no effect of tool task on either perceptual measure, and the results were comparable to the synchronous conditions of earlier experiments. In Experiment 3, this integration of the tools into the body image did not occur through body schema, but through the congruence of visual and tactual signals and the prior knowledge of how tactual stimuli are transmitted over the grasped tools. Most importantly, when participants used a short tool and observed a long tool during synchronous RTI, the elongation of forearm length that occurred in body image modified the representation of forearm length in body schema, as reflected in the forearm bisection measurements. Thus, these findings empirically confirm that the relationship between body schema and body image is not unidirectional, but reciprocal.

5.2. Limitations

While we were able to assess and confirm our hypotheses through these experiments, there were nonetheless certain limitations of our setup. We could not investigate the main effect of observed tool length during RTI. Rather, we could only glimpse at this effect through the interactions of ANOVAs. This limitation was due to the design of our experiments, as we determined the congruence of the observed tool length to the tool length of participants (either same- or different-length) to be a between-subjects factor in the experiments instead. Thus, the length of the rubber hand's tool changed both within-subjects and between-subjects. Future experiments where the between-subjects factor is the length of the observed tool rather than the congruence of it to the grasped tool would constitute the required design to investigate such an effect and fill the remaining gap.

Also, we observed an effect of perceived forearm contraction that repeatedly surfaced across all three experiments, except for the condition where the participants used a short tool and observed a long tool during synchronous RTI, which was the only condition that resulted in an elongation effect. We could not attribute this contraction effect to the decay in the prior elongation effect from tool-use since the short tool conditions also displayed a comparable contraction. Another potential explanation was that the forearm bisection task reflected a rolling average of the forearm midpoint position. However, since the effect persisted in Experiment 3 even though the position of the tool-grasping forearm was very similar in the tool-hold task and RTI, this explanation was also disregarded. Since, to our knowledge, no other work in the literature employed the forearm bisection task prior to and following RTI, we were not able to contrast this contraction effect with another study. While we could not empirically reveal the cause of this effect, we argue that the illusion experience might be responsible for it. However, such an explanation would require all conditions to reflect such a contraction effect. We contend that this was in fact the case, but when participants observed a long tool during the illusion after tool-use, an elongation effect overrode the contraction effect for the short-tool-graspers and a similar process resulted in a null effect for the long-tool-graspers.

6. Conclusion

All in all, our results support the theoretical approach that motor and perceptual body representations–body schema and body image–can reciprocally affect each other. In three experiments, we were able to display that a change in the visuotactile information regarding the length of a tool could modify a pointing response regarding the length of the forearm. Most importantly, we demonstrated that this effect was unidirectional, only allowing an extension of the forearm length, and depended on prior tool-use and embodiment of the observed hand and tool. We hope this work provides a valuable framework for future studies to further illuminate the relationship between motor and perceptual systems of bodily information, which would, in turn, help consolidate decades of disconnected findings in tool-use and RHI paradigms under a coherent theory of body representation.

7. Declaration of Interest

The authors declare no competing interests.

8. Author Contributions

Author 1: Conceptualization, Methodology, Resources, Investigation, Data curation, Project administration, Supervision, Software, Formal analysis, Visualization, Writing - original draft, Writing - review & editing. ***Author 2*****:** Conceptualization, Methodology, Funding acquisition, Resources, Supervision, Writing - review & editing. ***Author 3*****:** Conceptualization, Methodology, Writing - review & editing. ***Author 4*****:** Conceptualization, Methodology, Resources, Project administration, Supervision, Formal analysis, Writing - review & editing.

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Supplementary Material

1. Additional Analyses

1.1. Pain Scores

1.1.1. Experiment 1

It was important to establish that the amount of pain resulting from tool-use did not affect the results differently for the short and long tool conditions. To control this, a Wilcoxon signed-rank test was conducted to compare the pain scores according to tool length of participants since the distribution of the difference scores was symmetrical but non-normal. There was no significant difference between the short ($M = 5.58$, $SD = 2.64$) and long ($M = 5.33$, $SD = 2.73$) tool conditions; $T = 124.00$, $p > .93$, $r = -.017$. This result suggested that the amount of pain/numbness/tingling caused by the short and long tools was not different in Experiment 1.

1.1.2. Experiment 2

Due to the symmetric but non-normal distribution of the difference score, a Wilcoxon signed-rank test was conducted to compare the pain scores according to tool length of participants. There was no significant difference between short ($M = 5.46$, $SD = 2.28$) and long ($M = 5.88$, $SD = 2.29$) tool conditions; $T = 93.00$, $p > .18$, $r = .27$. This result indicated that the amount of pain/numbness/tingling caused by the short and long tools was not different in Experiment 2.

1.1.3. Experiment 3

Due to the symmetric but non-normal distribution of the difference score, a Wilcoxon signed-rank test was conducted to compare the pain scores according to tool length of participants. There was no significant difference between short ($M = 4.63$, $SD = 3.20$) and long ($M = 4.54$, $SD = 3.22$) tool conditions; $T = 65.50$, $p > .75$, $r = .065$. This result revealed that the amount of pain/numbness/tingling caused by the short and long tools was not different in Experiment 3.

1.1.4. Tool-use vs. Tool-hold

Additionally, we intended to establish that the amount of pain resulting from the tool-hold task is not different from that of the tool-use task. A Mann-Whitney U test was conducted to compare the pain scores according to the tool task since the distributions were non-normal. There was no significant difference between tool-hold (M = 4.58, SD = 3.18) and tool-use (M = 5.56, SD = 2.46) conditions; U = 2713.00, p = .080, r = .15. This result implied that the amount of pain/numbness/tingling caused by the tool-hold and the tool-use tasks was not different.

1.2. Task Duration

1.2.1. Experiment 1

Another factor that might have played a role in the results was the duration of the tool-use task. The task ended when the participants completed all four blocks; thus, the task duration varied among the participants. A within-subjects t-test was conducted to compare tool task duration according to the tool length of participants. There was a significant difference between the short (M = 729.46, SD = 95.78) and the long (M = 794.25, SD = 133.74) tool conditions; $t(23)$ = -2.66, p = .014, d = -.54. This result indicated that the time participants actively used the tool was significantly longer in the long tool condition of Experiment 1. Thus, to ensure that the effects we found did not originate from this discrepancy, we bisected the participants according to their tool task duration for both the short and the long tool and checked the effect of tool task duration on all relevant results.

1.2.1.1. Forearm bisection pre/post tool task with long tool

In order to see whether the change in forearm length after the tool task with the long tool differed significantly between the shorter-duration ($M = 8.60$, $SD = 14.63$) and the longer-duration ($M = 8.74$, $SD = 23.41$) groups, a between-subjects t-test was conducted. The result suggested no significant effect of tool task duration on the change in forearm length after the tool task in the long tool condition, $t(22) = .60$, $p > .56$, $d = .24$.

1.2.1.2. Proprioceptive Drift

In order to see whether proprioceptive drift differed significantly between the shorter-duration ($M = 3.56$, $SD = 3.26$) and the longer-duration ($M = 2.79$, $SD = 3.76$) groups, a between-subjects t-test was conducted. The result indicated no significant effect of tool task duration on proprioceptive drift, $t(46) = .75$, $p > .46$, $d = .22$.

1.2.1.3. Forearm bisection pre-post RTI with short tool

In order to see whether the change in forearm length after RTI in the (grasped) short tool condition differed significantly between the shorter-duration ($M = 2.21$, $SD = 8.16$) and the longer-duration ($M = -3.27$, $SD = 11.52$) groups, a between-subjects t-test was conducted. The result revealed no significant effect of tool task duration on the change in forearm length after RTI in the short tool condition, $t(22) = 1.35$, $p > .19$, $d = .55$.

After conducting these analyses, we see that none of the results were significant, all ps > .19. Thus, we concluded that the difference in tool-use duration among participants did not affect our results.

1.2.2. Experiment 2

A within-subjects t-test was conducted to compare tool task duration according to tool length of participants. There was a significant difference between the short ($M = 689.29$, $SD =$

117.04) and the long (M = 782.46, SD = 121.70) tool conditions; $t(23) = -4.00$, $p = .001$, $d = -.82$. This result indicated that the time participants actively used the tool was also longer in the long tool condition of Experiment 2. Thus, to ensure that the effects we found did not originate from this discrepancy, we once again bisected the participants according to their tool task duration for both the short and the long tool and checked the effect of tool task duration on all relevant results.

1.2.2.1. Forearm bisection pre/post tool task with long tool

In order to see whether the change in forearm length after the tool task with the long tool differed significantly between the shorter-duration (M = 7.40, SD = 11.91) and the longer-duration (M = 7.84, SD = 9.09) groups, a between-subjects t-test was conducted. The result suggested no significant effect of tool task duration on the change in forearm length after the tool task in the long tool condition, $t(22) = -.10$, $p > .91$, $d = -.042$.

1.2.2.2. Proprioceptive Drift

In order to see whether proprioceptive drift differed significantly between the shorter-duration (M = 3.00, SD = 3.33) and the longer-duration (M = 4.37, SD = 2.80) groups, a between-subjects t-test was conducted. The result revealed there was no significant effect of tool task duration on the proprioceptive drift, $t(46) = -1.54$, $p > .13$, $d = -.44$.

After conducting these analyses, we see that none of the results were significant, all ps > .13. As a result, we concluded that the difference in tool-use duration among participants did not affect the results.

1.2.3. Experiment 3

Due to the non-normal but symmetric distribution of the difference score, a Wilcoxon signed-rank test was conducted to compare the tool task duration according to the tool length of participants. There was no significant difference between the short (*M* = 760.00, *SD* = 148.65) and the long (*M* = 753.88, *SD* = 146.93) tool conditions; *T* = 144.50, *p* > .87, *r* = -.032. This result indicated that the time participants actively used the tool with the short and long tools was not different in Experiment 3.

1.2.4. Tool-use vs Tool-hold

It was also important to ascertain that the duration of the tool-hold task is not different from that of the tool-use task. In order to see whether task duration differed significantly between the tool-hold (*M* = 3.00, *SD* = 3.33) and the tool-use (*M* = 4.37, *SD* = 2.80) conditions, a between-subjects t-test was conducted. The result suggested no significant effect of task type on duration, $t(142) = .30$, $p > .76$, $d = .052$. Thus, we concluded that the time it took to complete the tool-hold and the tool-use tasks were comparable.

2. Questionnaire

English translation of the questionnaire (original in *Anonymized Language*):

Rubber Tool Illusion Questionnaire

For the statements below, -3 means "completely disagree," +3 means "completely agree," and 0 means "do not agree or disagree." Please rate the statements below according to your most recent experience of the illusion on a scale from -3 to +3.

	-3	-2	-1	0	+1	+2	+3
1) It seemed like I was watching my own hand grasping the tool, not the rubber hand.	☐	☐	☐	☐	☐	☐	☐
2) It seemed like the tool I grasped was in the position of the tool grasped by the rubber hand.	☐	☐	☐	☐	☐	☐	☐

3) It seemed like the rubber hand grasping the tool was moving towards my own hand.	☐	☐	☐	☐	☐	☐	☐
4) It seemed like the rubber hand grasping the tool was my own hand.	☐	☐	☐	☐	☐	☐	☐
5) It seemed like I had three hands.	☐	☐	☐	☐	☐	☐	☐
6) It seemed like the rubber hand grasping the tool was a part of my body.	☐	☐	☐	☐	☐	☐	☐
7) I had a tingling sensation in my own hand.	☐	☐	☐	☐	☐	☐	☐
8) It seemed like the rubber hand grasping the tool was in the position of my own hand.	☐	☐	☐	☐	☐	☐	☐
9) It seemed like the rubber hand grasping the tool belonged to me.	☐	☐	☐	☐	☐	☐	☐
10) I found this experience interesting.	☐	☐	☐	☐	☐	☐	☐
11) It seemed like I could move the tool grasped by the rubber hand if I wanted to.	☐	☐	☐	☐	☐	☐	☐
12) It seemed like my own hand became rubbery.	☐	☐	☐	☐	☐	☐	☐
13) It seemed like I could not move the tool I grasped.	☐	☐	☐	☐	☐	☐	☐
14) It seemed like my own hand disappeared.	☐	☐	☐	☐	☐	☐	☐
15) The touch of the brush on the tool I grasped was pleasant.	☐	☐	☐	☐	☐	☐	☐
16) It seemed like my own hand was out of my control.	☐	☐	☐	☐	☐	☐	☐
17) I found this experience enjoyable.	☐	☐	☐	☐	☐	☐	☐

18) It seemed like I could move the tool I grasped if I wanted to.	☐	☐	☐	☐	☐	☐	☐
19) It seemed like my hand was moving towards the rubber hand grasping the tool.	☐	☐	☐	☐	☐	☐	☐
20) It seemed like the tool grasped by the rubber hand was in my control.	☐	☐	☐	☐	☐	☐	☐
21) It seemed like I could not really tell where my own hand was.	☐	☐	☐	☐	☐	☐	☐
22) It seemed like the experience of my hands was less vivid than normal.	☐	☐	☐	☐	☐	☐	☐
23) I had a sensation that my hand was numb.	☐	☐	☐	☐	☐	☐	☐
24) It seemed like the touch I felt was caused by the brush touching the tool grasped by the rubber hand.	☐	☐	☐	☐	☐	☐	☐
25) It seemed like the rubber hand started to resemble my own hand.	☐	☐	☐	☐	☐	☐	☐

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