INTERACTIONS OF BODY REPRESENTATIONS

IN RUBBER HAND ILLUSION AND TOOL-USE PARADIGMS

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INTERACTIONS OF BODY REPRESENTATIONS IN RUBBER HAND ILLUSION AND TOOL-USE PARADIGMS

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DECLARATION OF ORIGINALITY

I, Mahmut Alp Erkent, certify that

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- this thesis contains no material that has been submitted or accepted for a degree or diploma in any other educational institution;
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ABSTRACT

Interactions of Body Representations

in Rubber Hand Illusion and Tool-use Paradigms

In neuropsychological literature, numerous case studies suggest two separate body representations in the brain; one for perception, called the *body image*, and one for action, called the *body schema*. *Rubber hand illusion* and *tool-use* paradigms have been used frequently to investigate these body representations, respectively. Although these experimental paradigms are thought to affect different body representations, interactions between them are inevitable, considering the common sensory modalities targeted by the techniques used for measuring their effects. Still, there has been minimal overlap between these related fields of study. In this thesis, we combined these paradigms in a novel experimental setup and comparatively examined the resulting changes in body representations. Specifically, after a tool-use task where subjects actively used a grabber tool with their right hand to move cubes close to or away from their body, we observed an increase in the metric representation of the right forearm length depending on the length of the tool used. Subsequently, the "tool-holding" rubber hand illusion also increased the forearm length representation if the subject saw a longer tool held by the rubber hand. Follow-up experiments showed that this effect in rubber hand illusion depends on prior active use of the tool, embodiment of the observed hand and tool, and a length disparity between the held and observed tools during RHI. Overall, these results reveal for the first time that the representation of forearm length, a component of body schema, can be modified through changes in body image.

ÖZET

Alet Kullanımının ve Plastik El İllüzyonunun

Dayandığı Beden Temsillerinin Karşılıklı İlişkileri

Nöropsikoloji literatüründeki birçok vaka çalışması beyinde iki ayrı beden temsili bulunduğuna işaret etmektedir: algı için *beden algısı*, eylem için ise *beden şeması*. *Plastik el illüzyonu* ve *alet kullanımı* paradigmaları, bu beden temsillerini (bu sırayla) incelemek için sıklıkla kullanılmış, fakat birbirlerinden bağımsız bir şekilde süregelen iki farklı literatür oluşturmuştur. Her ne kadar bu iki deney paradigmasının farklı beden temsillerini etkilediği kabul edilse de ölçümleme tekniklerinin hedeflediği duyu modaliteleri göz önünde bulundurulduğunda, bu paradigmaların birbirleriyle etkileşimleri kaçınılmazdır. Bu tezde, alet kullanımı ve plastik el illüzyonu paradigmalarını özgün bir deney kurgusu ile birleştirerek beden temsillerinde sebep oldukları değişimleri karşılaştırmalı olarak incelenmiştir. Özellikle, katılımcıların sağ elleriyle kıskaçlı bir alet kullanarak çeşitli küpleri yakına veya uzağa taşıdıkları bir alet kullanımı prosedüründen sonra, kullandıkları aletin uzunluğuna bağlı olarak sağ ön kol uzunluğunun metrik temsilinde bir artış gözlemlenmiştir. Akabinde, "alet tutan" plastik el illüzyonu prosedürü sırasında plastik elin daha uzun bir aleti tuttuğunu gözlemlemek yine ön kol uzunluğunun temsilinde bir artışa sebep olmuştur. Kontrol deneyleri ise bu etkinin, illüzyon öncesinde aletin aktif olarak kullanılmış olmasına, illüzyon sırasında gözlemlenen aletin ve kolun sahiplenilmesine ve gözlemlenen aletle tutulan aletin uzunluklarının farklı olmasına bağlı olduğunu göstermiştir. Bu çalışma sonucunda, beden şemasının bir parçası olan ön kol uzunluğu temsilinin beden algısı aracılığı ile değiştirilebileceği açığa çıkarılmıştır.

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To my loving wife, Beril

and my adorable little pal, Luna

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BI	Body Image
BS	Body Schema
cm	Centimeters
g	Grams
PPS	Peripersonal Space
RHI	Rubber Hand Illusion
VAS	Visual Analogue Scale

CHAPTER 1

INTRODUCTION

Voluntary action requires neural models of the self and the environment. As we grow up, our brains gradually learn how to actuate our limbs to move around and how to manipulate objects with these limbs to maintain our survival. When we move, our brains also observe how our immediate surroundings change through our actions by integrating the information from different sensory modalities. The match between the proprioceptive and visual information from a moving arm generates a sense of ownership over the arm. Meanwhile, when our intention to reach with our arm matches the sensory information as we execute the reaching movement, we experience a sense of agency over the arm. The senses of ownership and agency have been argued to comprise the fundamental aspects of our self-experience, defining the boundary between the self and the environment (Gallagher, 2000).

For the last twenty-five years, the extent of this boundary has been thoroughly investigated, albeit with two distinct approaches. One experimental practice has focused on the sense of agency and examined how our actions, judgments, and neural processes change as we extend the proficient control of our limbs to a tool and manipulate the environment with it. A separate tradition has instead opted to influence the sense of ownership by creating conflicts in multisensory integration and inspecting the changes as we embody artificial hands. While the scientific approach and jargon differed between these two bodies of literature, what they studied was very similar: how does the brain represent the body? When we observe an artificial hand being stroked synchronously with our own unseen hand, or when we use tools to extend our reach, do these tools and artificial hands become a part of our bodies?

Over the last decade, although there has been some effort to conjoin these research programs theoretically, experimental attempts have been few and one-sided. This thesis aims to examine the changes in body representations in a novel experimental setup that combines the tool-use and rubber hand illusion (RHI) paradigms for a comparative study. Employing an RHI procedure that involves the same tool wielded in the preceding tool-use task, this thesis intends to bridge the gap between the research practices mentioned above by unveiling the interaction of these paradigms on perceptual judgments of limb size and location. Ultimately, this thesis aspires to reveal the empirical evidence of the sought-after link between the body representations investigated via these paradigms.

CHAPTER 2

LITERATURE REVIEW

In an attempt to summarize key findings in the literature that will clarify the aim of this thesis and provide the necessary background to evaluate its results, this section will first introduce the theoretical framework of the study of body representations. Then, it will systematically detail the experimental approaches utilized to investigate these representations. Finally, it will describe the gap in the literature that the thesis intends to fill and state the hypotheses of the thesis to conclude the section.

2.1 Body representations in the brain

At first consideration, it might not be so obvious why many scholars have theorized there to be more than one mental representation of the body. The first suggestion of a dichotomy in how we represent our bodies was recorded over a century ago when Head and Holmes (1911) documented the distinction between a visual "image" and a postural "schema" of the body from their observations on patients with cerebral lesions. Following the discovery of a cortical organization that reflects the functional processing of visual information (Ungerleider & Mishkin, 1982), scientists have proposed separate neural pathways for perception and action in visual (Goodale & Milner, 1992), and later on, somatosensory (Dijkerman & de Haan, 2007) processes. According to this view, "body image" (BI) is a stable representation responsible for perception and recognition, whereas "body schema" (BS) is a dynamic representation used for sensorimotor action (Gallagher, 2005). A thorough examination of numerous neuropsychological cases and disorders has supported that there exists (at least) two distinct types of body representation (de Vignemont, 2010). Decisively, almost a century after its first mention, Anema et al. (2009) have confirmed this dichotomy by reporting a double dissociation between two stroke patients: while one patient could accurately point towards the position on their hand where they had been touched but could not pinpoint the same position on a hand sketch, another patient presented the opposite pattern. All in all, although there has not yet been a consensus in the field on the number of different body representations that exist in human brain (de Vignemont, 2017), this dyadic taxonomy of BI and BS has constituted the conventional model.

2.1.1 Body schema

As we reach for a mug, the brain needs to know not only the location of the mug's handle but also the precise position of the hand to coordinate the action. BS is thought to provide this information through an unconscious, plastic, holistic, online, action-oriented sensorimotor representation of the posture, size, and position of body parts (Martel et al., 2016). This representation derives information mainly from bottom-up proprioceptive, tactile, and kinesthetic senses (Cardinali, Brozzoli, et al., 2009). The neural foundations of BS involve the coordination of several networks, including the motor network, specialized parietal systems, and the inferior branch of the right frontoparietal superior longitudinal fasciculus network (Naito et al., 2016). Much of the research on BS derives from the work on bodily disorders, especially from cases of deafferentation, personal neglect, and apraxia (de Vignemont, 2010). In neurotypical participants, changes in BS have been investigated with motor or somatosensory techniques involving forearm bisection (Sposito et al., 2012), tactile localization (Anema et al., 2009), tactile distance judgments (Miller et al., 2014), pointing to anatomical landmarks (Cardinali et al., 2011) and kinematic recordings

(Cardinali et al., 2012), as these measures are usually conducted preceding and following a kinesthetic illusion (Naito et al., 2016), motor imagery (Fourkas et al., 2008) or tool-use (Cardinali, Frassinetti, et al., 2009).

2.1.2 Body image

While there is general agreement on the definition of BS, BI, on the other hand, remains a contested term. This dispute mainly originates from the complex nature of a perceptual body model, as it incorporates many distinct aspects of conscious, phenomenological knowledge about the body and overlaps with other concepts like body ownership and bodily awareness. Granted there have been posited subdivisions of several body representations within BI (de Vignemont, 2017), this thesis will stick with the umbrella term of BI for the sake of practicality as it has been the subject matter of hundreds of theoretical and experimental work.

Similar to demarcations in other dichotomies, BI is generally described as opposed to BS in the dyadic taxonomy. In this manner, BI is defined as the conscious, fragmented representation of the body used for perception. (Kammers et al., 2010). It is thought to store the body percept, body concept, body affect (de Vignemont, 2010), visual metrics and structural information of body parts (Martel et al., 2016). While BI is conjectured to be grounded on previous sensory experiences and stored semantic/lexical body knowledge, it also incorporates visual, auditory (Martel et al., 2016), and tactile (de Vignemont, 2010) information.

The neural underpinnings of BI include the right temporoparietal junction (Tsakiris et al., 2008) for self-attribution of body parts, intraparietal sulcus, and premotor cortex for hand and face ownership, and supramarginal gyrus, insula, and superior temporal gyrus for self-identification and self-location (Blanke et al., 2015). Similar to BS, most of the work on BI was done through investigation of neuropsychological cases, which revealed that conditions like numbsense, personal neglect, apraxia, autotopagnosia, body-specific aphasia (de Vignemont, 2010), anosognosia, somatoparaphrenia, body integrity identity disorder, bulimia, and anorexia nervosa (Martel et al., 2016) might involve changes in BI. On the other hand, changes in BI of healthy subjects are investigated via tasks of naming or pointing to images of body parts, matching body parts to functions and body-related objects (de Vignemont, 2010), and in the case of RHI, proprioceptive drift measurements and subjective experience questionnaire ratings (Botvinick & Cohen, 1998).

2.2 Experimental paradigms for investigating body representations

Although much of the work in these fields have been clinical case studies, numerous scientists have attempted to investigate body representations of neurotypical participants in controlled experiments. However, there has been a deep divide in the literature for the last twenty-five years, as those interested in BS have preferred tool-use as the primary method of investigation, while its BI counterpart became RHI.

2.2.1 Tool-use

After the seminal single-cell recording study of Iriki et al. (1996), where monkeys were trained to use a rake-shaped tool to retrieve food located outside their reach and revealed enlargement in the visual receptive fields of parietal bimodal cells after using the tool, tool-use became the go-to experimental paradigm to inspect body-related changes in sensorimotor processing. Although these changes were inadvertently attributed to BS in the article, it was later revealed that they reflected a modification of peripersonal space (PPS) instead (Farnè & Làdavas, 2000). Defined as the space immediately surrounding the body and represented by the brain to facilitate interaction with nearby objects (Holmes & Spence, 2004), PPS was at the core of tool-use research for the next decade until Cardinali, Frasinetti et al. (2009) showed that it was also possible to utilize the tool-use paradigm to modify BS, as originally intended by Iriki and colleagues. After a ten-minute tool-use task with a mechanical grabber tool, they demonstrated changes in the kinematic recordings of free-hand movements that suggest elongation in the representation of the tool-using arm. Additionally, they confirmed this change by asking the participants to perform unsighted ballistic pointing movements towards the elbow, wrist, and middle fingertip of their tool-using arm and observing an increase in the length between the wrist and the elbow after tool-use. The ballistic characteristic of pointing movements was shown to recruit BS but not BI (Cardinali et al., 2012),

In another article, the same group tried to differentiate BI and BS based on the localization task (Cardinali et al., 2011). They theorized that touching the anatomical locations before the response would recruit BS while verbally stating them would employ BI. They also conducted perceptual and motor tasks, where participants either verbally reported the corresponding number on the meter that coincided with the perceived position of the target or pointed towards the target in a ballistic motion with their eyes closed. In the end, results indicated that both perceptual and motor tasks were sensitive to the elongation effect; however, the effect was measured only if the task was driven by tactile input.

Shortly after, Sposito et al. (2012) showed that the forearm-lengthening effect depended on functional gains in reachable space, as it occurred only with a 60-cm-long tool and not with a 20-cm-long one. However, in this study, there was no mention of a tactually-driven response. The effect was measured by verbally instructing the blindfolded participants to bisect the forearm of the limb they used the tool with, before and after the task.

Another constraint for this effect was later uncovered to be the embodiment of the tool-using arm. Garbarini et al. (2015) investigated four brain-damaged hemiplegic subjects as these subjects observed the experimenter's arm carry out a tool-use task in a position that coincided with where their contralesional arm would be. This manipulation led to a pathological embodiment of the experimenter's arm as their own. This condition was later compared to another where the experimenter's arm was more distal to the subjects and did not evoke such an embodiment. Forearm bisection results revealed that embodiment of the tool-using arm was necessary to induce the elongation effect.

Remarkably, Baccarini et al. (2014) discovered that imagining using the tool was enough to trigger this effect. They asked participants to execute free-hand reach-to-grasp movements before and after two mental imagery tasks, where they were instructed to imagine performing the same movements (fifty-four times) either with their free hand or with a grabber tool. Kinematic recordings of the free-hand reach-to-grasp movements after the imagery tasks demonstrated changes that suggest the elongation effect for the tool imagery condition.

Overall, these findings on tool-use related changes reveal certain constraints on BS modification. An enlargement of arm representation depends on using a tool that extends reachable space and embodying the limb that uses the tool. Moreover, a tactually-mediated response might ease access to BS, but it is not always essential. Lastly, it is also possible to induce this effect via detailed imagination of executing the task with the tool.

2.2.2 Rubber hand illusion

Inspired by the mirror illusion of Ramachandran et al. (1995), where phantom limb patients reported feeling touch on their amputated hand after viewing their intact hand being touched through the mirror as its position was superimposed on their phantom hand, Botvinick and Cohen (1998) designed a similar illusion that could be conducted with healthy subjects to investigate the sense of ownership. For this illusion, subjects placed their arm behind a vertical screen that occluded it from their view and observed a rubber hand placed in front of them get brushed synchronously or asynchronously with their hidden hand for ten minutes. As a result, subjects that experienced synchronous stimulation during RHI reported that the location of their index finger had drifted towards the rubber hand, and they felt as if the rubber hand was their hand.

After the release of this seminal article, hundreds of other studies were conducted to reveal the effects of different parameters on the results, which also produced great variability between methods. Over time, these variations established certain temporal, spatial, and anatomical constraints to produce the effects of the illusion (de Vignemont & Farne, 2010). Notably, the illusion only worked if the stroked object viewed by the participant was hand-shaped, suggesting a modulation of the effect by a template-matching process. Since the illusion was also contingent on visual signals overweighing proprioceptive ones to induce drift in perceived hand location, the effects of the illusion were often attributed to BI.

Studies showed a high correlation between the drift and questionnaire measures, which led the scholars of the field to suspect these measures to be implicit and explicit measures of the same construct (BI), respectively. However, later studies revealed that although the temporal window that these effects are sustained are also similar (Abdulkarim et al., 2021), manipulating the position of the participant's hand without them noticing changed only the proprioceptive drift results (Abdulkarim & Ehrsson, 2016), meaning that implicit-level changes had no causal effect on the explicit-level.

Other studies have further differentiated the proprioceptive drift measurements as perceptual and motor responses. Perceptual responses, where participants verbally indicated or matched the position of their affected hand, were conjectured to tap into BI; while motor responses, where participants pointed towards or executed a pointing or grasping motion with their affected hand, were posited to measure BS-related changes (Riemer et al., 2019). Results of motor responses are particularly important, as further examination of these results in the remaining part of this section aligns with the goal of the thesis to investigate the interaction of BI and BS.

First off, the original RHI study (Botvinick & Cohen, 1998) featured a motor response, but this response involved dragging the finger along a line until it matched the perceived position of the index finger. Since this response did not qualify as a ballistic movement, it might be contaminated by other cognitive processes and not reflect an isolated change in BS (for a more detailed discussion on the difference between fast and slow pointing movements, see Króliczak et al., 2006).

Holmes et al. (2006) investigated if reaching movements would be affected by the visual characteristics of the observed hand, which was either the participant's own hand, a rubber hand, or a wooden block seen through a mirror. The results revealed that visual exposure to the real hand or the rubber hand was enough to affect reaching movements, so the illusion itself (synchronicity) played no part in this effect.

In a series of studies, Kammers and colleagues tried distinguishing between motor and perceptual responses to RHI. Firstly, they systematically compared consecutive perceptual and motor responses in the same procedure (Kammers, de Vignemont, et al., 2009). The results suggested ballistic pointing responses towards the other index finger were insensitive to the illusion, regardless of whether the pointing hand was the one affected by the illusion or not. Conversely, perceptual judgments remained sensitive to RHI even after participants executed motor responses, so the proprioceptive update brought about during the motor responses with either hand did not change the perceptual effect of the illusion. In the following study, using a video-RHI setup, they investigated if induction of the illusion with active movements rather than passive ones would change these responses (Kammers, Longo, et al., 2009). Contrary to the classical version, where the illusion is induced with tactile stimuli on both the rubber hand and participants' own hand, they showed participants a video display instead, which showed a live feed of the occluded hand as it was either actively or passively moved. They found no significant effect of synchronicity on motor responses with neither the passive nor active induction, which meant that embodiment of the observed hand did not affect the resulting drift in pointing responses. However, an interaction between induction type and response type revealed that passive induction led to a larger effect on perceptual responses, while active induction resulted in more bias on motor responses. Lastly, they examined the grasping response via a vertical RHI setup (rather than the classical, horizontal setup) and manipulated the grip aperture of the rubber hand (Kammers et al., 2010). Results indicated that the rubber hand's grip aperture affected the participant's grip aperture on both motor grasping responses and perceptual grip aperture matching tasks. However, since there was no asynchronous condition in this experiment, this effect might yet again be solely due to visual information regarding the aperture rather than the embodiment of the rubber hand.

Likewise, when Heed et al. (2011) investigated the effect of the size of the rubber hand, they found that seeing a larger hand during RHI affected the motor grasping response, independent of RHI synchronicity. On the other hand, synchronicity affected the perceptual hand size estimation task, but only in the synchronous small hand condition.

Contrary to the findings of Kammers, Longo, et al. (2009), Kalckert and Ehrsson (2012) showed that synchronicity affected motor responses with the unaffected hand towards the affected hand after active induction in a vertical RHI setup. However, there was no difference between the synchronous active and synchronous passive induction conditions with this measure. A follow-up study compared active and tactile induction, measured by motor responses (Kalckert & Ehrsson, 2014). Again, conflicting with previous findings, results suggested that both induction methods affected motor responses, and their effects were similar between the synchronous conditions.

Finally, Riemer et al. (2013) compared the classical tactile induction with active induction and used perceptual and motor responses to measure the effect of the illusion. Results indicated that tactile induction could influence both perceptual and motor responses. Similar to Kammers, Longo, et al. (2009), there was an interaction between the induction type and response type, with a larger perceptual response after tactile and larger motor response after active induction, implying that representations for observed and executed movements might be shared. Moreover, while questionnaire ratings and perceptual responses were correlated between tactile and active induction conditions, motor responses were not (more drift after active induction), suggesting that BS alterations in RHI are less stable than alterations in BI.

Overall, although some of these results may indicate contradictory findings, these disagreements most likely result from differences in methodological and analytical approaches (for a more detailed discussion of such differences, see the introduction section of Riemer et al., 2013). In general, tactile or passive RHI induction led to changes in BI measures. Often, when a BS measure was affected, it was either solely due to visual information, independent of the embodiment of the rubber hand (Heed et al., 2011; Holmes et al., 2006; Kammers et al., 2010), or as a result of active induction of the illusion (Kalckert & Ehrsson, 2012, 2014; Riemer et al., 2013). However, in two of these studies, tactile induction did indeed lead to changes in BS measures (Kalckert & Ehrsson, 2014; Riemer et al., 2013), while four others failed to report any effect of tactile RHI on BS (Heed et al., 2011; Holmes et al., 2006; Kammers, de Vignemont, et al., 2009; Kammers et al., 2010). All in all, these results imply that although it is rare to observe a stable change in BS that originates from changes in BI, it is nevertheless possible.

2.3 Research gap

After the discovery of the functional organization of the visual system (Ungerleider & Mishkin, 1982), the perception-action distinction became the conventional way of categorizing body representations. This approach was well-grounded, as it fitted most of the evidence acquired from neuropsychological, neural, and behavioral data regarding body representations. However, this basic model fell short when investigating the interaction between the perception- and action-oriented representations (for a more detailed discussion, see de Vignemont, 2010) since it did not ascribe any basis for an interaction to take place.

In the late 1990s, Rao and Ballard's seminal paper (1999) introduced the concept of predictive coding to the neuroscientific literature, which argued that the brain creates generative top-down models of the visual scene and uses bottom-up sensory information as error signals to update these models. Ever since, predictive or Bayesian models have become an essential part of the literature. Inspired by this Bayesian approach and David Marr's (1982) three-step model of visual perception, Pitron and de Vignemont (2017) proposed a model that aimed to account for the interaction between BS and BI. They argued that, rather than a fusion model where a single representation encodes bodily properties or an independence model where BI and BS work separately, the model best fitting to available evidence is a co-construction model, where BI and BS can interact and modify each another. In a follow-up article, they further specified this co-construction model into a serial model (see Figure 1), where BS has primacy over BI as indicated by developmental, neuropsychological, and behavioral evidence (Pitron et al., 2018). They concluded this article by stating the need for further 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 (especially for BI) via the tool-use paradigm.

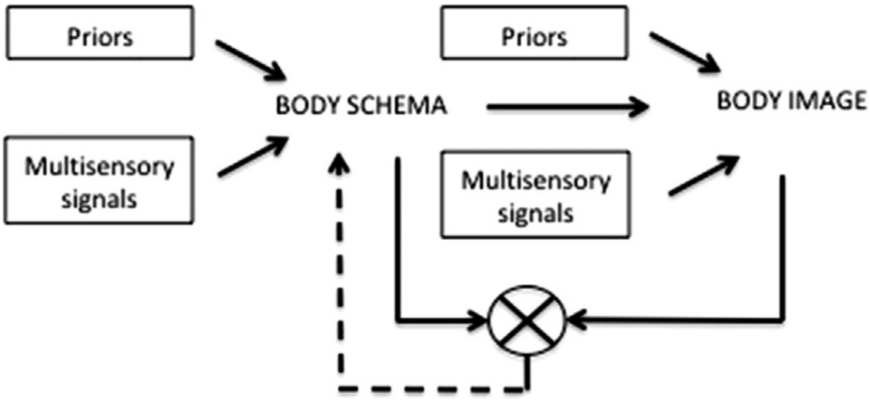

Figure 1. The serial model from Pitron et al. (2018)

While several studies, mentioned above, tried to differentiate between BS and BI effects with either tool-use or RHI paradigms, there have been only three articles (to our knowledge) that combined these two paradigms in one experimental setup (Cardinali et al., 2021; Weser et al., 2017; Weser & Proffitt, 2019). In Weser and colleagues' studies, they have shown that it was possible to induce the illusion by stroking the tip of the tool rather than the fingers holding it, and the strength of the illusion, measured by a perceptual drift task and subjective questionnaire, increased when the illusion was preceded by tool-use, or participants had a better skill for using the tool (Weser et al., 2017). However, while the illusion was successfully elicited through tactile stimulation of chopsticks, pliers, or tweezers, there was no effect of synchronicity when participants held a teacup, implying that a morpho-functional (tool's output) and sensorimotor (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. In these experiments, there was no rubber hand holding the tool, as participants observed the experimenter brushing the tool's prongs either synchronously or asynchronously. Their results indicated that prior tool use did not affect the perceptual responses, which conflicted with Weser and colleagues' findings. Additionally, after threatening the tool with a syringe post-RHI, the skin conductance response in the synchronous condition suggested the embodiment of the tool as a part of the body. All in all, these studies revealed that embodying a tool during RHI was possible. However, all measurements in these experiments were aimed at measuring changes solely in BI; there was no inspection of how BS measures changed due to RHI.

Finally, as stated in the previous section, BS measures employed in RHI experiments only quantified the endpoint errors for grasping/reach-to-point movements towards extrinsic objects/body parts. Although Kammers et al. (2010) and Heed et al. (2011) employed matching tasks to determine the perceived size or grip width of the rubber hand, these tasks were most likely perceptual as they did not require fast responses. In the end, none of these RHI studies investigated the effect of the illusion on the measures of BS that directly reflect changes in limb size.

2.4 Aim of the thesis

Our aim was to combine the tool-use and RHI paradigms in one experimental procedure to investigate how tool-use changes BI measures and how RHI changes BS measures. As mentioned in the previous section, findings regarding the effect of tool-use on BI are inconsistent: Weser et al. (2017) have found an effect, whereas Cardinali et al. (2021) have not. On the contrary, no prior study (to our knowledge) has directly inspected the effect of RHI on BS measures of limb size, and neither has been any prior attempt to modify the tool-use-related changes on BS through RHI.

Hence, we have designed an experiment that comprised of a tool-use task followed by a tool-holding RHI task where participants wielded the same tool they previously used. We measured BI through perceptual drift measures before and after RHI and the subjective experience questionnaire at the end of each block. On the other hand, BS was measured via forearm bisection tasks three times: at baseline, after tool-use, and after RHI. Each participant completed the experimental block twice, once with a short tool and once with a long tool. We conducted three experiments by modifying this general procedure to expose participants to an identical-looking tool held by the rubber hand, with either the same or different length compared to the one held by the participants, or have participants only hold the tool instead of using it during the tool task prior to RHI. Thus, we were able to investigate how observing a different-length tool during RHI would affect the BS measure of forearm length and how prior tool-use would affect the BI measures of a tool-holding RHI. Our hypotheses were: (i) using the long tool would increase the BS measure of forearm length, while the short tool would not (replicating previous evidence and validating the tool-use part of our setup); (ii) proprioceptive drift and embodiment scores of the questionnaire would be higher in the synchronous conditions than the asynchronous ones (replicating previous evidence and validating the RHI part of our setup); (iii) after tool use, BS measure of forearm length would increase if the participants observed a longer tool during synchronous RHI (a novel finding, indicating that changes in BI will modify BS measures of limb size); and (iv) this modification of BS through changes in BI would not take place if the participants did not use the tool prior to RHI (a novel finding, suggesting BS embodiment of the tool is necessary to modify BS through BI).

CHAPTER 3

EXPERIMENT 1

TOOL-USE AND RUBBER HAND ILLUSION WITH DIFFERENT TOOLS

Previous studies have shown that rubber hand illusion can change motor responses (end target of pointing or grasping movements, or kinematic changes during movement) and perceived limb location (position of body parts) (see Section 2.2.2). However, no prior work (to our knowledge) examined whether RHI could affect body metrics through motor judgments regarding limb length. To investigate this, we designed an experiment combining tool-use and RHI paradigms in a single procedure, enabling manipulation of perceived forearm length during RHI (see Figure 2). We achieved this by having participants first use either the long or short grabber tool during the tool-use task and integrate the tool into the internal representation of their forearm. Then, by having them experience the ownership of a rubber hand holding a longer/shorter tool during RHI, we aimed to manipulate their representation of the tool-integrated forearm length. Our first goal was to replicate the classical results of these paradigms with our experimental setup, meaning more extended forearm representation after tool-use with a long tool, and proprioceptive drift towards rubber hand and subjective embodiment of rubber hand after RHI. After establishing that our manipulations were effective, we predicted that we would detect an elongation effect if we let the participants observe a longer tool during synchronous RHI after using a short tool for the tool-use task. Thus, we intended to modify the BS representation of forearm length through changes induced in BI. We did not expect to see any shortening effect in the inverse condition, where participants observe a shorter tool during synchronous RHI after using a long tool during the tool-use task, because contraction effects are rarely observed in the literature (Martel et al., 2016).

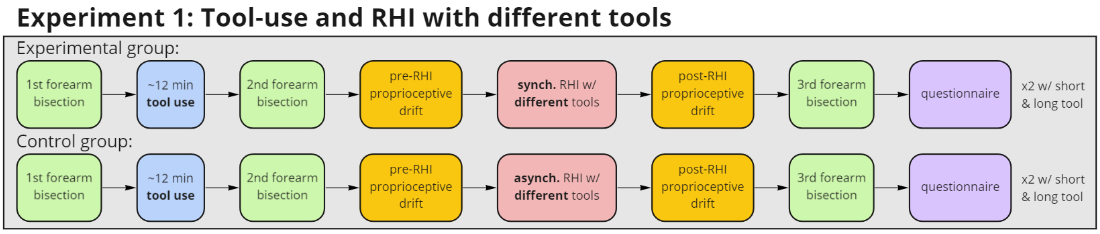

Figure 2. Procedure of Experiment 1

3.1 Participants

Twenty-four right-handed subjects (11 female, mean age 24.00, ranging between 19 and 38), who were either undergraduate or graduate students at Boğaziçi University, participated in the experiment. Participation of undergraduate students was compensated with course credits, while the rest volunteered. Participants had normal or corrected vision, reported no injury or neurological disorder, and gave written informed consent to participate. All subjects were naïve to the purpose of the study and participated only in Experiment 1. The study was approved by the university ethics committee (see Appendix A) and conducted according to the guidelines of the Declaration of Helsinki (World Medical Association, 2013).

3.2 Materials and methods

Before and following tool-use and RHI manipulations, forearm bisection tasks were conducted to compare BS changes in the right arm length (see Figure 2). Proprioceptive drift measurements were performed before and after RHI, and the subjective experience questionnaire was completed at the end of each block to quantify the strength of the illusion and changes in body image. Throughout the experiment, participants wore a black nitrile glove on their right hand to increase the resemblance of their hand to the rubber hand that also wore the same black glove. Finally, they were asked to wear a blindfold in certain parts of the procedure.

3.2.1 Forearm bisection task

Similar to the task described by Sposito et al. (2012), participants were seated on a chair and asked to keep their backs straight with their abdomen touching the table in front. They placed 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. After the task was explained in detail, they were blindfolded, and a platform was placed at about 4 cm above their right forearm to prevent tactile feedback of the left index finger touching the right forearm (see Figure 3). Then, the experimenter touched the tip of the right middle finger and the right elbow as the participants were asked to point with their left index finger to the midpoint of this limb segment in a ballistic movement, without halting or changing the movement trajectory once it started. A few practice trials were completed to accustom participants to the requested action. Once participants performed the pointing movement correctly, the task started. At each measurement, the position along the right parasagittal axis (laying along the right forearm) where the left index finger's tip touched the platform's top surface was recorded to the precision of 0.5 cm. When pointing, if another part of the limb touched the platform before the left index finger, that trial was repeated. After the experimenter recorded its position, participants returned their left hand to the initial position, and the subsequent trial started. A total of three measurements were collected. At the end of the task, the platform was removed, and the blindfolds were taken off.

Figure 3. Participants' initial posture during forearm bisection task

3.2.2 Tool-use task

Numerous findings in the literature informed the design of the tool-use task. The specific motor pattern employed by arm joints during the tool-use task was shown to be effective in forearm bisection measures (Romano et al., 2019). Thus, our task required movement in the shoulder, elbow, wrist, and hand joints to balance out any effect originating from a proximally- or distally-biased motor pattern during the task. Since previous tool-use tasks revealed that a tool that provided an extension in reaching space was crucial for an increase in the internal representation of forearm length (e.g., using a 60-cm-long tool vs. a 20-cm-long tool), we employed a similar approach and compared the difference between long and short tools while also aiming to maximize the number of movements that extended reaching space (Sposito et al., 2012). Employing a grabber tool provided both morphological (prongs resembling thumb and index finger) and functional (similar grasping motion) resemblance to how we would typically execute this task with our hands, which was shown to be crucial for tool embodiment (Miller et al., 2014; Cardinali et al., 2016). This similarity also allowed us to later compare the tool-use condition with a tool-hold condition in Experiment 3, where we asked participants only to hold the tool while performing the same tasks with their left hands, to see if active tool-use is necessary for a change in forearm bisection measures.

As a result, two similar mechanical grabber tools (77 and 47 cm in length) were employed for the tool-use task. Both grabbers consisted of two rubber prongs (10 cm long) at the distal end that closed symmetrically when the lever at the proximal handle (12 cm long) was squeezed, and an aluminum tube (55 and 25 cm long) that connected these two parts. Participants grasped the tool with their right hand from the handle, with the lever facing up and their index finger touching a black band on the tube to ensure a similar grip across all participants. The long tool effectively increased the participants' reach by 60 cm as the short tool did by 30 cm. Because of the weight difference between the tools (316 g and 243 g) and the long tool's center of mass being further away from the handle, an additional weight of 73 g was added towards the distal end of the short tool. This additional weight was placed at a position that deemed the perceived torque on the base of the thumb to be indiscernible between the two tools when blindfolded members of our lab passively held both tools (one in each hand) at a horizontal orientation (see Figure 4). A similar visual modification was also made to the long tool without adding weight. Finally, participants were asked to indicate the level of pain/numbness/tingling sensation they felt after the task on a 0-10 VAS measure (0: no pain/numbness/tingling sensation, 10: intolerable pain/numbness/tingling sensation) at the end of each block to account for any fatigue difference that persisted despite these modifications.

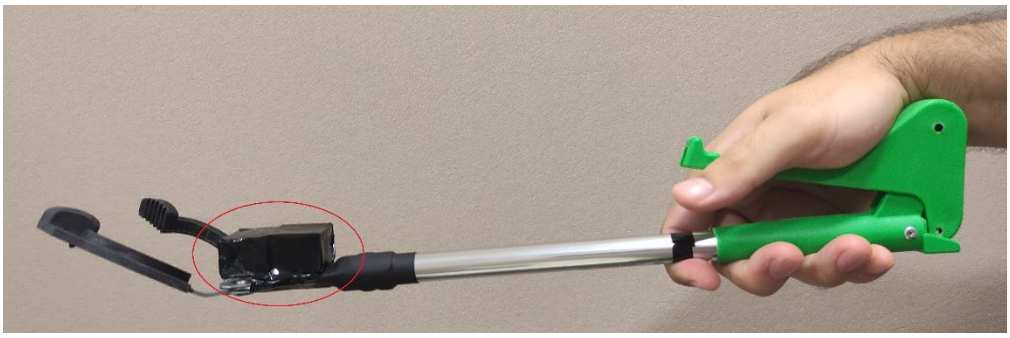

Figure 4. Prescribed grasp of (short) tool with added weight at distal end (in red circle)

After the participants correctly grasped the tool, they were asked to extend their right arm (while still holding the tool) in the parasagittal axis as far as they could without leaning forward, with their backs straight with their abdomen touching the table. Their maximum reach was noted, and the distal edge of the sheet containing the target squares for the tool-use task was fixed at this position (this measurement was repeated for both blocks—with the short and long tools—to account for spontaneous posture-related differences instead of shifting the papers by the length difference between tools). With this positioning, the furthest row of target squares was 10 cm proximal to their maximum reach with the tool, with a 10 cm separation between each row (a total of three rows). Then, the experimenter explained the necessary steps to execute the task of moving cubes from the baskets to the targets and back—a total of eighteen cubes with 6-cm-long edges and numbers on all six sides needed to be moved. Cubes were split between two baskets, initially #1 to #9 in the left one and #10 to #18 in the right one. Firstly, participants were to grab a specific cube from either basket using their left hand and place it on the center of the table, at around 30 cm from their body. Next, they needed to grab the cube with the tool by squeezing the lever, closing the prongs on it, then moving it to a specific target, placing it on the targeted spot, relaxing the lever, and retracting the tool. After all eighteen cubes were placed on the targets in a particular order (explained below), subjects recollected the cubes in reverse order: by picking up the designated cube with the tool, placing it around 30 cm from their body, grabbing it with their left hand and placing it in the designated basket. After all eighteen cubes were retrieved in a particular order and placed back in the baskets (with nine cubes in each basket), the task was complete. Before starting the tasks, participants were requested to place the first two cubes on corresponding targets and then retrieve them, closely following the instructions. Once participants executed the movements correctly, the tool-use procedure was started. Participants completed a total of four different tasks in each block, following these instructions:

i. Place cubes in increasing order on matching targets (using the ordered-target sheet, with #1 situated at the furthest leftmost target and #18 at the closest rightmost target)
    - Retrieve cubes in decreasing order, placing cubes from #1 to #9 in the right basket, cubes from #10 to #18 in the left basket

ii. Place cubes in decreasing order and on reverse targets, starting with cube #18 on target #1 (using the ordered-target sheet)
    - Retrieve cubes starting from the closest leftmost cube, moving towards right and then to the next row, placing odd cubes on the left basket, even cubes on the right basket

iii. Place cubes on matching targets starting from the furthest rightmost target, moving closer and then to the next column (using the random-target sheet, with numbers randomly distributed)
   - Retrieve cubes starting from the closest rightmost cube, moving further and then to the next column, placing single-digit cubes in the right basket and double-digit cubes in the left basket (see Figure 5)

iv. Place cubes on the middle-row targets in increasing order (disregarding the target numbers on the random-target sheet), forming three-cube-high stacks starting from the leftmost target (e.g., place cube #1 on the leftmost middle target, then cube #2 on top of cube #1, then cube #3 on top of cube #2; then move to right and place cube #4 on the next target, then cube #5 on top of cube #4, …)
   - Retrieve cubes in decreasing order, placing cubes from #1 to #9 in the right basket, cubes from #10 to #18 in the left basket

Figure 5. Snapshot of tool-use task with long tool on random-target sheet

Tasks were designed to increase in complexity, to incur a constant cognitive load on the participants to keep them focused on the task, and to bring about many reaching movements in varying frontal directions. Each participant completed all four tasks in the stated order. Instructions on the next task were given after the previous task was completed. While receiving the instructions, participants were free to rest their right hand on the table for a few seconds while still holding the tool, as they were warned not to let go of the tool until all tasks were completed (this was done to ensure the integration of the tool to the BS). The experimenter monitored the correct grasp and execution throughout the tasks, warning participants and requesting a correction if necessary. To prevent excessive fatigue, participants were initially urged and frequently reminded during the task to drag the distal tip of the tool along the surface of the table for reaching and retrieving movements instead of holding it up in the air all the time. Since participants performed the tasks at varying speeds, each participant's total duration was timed to account for any effect of tool-use duration on the bisection task.

3.2.3 Tool-holding rubber hand illusion

In previous tool-holding RHI setups, the illusion was successfully elicited by having the rubber hand and participant hold chopsticks or pliers (but not teacups) while synchronously stroking the tips of the objects instead of the fingers (Weser et al., 2017; Weser & Proffitt, 2019). Similarly, we have employed a setup where both the participant and the rubber hand held either the long or the short grabber tool, and tactile stimuli were delivered to the distal end of the tools to induce the illusion. To enable the vertical movement of the tool as the experimenter stroked the distal tip with a paintbrush, clasps and rubber bands were utilized to fixate the proximal end of the tool to the table (see Figure 6). Sponges were placed below the handle and the shaft of the tool to support its weight and provide space below the tool as it moves downward during the stroke. A wooden hand model was used as the rubber hand since its flexible finger joints allowed changing the tool in between blocks and adjusting the grip to emulate each participant's hand configuration.

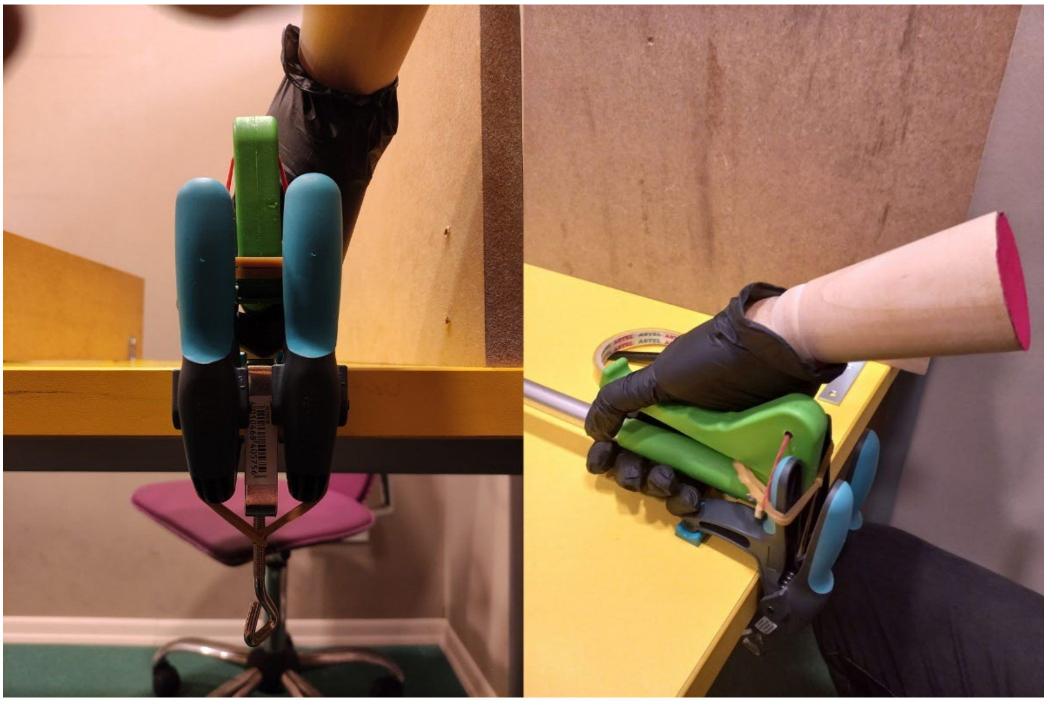

Figure 6. Tool-holding rubber hand mechanism enabling vertical mobility

After completing the tool-use task and forearm bisection measurements, participants were asked to move to the other end of the table, where the RHI setup was hidden from sight under a wooden panel (70 x 60 cm) covered by a black smock. They were comfortably seated and blindfolded as the experimenter removed the black smock and the wooden panel over the RHI setup and carefully placed the participant's right hand 15 cm distal to the rubber hand, which, in turn, was also positioned 15 cm distal to the midsagittal plane. Contrary to the general approach in the field, the rubber hand was not placed on the body midline because previous research has indicated a perceptual bias for limb position towards the trunk that might exaggerate the drift results (Preston, 2013). Participants held the same tool they were holding during the tool-use task, while the prongs of the tool were fixed in the closed position so that participants would not need to apply pressure on the lever throughout the rest of the procedure, and participants' right elbow was placed on a platform that is level with their hand to prevent unnecessary fatigue. The tool held by the rubber hand was switched beforehand to ensure that participants observed either a longer or a shorter tool (and not the same tool) during the illusion. Then, the black smock was put on participants to prevent any visual cue regarding the position of their arm. Finally, after ensuring the tool is held in the same configuration as the rubber hand, with both tools laying on the sponges parallel to the short edge and perpendicular to the long edge of the table, the wooden panel was replaced in its initial horizontal position and covered with the black smock.

After conducting the pre-RHI proprioceptive drift measure, the participant was blindfolded again as the experimenter removed the black smock from the top of the box and repositioned the wooden panel vertically between the rubber hand and the participant's hand (see Figure 7). The black smock was then fixed to the wooden panels with clamps to prevent any unwanted visual cue regarding the participant's hand location or proximal part of the rubber hand mechanism, only allowing a partial view of the rubber hand (up to the first four fingers, excluding the little finger). Later, blindfolds were removed, and the participant was asked to confirm that they could see the rubber hand and the tool held by the rubber hand. They were reminded not to move their hand throughout the illusion and informed that their hand was situated behind the wooden panel and they were observing the rubber hand. They were instructed to focus on the distal end of the tool held by the rubber hand for the next two minutes while the experimenter stroked the tip of the tool with a paintbrush. A period of two minutes was chosen since previous results in the literature 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 vertical movement of the tip on their hand, at a rate of one stroke each 2-3 seconds, either synchronously or asynchronously. Asynchronous stimuli were administered with an unpredictable, random delay since certain theories of predictive coding surmise that predictability of tactile stimuli has a strong effect on body representations (Clark, 2013). During the stroking, the experimenter monitored that the participant did not move their gaze or hand. After two minutes, the participant was again blindfolded, and the wooden plate was returned to its initial horizontal position and covered with the black smock to start the post-RHI proprioceptive drift measure.

Figure 7. Representative image of RHI setup with short tools in both rubber hand and participant's hand

3.2.4 Proprioceptive drift

In the literature, proprioceptive drift has been differentiated as either a perceptual or a motor task. Perceptual tasks, where participants are asked to indicate the position of their affected hand verbally, without any motor movement, have been linked with changes in BI; while motor tasks, where participants are asked to point at the position of their affected hand in a ballistic movement, have been accepted to reflect changes in BS (Kammers, de Vignemont, et al., 2009; Kammers, Longo, et al., 2009; Riemer et al., 2013). In our experiment, we aimed to detect the implicit changes in BI through the proprioceptive drift measure; therefore, we adopted a perceptual task.

After the second forearm bisection measure, the participant's right hand was placed in the box, and the wooden plate was positioned horizontally and covered with the black smock, as specified previously (see Section 3.2.3). The experimenter sat across the table and confirmed, according to the paper ruler taped to the side of the wooden panel facing the experimenter, that the tip of the participant's tool was placed at the 18th cm and the rubber hand's tool at the 33rd cm points (see Figure 8). If necessary, adjustments were made to correct tool position and alignment. Then, the participant was reminded not to move their hand or change their body posture throughout this procedure, and their blindfolds were removed. They were briefed about how their hand was placed in a parallel direction to the short edge of the table, still holding the same tool they held during the tool-use task. Next, they were asked to verbally indicate the point that coincided with the tip of the tool they were holding on the ruler that was placed at a random position on the frontoparallel axis along the edge of the wooden plate close to the experimenter (see Figure 9). They were asked to repeat this measurement five times, closing their eyes and turning their face towards the front between the measurements. At the same time, the experimenter shifted their own position, the position of the ruler, and the smock on the frontoparallel axis to prevent the participant from taking any of these objects as a reference as they repeated the measurement. The participant was also reminded to answer according to the position they *felt* the tip of the tool they were holding was located, not taking any other point as a reference or using any cognitive strategy to deduce the position. After the participant indicated the position of the tip of the tool they held on the ruler five times to the precision of the closest millimeter, they were blindfolded again, and the RHI procedure was initiated. After the RHI, proprioceptive drift measurement was repeated in the same manner, stressing to the participant that they should verbally state the position of the tool *they* were holding, not to allow any confusion after observing the tool held by the rubber hand. Finally, they moved to the other end of the table to carry out the last forearm bisection task.

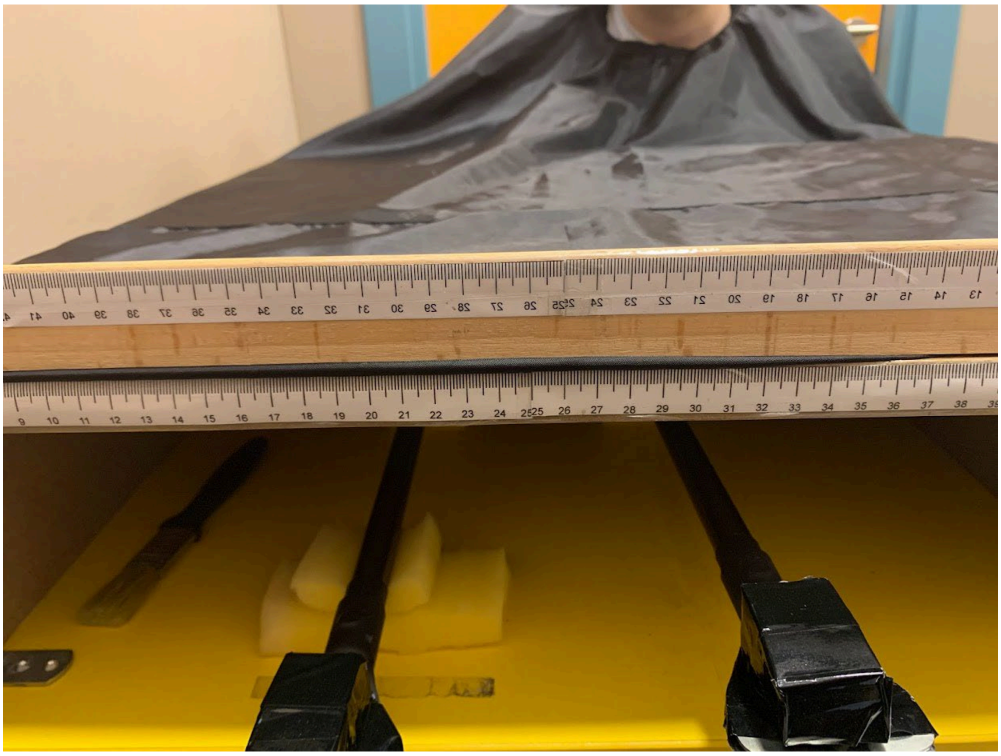

Figure 8. Experimenter's point of view during proprioceptive drift tasks with long tools in both rubber hand and participant's hand

Figure 9. Participants' point of view during proprioceptive drift tasks

3.2.5 Subjective experience questionnaire

The questionnaire from Longo and colleagues (2008) was translated into Turkish, adapted to a tool-holding version of RHI, and used in the experiment as an explicit measure of changes in BI (see Appendix B). Each of the twenty-five statements was measured on a Likert scale from -3 to 3. Statements reflected five dimensions of the illusion: 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).

Following the completion of the third and final forearm bisection task, participants were instructed to fill out the questionnaire, thinking about their experience of the illusion during that block. After they answered all the statements in the questionnaire, the experimental block concluded.

3.3 Experimental design

With a 2 x 2 mixed design, tool length (long or short) was the within-subjects factor, while RHI synchronicity (synchronous or asynchronous) was the between-subjects factor. RHI synchronicity was employed 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 the RHI (Lush et al., 2020). Participants completed the experimental block twice with either the long or the short tool, where they held the same tool throughout both the tool-use and RHI tasks. There was a minimum of 10 minutes of break time between the two blocks, during which participants were encouraged to physically move and cognitively engage in different activities to reset any carryover effects from the first block. The order of the blocks was counterbalanced. Overall, there were four different conditions in Experiment 1: (i) using long tool, seeing short tool, synchronous; (ii) using long tool, seeing short tool, asynchronous; (iii) using short tool, seeing long tool, synchronous; and (iv) using short tool, seeing long tool, asynchronous.

3.4 Results and discussion

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 RHI 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 other between the proprioceptive drift and the change in forearm length pre and post synchronous RHI. 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. All tests were two-tailed. Nonparametric alternatives were used if a violation of assumptions prevented the use of parametric ones.

3.4.1 Forearm bisection pre/post tool task

Participants executed pointing movements towards the midpoint of their right forearm (the limb section from the tip of their middle finger to their elbow) three times during the experiment: before tool task (baseline, first), after tool task/before RHI (second), after RHI (third). These bisection results were recorded as percentage measurements, calculated with the formula [(x/arm length)*100], where x is the subjective midpoint, measured to the nearest 0.5 cm in the parasagittal axis. 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, while a value less than %50 marked an underestimation.

A two-way within-subjects ANOVA was conducted on the first two forearm bisection results with *held tool length* (short and long) and *bisection* (pre tool task and post tool task) as within-subjects variables. There were no outliers, and the assumption of normality was met. There was no significant main effect of held 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 a significant 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 task ($M = 41.94$, $SD = 2.05$)

compared to pre tool task ($M = 46.28$, $SD = 2.08$) in the long tool condition, $p = .036$ (see Figure 10). The same comparison was not significant for the short tool condition, $p > .21$.

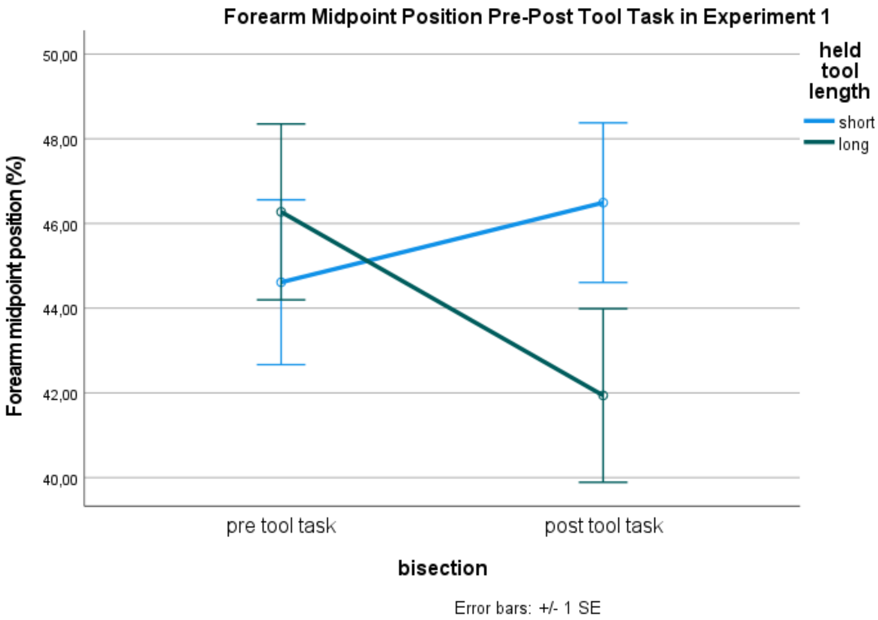

Figure 10. Interaction between held tool length and pre/post tool task bisection on forearm bisection results in Experiment 1

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 were able to confirm the first hypothesis and replicate the results in the literature regarding tool-use and forearm bisection tasks with our experimental setup.

3.4.2 Proprioceptive drift

Participants judged the location of the tip of the tool they were holding before and after RHI by verbally reporting the point on a ruler that laid on the frontoparallel axis where the tip of the tool coincided. These two measurements were then subtracted from each other [post-pre] to calculate proprioceptive drift. A positive result marked a shift towards the rubber hand, while a negative result marked a shift away from the rubber hand.

A mixed two-way ANOVA was conducted on proprioceptive drift results with *RHI synchronicity* (asynchronous and synchronous) as the between-subjects variable and *held tool length* (short and long) as the within-subjects variable. An upper outlier in the "long tool & asynchronous" cell was winsorized to match the closest value. The assumptions of normality, homogeneity of variances and covariances were met. There was a significant main effect of the RHI synchronicity, $F(1, 22) = 7.27$, $p = .013$, $\eta_p^2 = .25$, with the participants that experienced synchronous RHI ($M = 4.79$, $SD = .80$) reporting more drift than those that experienced asynchronous RHI ($M = 1.74$, $SD = .80$). There was also a significant main effect of held tool length, $F(1, 22) = 5.53$, $p = .028$, $\eta_p^2 = .20$, with the participants that held the long tool (and observed the short tool during RHI; $M = 4.17$, $SD = .81$) reporting more drift than the participants that held the short tool (and observed the long tool during RHI; $M = 2.36$, $SD = .53$). The interaction between RHI synchronicity and held tool length was not significant, $F(1, 22) =.86$, $p > .36$, $\eta_p^2 = .038$ (see Figure 11).

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 "holding long tool & synchronous" condition. There was a negative non-significant correlation, $r(12) = -.14$, $p = .51$.

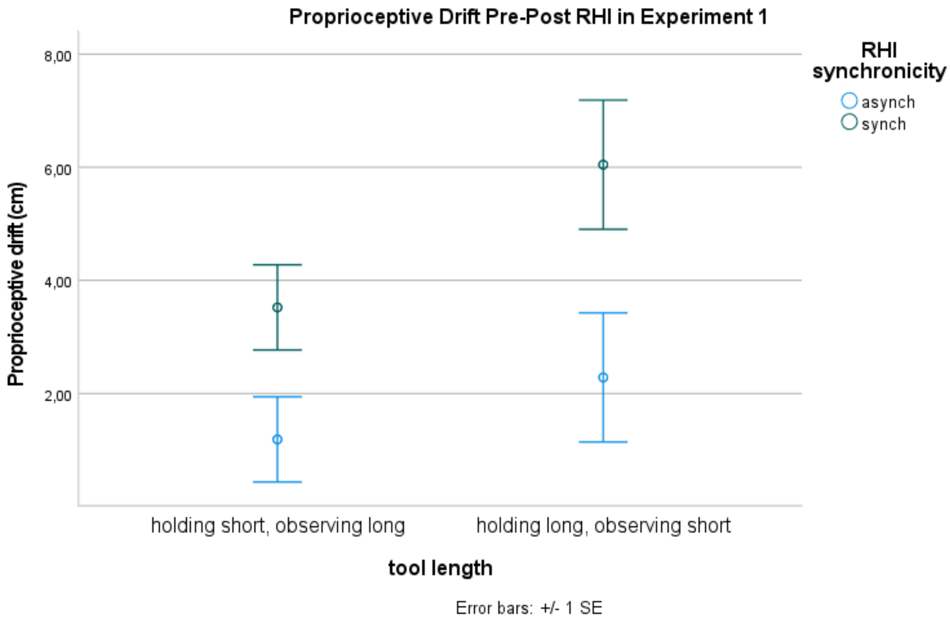

Figure 11. Interaction between tool length and RHI synchronicity on proprioceptive drift results in Experiment 1

These results suggested that synchronous RHI enabled implicit embodiment of the rubber hand and the tool it held through the BI. Thus, we were able to confirm the second hypothesis and replicate the classical RHI paradigm with our tool-holding RHI 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 measurements and the change in forearm length after tool-use suggested otherwise. Since observing a different-length tool during RHI might also be a factor, before making any strong inferences, this effect should be reassessed in comparison with Experiment 2, where participants observed same-length tools during RHI.

3.4.3 Subjective experience questionnaire

A mixed three-way ANOVA was conducted on the mean ratings of questionnaire components (embodiment, loss of hand, movement, affect, deafference) with *RHI synchronicity* (asynchronous and synchronous) as the between-subjects variable, and *held tool length* (long and short) and *components* 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 were no outliers in any subgroup. The homogeneity of covariances assumption was met. The normality assumption was violated for three subgroups (out of twenty), which was omitted since the test is robust for minor violations. Sphericity assumption was also violated in the components variable ($\varepsilon = 0.69$); thus, Greenhouse-Geisser corrected results were accepted. There was no significant main effect of RHI synchronicity, $F(1, 22) = 1.27$, $p > .27$, $\eta_p^2 = .055$. There was also no significant main effect of held 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 RHI 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 12). 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, $r(48) = .33$, $p = .024$.

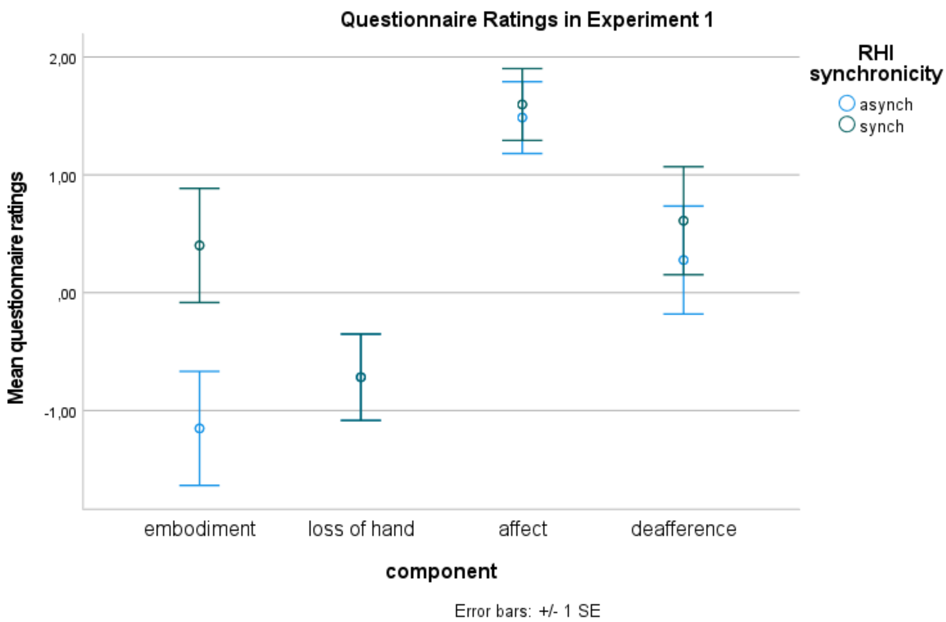

Figure 12. Interaction between RHI synchronicity and components on mean questionnaire scores in Experiment 1

Overall low positive scores in the synchronous group were consistent with the previous tool-version 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, these low scores were deemed acceptable. The lack of a main effect of RHI 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 nevertheless reflected an explicit embodiment of the rubber hand and the tool it held into the BI, confirming our second hypothesis. Moreover, a significant positive correlation between the proprioceptive drift and embodiment results supported the established close relationship between these two measurements.

3.4.4 Forearm bisection pre/post RHI

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

A mixed two-way ANOVA was conducted on the change in forearm length after RHI with *RHI synchronicity* (asynchronous and synchronous) as the between-subjects variable and *held tool length* (long and short) as the within-subjects variable. There were no outliers, and the assumptions of normality, homogeneity of variances and covariances were met. There was no significant main effect of RHI synchronicity, $F(1, 22) = 1.30$, $p > .26$, $\eta_p^2 = .056$. However, there was a significant main effect of held tool length, $F(1, 22) = 11.02$, $p = .003$, $\eta_p^2 = .33$, with the participants that held the short tool (and observed the long tool during RHI; $M = -.53$, $SD = 1.92$) reporting less contraction in forearm length than those that held the long tool (and observed the short tool during RHI; $M = -8.79$, $SD = 2.54$). While the interaction between RHI 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 RHI between the synchronous ($M = 3.71$, $SD = 2.71$) and asynchronous ($M = -4.78$, $SD = 2.71$) conditions, $p = .038$ (see Figure 13). 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 RHI in the “holding long tool & synchronous” condition. There was a positive non-significant correlation, $r(12) = .32$, $p > .30$.

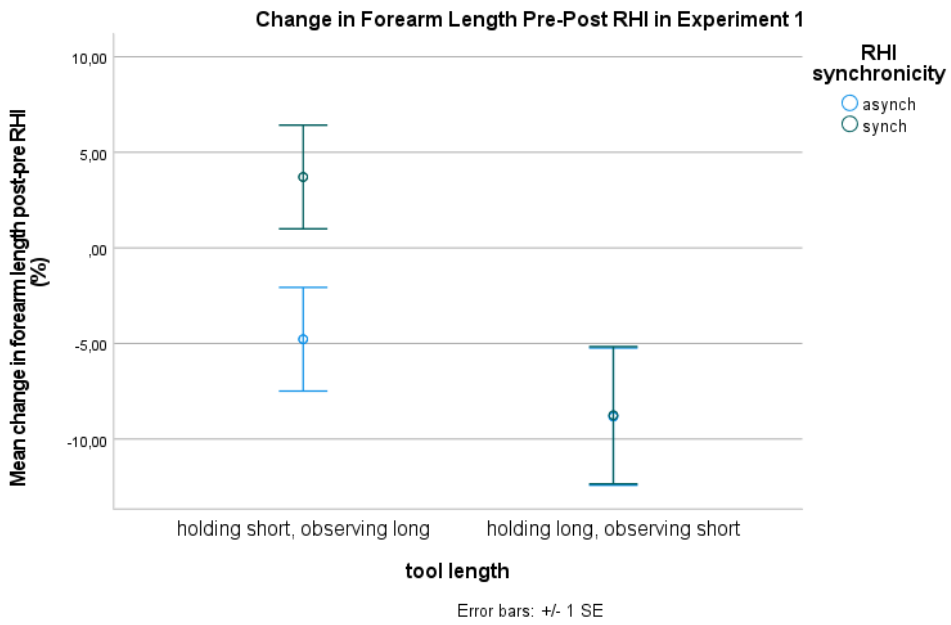

Figure 13. Interaction between tool length and RHI synchronicity on the change in forearm length after RHI in Experiment 1

These results indicated that after a tool-use task, observing a longer tool during synchronous RHI increased the BS measure of forearm length. While the significant main effect of tool length revealed that visual information regarding the tool length had an effect on the change in forearm length by itself, this effect was amplified when the illusion was synchronous, revealing a significant elongation effect that resulted from embodying the rubber hand and the longer tool it held.

On the other hand, there was a contraction effect for observing a shorter tool during synchronous RHI, but this contraction effect was not significantly different from the contraction effects in asynchronous conditions. This general trend for forearm length contraction could be attributed to the decay in the elongation effect for those who embodied the long tool prior to RHI. It is widely accepted in the literature that the integration of a tool into the BS 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 RHI, a decay of prior elongation is not enough to explain this general contraction effect. Alternately, this effect might also originate from observing a different-length tool during RHI. A comparison with Experiment 2 would reveal if the effect persists when the incongruency between the held and observed tool length is resolved.

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

3.4.5 Pain scores

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 held tool length since the distribution of the difference score 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.

3.4.6 Tool task duration

Another factor that might play a role in the results is the duration of the tool task. The tool task ended when the participants completed all four tasks. Thus, the duration of the task varied among the participants. A within-subjects t-test was conducted to compare tool task duration according to held tool length. There were no outliers, and the assumptions of normality and homogeneity were met. 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 (by about 65 seconds on average) 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.

3.4.6.1 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. An upper outlier in the "longer-duration" cell was winsorized to match the closest value. The assumptions of normality and homogeneity were met. 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, $t(22) = .60$, $p > .56$, $d = .24$.

3.4.6.2 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. An upper outlier in the "longer-duration" cell was winsorized to match the closest value. The assumptions of normality and homogeneity were met. The result indicated there was no significant effect of tool task duration on proprioceptive drift, $t(46) = .75$, $p > .46$, $d = .22$.

3.4.6.3 Forearm bisection pre/post RHI with short tool

In order to see whether the change in forearm length after RHI in the (held) 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. There were no outliers, and the assumptions of normality and homogeneity were met. The result suggested no significant effect of tool task duration on the change in forearm length after RHI in the short tool condition, $t(22) = 1.35$, $p > .19$, $d = .55$.

After conducting these analyses, we could safely conclude that tool task duration did not significantly affect our results.

CHAPTER 4

EXPERIMENT 2

TOOL-USE AND RUBBER HAND ILLUSION WITH SAME TOOLS

In order 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 RHI (see Figure 14). Through this control experiment, we aimed to show that observing a longer tool in RHI by itself was enough to produce the elongation effect. To substantiate this aim, we planned to compare the condition where participants used the short tool during the tool-use task and observed the long tool during synchronous RHI in Experiment 1 with the condition where participants used the short tool during the tool-use task and observed the short tool during synchronous RHI in Experiment 2.

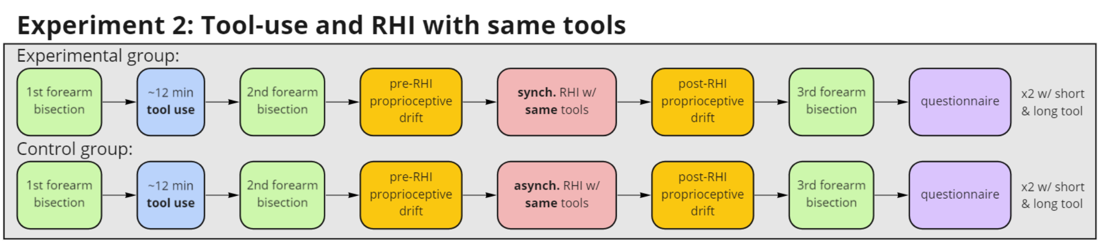

Figure 14. Procedure of Experiment 2

4.1 Participants

Twenty-four right-handed undergraduate students (11 female, mean age 21.29, ranging between 19 and 27) of Boğaziçi University participated in the experiment. They had normal or corrected vision, reported no injury or neurological disorder, and gave written informed consent to participate. All subjects were naïve to the purpose of the study and participated only in Experiment 2. They were compensated with course credit for their participation. The study was approved by the university ethics committee (see Appendix A) and was conducted according to the guidelines of the Declaration of Helsinki (World Medical Association, 2013).

4.2 Materials and methods

All materials and methods were conducted identically to those in Experiment 1. The only difference was that participants observed a tool identical to the one they held during RHI.

4.3 Experimental design

Similar to Experiment 1, a 2 x 2 mixed design was employed. Tool length (long or short) was the within-subjects factor, while RHI synchronicity (synchronous or asynchronous) was the between-subjects factor. The only difference from Experiment 1 was that during RHI, participants both held and saw a tool of the same length. Participants completed the experimental block twice with either the long or the short tool, where they held the same tool throughout both the tool-use and RHI tasks. There was a minimum of 10 minutes of break time between the two blocks, during which participants were encouraged to physically move and cognitively engage in different activities to reset any carryover effects from the first block. The order of the blocks was counterbalanced. Overall, there were four different conditions in Experiment 2: (i) using long tool, seeing long tool, synchronous; (ii) using long tool, seeing long tool, asynchronous; (iii) using short tool, seeing short tool, synchronous; (iv) using short tool, seeing short tool, asynchronous.

4.4 Results and discussion

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 RHI.

4.4.1 Forearm bisection pre/post tool task

A two-way within-subjects ANOVA was conducted on the first two forearm bisection results with *held tool length* (short and long) and *bisection* (pre tool task and post tool task) as within-subjects variables. There were no outliers, and the assumption of normality was met. There was no significant main effect of held 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 task ($M = 47.07$, $SD = 1.51$) compared to pre tool task ($M = 49.16$, $SD = 1.28$). 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 task ($M = 45.66$, $SD = 1.58$) compared to pre tool task ($M = 49.47$, $SD = 1.53$) in the long tool condition, $p = .002$ (see Figure 15). The same comparison was not significant for the short tool condition, $p > .66$.

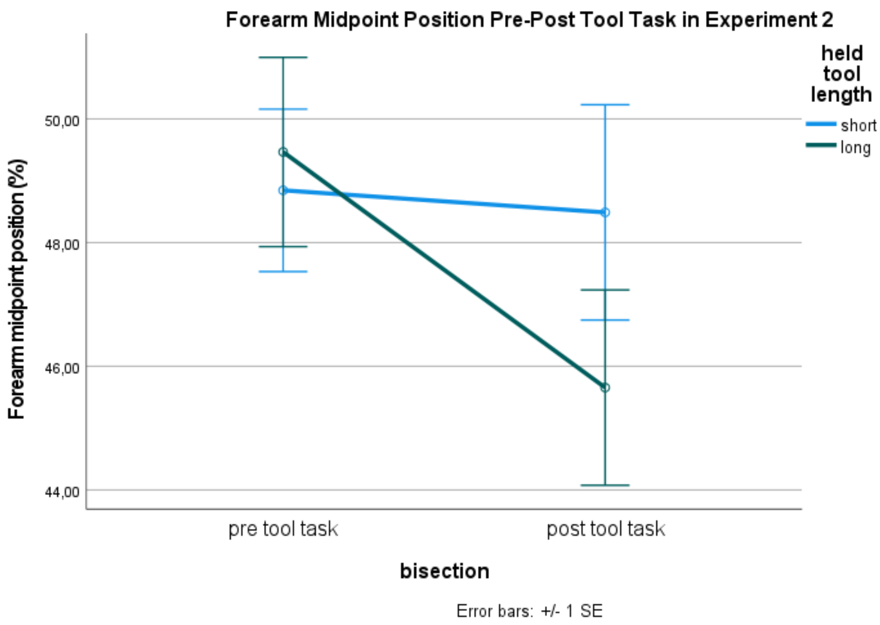

Figure 15. Interaction between held tool length and pre/post tool task bisection on forearm bisection results of Experiment 2

We have replicated the elongation effect with the long tool shown in Experiment 1. Additionally, there was a significant difference between pre and post tool use bisection measurements regardless of tool length. Compared with Experiment 1, the reason for this difference between the experiments is probably a random error due to individual differences. There was a small nonsignificant contraction effect for the short tool in Experiment 1, where we observed no effect of bisection. On the other hand, a small nonsignificant elongation effect for the short tool and a larger elongation effect for the long tool in Experiment 2 resulted in a significant difference between pre and post bisection measurements.

4.4.2 Proprioceptive drift

A mixed two-way ANOVA was conducted on proprioceptive drift results with *RHI synchronicity* (asynchronous and synchronous) as the between-subjects variable and *held tool length* (short and long) as the within-subjects variable. An upper outlier in the “long tool & synchronous” cell was winsorized to match the closest value. The assumptions of normality, homogeneity of variances and covariances were met. There was a significant main effect of the RHI synchronicity, $F(1, 22) = 16.14$, $p = .001$, $\eta_p^2 = .42$, with the participants that experienced synchronous RHI ($M = 5.48$, $SD = .67$) reporting more drift than those that experienced asynchronous RHI ($M = 1.67$, $SD = .67$). On the other hand, there was no significant main effect of held tool length, $F(1, 22) = 2.07$, $p > .16$, $\eta_p^2 = .086$. The interaction between RHI synchronicity and held tool length was not significant either, $F(1, 22) = 3.42$, $p = .078$, $\eta_p^2 = .135$ (see Figure 16).

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, $r(12) = -.24$, $p > .45$.

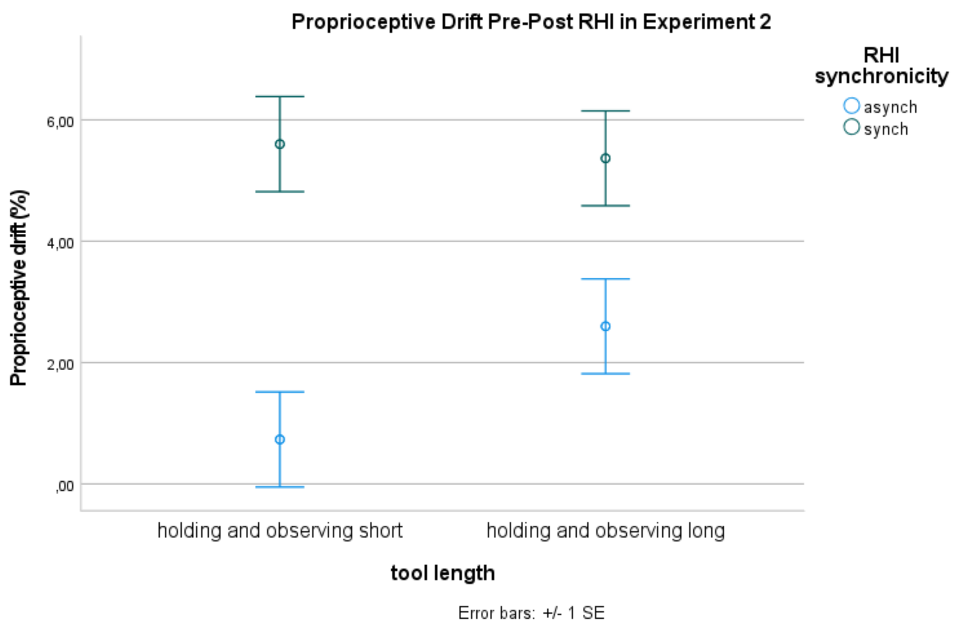

Figure 16. Interaction between tool length and RHI synchronicity on proprioceptive drift results in Experiment 2

We have also replicated the implicit embodiment of the rubber hand and the tool it held in the synchronous RHI 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 RHI 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 held tool length in Experiment 1 most likely arose due to the decrease in illusion strength as participants observed different-length tools during RHI.

4.4.3 Subjective experience questionnaire

A mixed three-way ANOVA was conducted on the mean ratings of questionnaire components (embodiment, loss of hand, movement, affect, deafference) with *RHI synchronicity* (asynchronous and synchronous) as the between-subjects variable, and *held tool length* (long and short) and *components* as within-subjects variables. A lower outlier in the "short tool & synchronous & embodiment" cell, a lower outlier in "short tool & asynchronous & affect" cell, and a lower outlier in "short tool & synchronous & affect" cell were winsorized to match the closest values. Normality assumption was violated for four subgroups (out of twenty), which was omitted since the test is robust for minor violations. Sphericity and homogeneity of variances and covariances assumptions were met. There was a significant main effect of RHI synchronicity, $F(1, 22) = 5.00$, $p = .036$, $\eta_p^2 = .19$, as the participants that experienced synchronous RHI ($M = .80$, $SD = .24$) rated questionnaire statements more positively than those that experienced asynchronous RHI ($M = .055$, $SD = .24$).

There was no significant main effect of held 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 RHI 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 17). 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 RHI 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, $r(48) = .51$, $p < .001$.

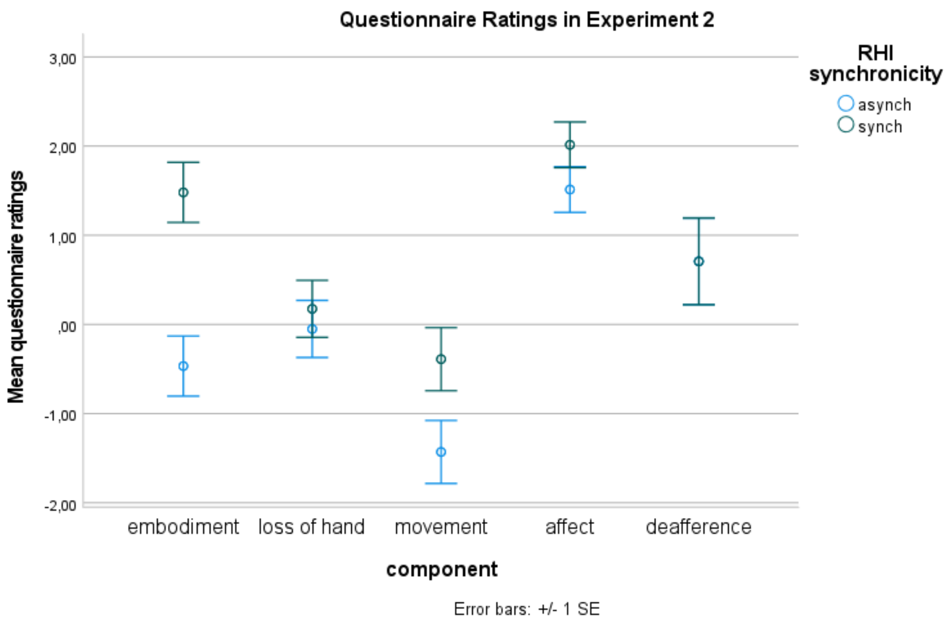

Figure 17. Interaction between RHI synchronicity and components on mean questionnaire scores in Experiment 2

Paralleling the proprioceptive drift results, we have replicated the explicit embodiment of the rubber hand and the tool it held in the synchronous RHI condition of Experiment 1. Additionally, there was a main effect of RHI synchronicity in Experiment 2 in contrast with Experiment 1, mainly due to the strong effect in embodiment component. As the incongruency of held and observed tool length was resolved in Experiment 2, participants rated the statements more positively overall, with an additional boost to the synchronous condition compared to Experiment 1. The stronger positive correlation between the drift and embodiment ratings compared to Experiment 1 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.

4.4.4 Forearm bisection pre/post RHI

A mixed two-way ANOVA was conducted on the change in forearm length after RHI with *RHI synchronicity* (asynchronous and synchronous) as the between-subjects variable and *held tool length* (long and short) as the within-subjects variable. A lower outlier in the "long tool & synchronous" cell was winsorized to match the closest value. The assumptions of normality, homogeneity of variances and covariances were met. There was no significant main effect of RHI synchronicity, $F(1, 22) = 1.68$, $p > .20$, $\eta_p^2 = .071$, and held tool length, $F(1, 22) = .60$, $p > .44$, $\eta_p^2 = .026$, and no significant interaction between RHI synchronicity and tool length, $F(1, 22) = .98$, $p > .33$, $\eta_p^2 = .043$ (see Figure 18). 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 RHI in the "long tool & synchronous" condition. There was a negative non-significant correlation, $r(12) = -.32$, $p > .31$.

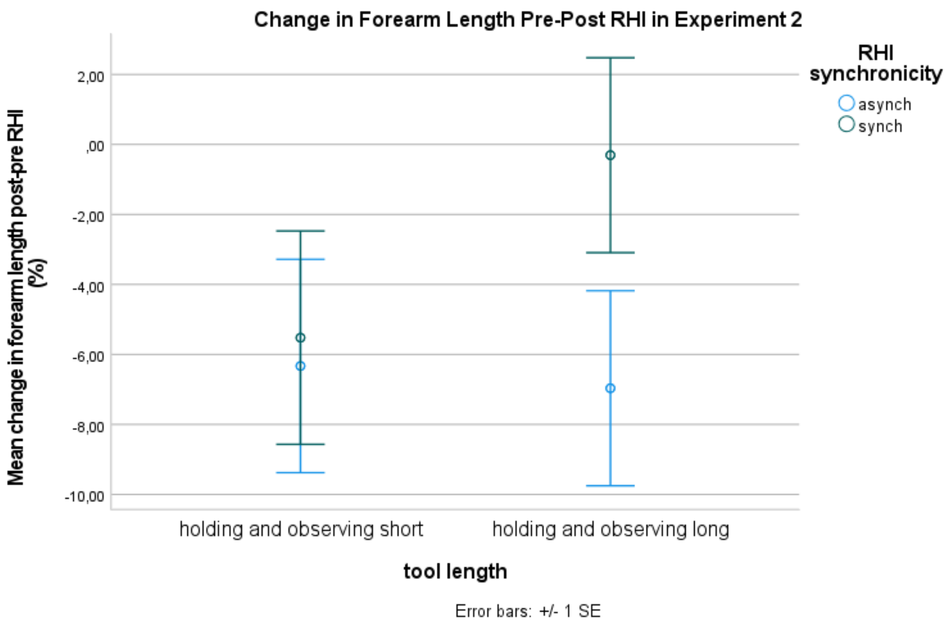

Figure 18. Interaction between tool length and RHI synchronicity on the change in forearm length after RHI in Experiment 2

These results revealed that the general trend towards forearm contraction observed in Experiment 1 was not due to observing different-length tools during RHI, 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 RHI, 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 RHI. 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 RHI, 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 became apparent that the forearm bisection task results might also reflect a moving average of recent forearm midpoint position. Comparing these results with Experiment 3 might give us more insight into this effect since participants kept their forearm in a similar position in the tool-hold task to that of RHI in Experiment 3.

Nevertheless, a pooled analysis of Experiments 1 and 2 was warranted to test our third hypothesis and see if the significant elongation effect produced in Experiment 1 still held up when compared to the short tool condition of Experiment 2.

4.4.5 Forearm bisection pre/post RHI on pooled E1 & E2 data

A mixed three-way ANOVA was conducted on the change in forearm length after RHI with pooled data of Experiments 1 and 2. *Held tool length* (long and short) was the within-subjects variable while *RHI synchronicity* (asynchronous and synchronous) and *observed tool length* (same or different) were between-subjects variables. A lower outlier in the "long tool & synchronous & same tool" cell was winsorized to match closest value. The assumptions of normality, homogeneity of variances and covariances were met. There was no significant main effect of RHI 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 held tool length, $F(1, 44) = 2.38$, $p = .13$, $\eta_p^2 = .051$. There was also no significant interaction between RHI synchronicity and held tool length, $F(1, 44) = .11$, $p > .74$, $\eta_p^2 = .002$, and between RHI synchronicity and observed tool length $F(1, 44) = .013$, $p > .90$, $\eta_p^2 < .001$. However, there was a significant interaction between held 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 held the short tool ($M = -.53$, $SD = 2.04$) or the long tool ($M = -8.79$, $SD = 2.27$) while observing different-length tools, $p = .004$. Most importantly, the three-way interaction between held tool length, observed tool length, and RHI synchronicity was not significant, $F(1, 44) = 3.41$, $p = .072$, $\eta_p^2 = .072$. However, a planned comparison revealed a significant effect between the conditions where the short tool holding participants observed a different tool ($M = 3.71$, $SD = 2.89$) or the same tool ($M = -5.52$, $SD = 2.89$) during synchronous RHI, $p = .029$ (see Figure 19). The same comparison was not significant in long tool holding participants, $p = .070$, or in short tool holding asynchronous RHI conditions, $p > .70$.

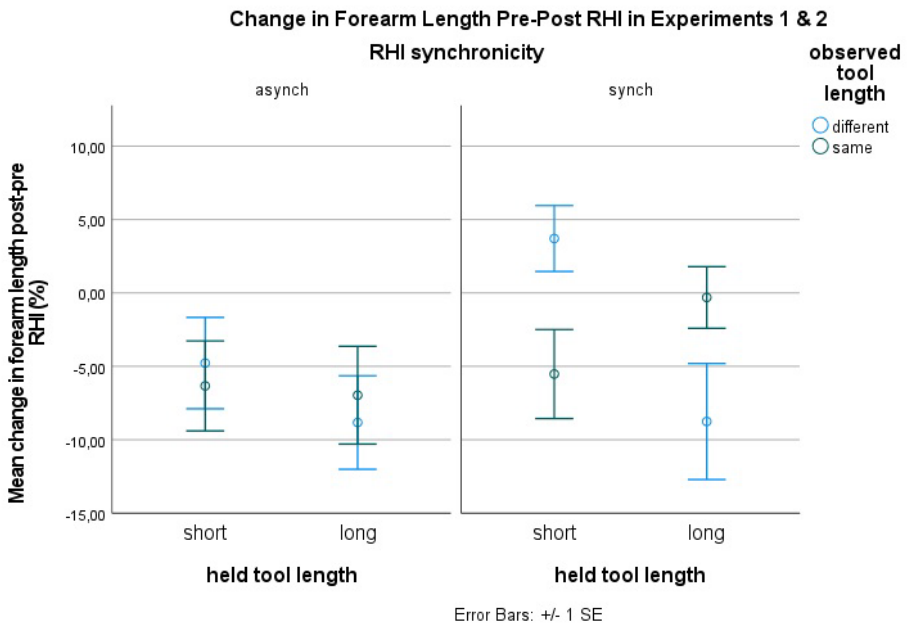

Figure 19. Three-way interaction between held tool length, observed tool length, and RHI synchronicity on the change in forearm length after RHI in pooled data of Experiments 1 & 2

These results indicated that the elongation effect observed in Experiment 1 resulted solely from observing a longer tool during synchronous RHI. Thus, we can conclude that it is indeed possible to modify BS through changes induced in BI via RHI, confirming our third hypothesis. Additionally, a closer inspection of Figure 19 suggested the main effect of observing a long tool over a short one during RHI. While this effect was negligible in asynchronous conditions, it was amplified in synchronous ones. However, due to the design of our experiment, we were not able to investigate the significance of the effect of observing a long tool or a short tool during RHI, as this variable changed both within and between subjects.

4.4.6 Pain scores

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 held tool length. 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 suggested that the amount of pain/numbness/tingling caused by the short and long tools was not different in Experiment 2 either.

4.4.7 Tool task duration

A within-subjects t-test was conducted to compare tool task duration according to held tool length. A lower outlier in the difference score was winsorized so that both task durations for the outlier matched the task durations of the closest case in the difference score. The assumptions of normality and homogeneity were met. 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.

4.4.7.1 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. There were no outliers, and the assumptions of normality and homogeneity were met. 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, $t(22) = -.10$, $p > .91$, $d = -.042$.

3.4.6.2 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. An upper and a lower outlier in the "longer-duration" cell were winsorized to match the closest values. The assumptions of normality and homogeneity were met. The result indicated there was no significant effect of tool task duration on proprioceptive drift, $t(46) = -1.54$, $p > .13$, $d = -.44$.

After conducting these analyses, we could safely conclude that tool task duration did not significantly affect our results.

CHAPTER 5

EXPERIMENT 3

TOOL-HOLD AND RUBBER HAND ILLUSION

WITH SAME OR DIFFERENT TOOLS

A comparison of the first two experiments showed that after using a tool for a short period, it was possible to manipulate the internal representation of body metrics by observing a longer tool during RHI. Observing such an effect through RHI prompted us to investigate if active tool use was a necessary prior to enable modification of BS via RHI. Previous works have shown that only imagining an action with a tool might be enough to increase corticospinal facilitation for relevant muscles (Fourkas et al., 2008) and integrate the tool into the BS (Baccarini et al., 2014). Thus, we decided to change the tool-use task into a tool-hold task, where participants conducted the task with their left hand while only holding the tool in their right hand. Following tool-hold tasks, participants experienced synchronous RHI where they either saw a tool with the same length or a different length (see Figure 20). As a result, since we did not plan to urge participants to actively imagine completing the task with the tool, unlike in previous experiments, we did not expect to see any effect through tool-use or RHI manipulations.

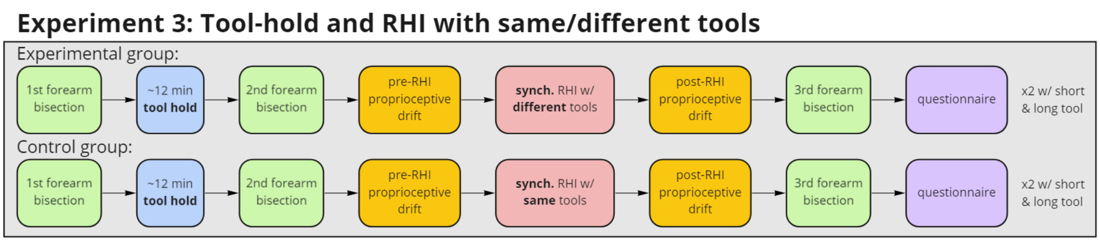

Figure 20. Procedure of Experiment 3

5.1 Participants

Twenty-four right-handed undergraduate students (18 female, mean age 20.50, ranging between 19 and 27) of Boğaziçi University, who were compensated with course credit, participated in the experiment. They had normal or corrected vision, reported no injury or neurological disorder, and gave written informed consent to participate. All subjects were naïve to the purpose of the study and participated only in Experiment 3. The study was approved by the university ethics committee (see Appendix A) and was conducted according to the guidelines of the Declaration of Helsinki (World Medical Association, 2013).

5.2 Materials and methods

For Experiment 3, there were certain modifications to the tool-use (now tool-hold task) and the RHI tasks, while other materials and methods were identical to previous experiments.

5.2.1 Tool-hold task

Participants were instructed to extend their right arm (this time without holding the tool) in the parasagittal axis as far as they could without leaning forward, with their backs straight with their abdomen touching the table. Their maximum reach was noted, but this time, instead of fixing the distal edge of the target sheet at this position like in previous experiments, the distal edge of the target sheet was fixed 10 cm further so that the furthest row of targets would coincide with maximum reach. To imitate the two-step procedure of previous experiments, but without using the tool, participants were instructed to grasp the cube using the left thumb and index finger (similar to prongs of the tools), place it next to a piece of sponge situated around 15 cm in front of them, touch the sponge with the index finger, pick the cube back up, and place it on the target. After placing all eighteen cubes in this manner, participants were instructed to follow the reverse procedure to recollect the cubes: grasp cubes with the thumb and index finger, place them next to the sponge, touch the sponge with the index finger, grab the cube, and place it in the designated basket. As participants executed the tasks with their left hand, they were instructed to press on the lever to close the prongs of the tool, which was grasped in the same manner as in previous experiments. Throughout the procedure, the proximal end of the tool was situated on the edge of the table, and its distal tip was resting on the table (see Figure 21). Placing the sheet 10 cm further, grasping cubes with the thumb and the index finger to resemble prongs of tools, and asking the participant to actively press on the lever while executing the task were minor modifications intended to increase the probability of a possible effect on bisection measurements. Before starting the tasks, participants were requested to place the first two cubes on corresponding targets and then retrieve them. Once they executed the movements correctly, the procedure was initiated. The tasks performed in Experiment 3 were identical to previous experiments, but each was executed with the left hand, without a tool. The total duration was recorded to compare with previous experiments.

Figure 21. Snapshot of tool-hold task with long tool on random-target sheet

5.2.2 Tool-holding rubber hand illusion

Contrary to previous experiments, there was no asynchronous stimulus condition. Both groups experienced synchronous RHI; while one group saw a same-length tool in the rubber hand, the other group observed a different-length tool.

5.3 Experimental design

Although this experiment also employed a 2 x 2 mixed design and tool length (long or short) was the within-subjects factor, unlike previous experiments, the between-subjects factor was tool match during RHI (same or different). Another difference from earlier experiments was that all participants experienced synchronous RHI. Participants completed the experimental block twice with either the long or the short tool, where they held the same tool throughout both the tool-use and RHI tasks. There was a minimum of 10 minutes of break time between the two blocks, during which participants were encouraged to physically move and cognitively engage in different activities to reset any carryover effects from the first block. The order of the blocks was counterbalanced. Overall, there were four different conditions in Experiment 3: (i) holding long tool, seeing long tool, synchronous; (ii) holding long tool, seeing short tool, synchronous; (iii) holding short tool, seeing long tool, synchronous; (iv) holding short tool, seeing short tool, synchronous.

5.4 Results and discussion

Unlike Experiments 1 and 2, mixed ANOVA analyses on the proprioceptive drift, questionnaire, and forearm bisection results pre and post RHI task 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 experiments to compare the questionnaire ratings, proprioceptive drift results, and forearm bisection results pre and post RHI.

5.4.1 Forearm bisection pre/post tool task

A two-way within-subjects ANOVA was conducted on the first two forearm bisection results with *held tool length* (short and long) and *bisection* (pre tool task and post tool task) as within-subjects variables. There were no outliers, and the assumption of normality was met. There was no significant main effect of held 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 held 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 task ($M = 48.89$, $SD = 2.04$) and the pre tool task ($M = 50.59$, $SD = 1.59$), $p > .18$. The same comparison was not 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 the elongation effect in 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 grasp 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 were not enough to incur an effect similar to active imagery of tool-use.

5.4.2 Proprioceptive drift on pooled E1 & E2 & E3 data

Since there was not any 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 length* (same and different) and *tool task* (tool-use and tool-hold) were between-subjects variables, while *held tool length* (short and long) was the within-subjects variable. An upper outlier in the "long tool & tool-use & same-tool" cell was winsorized to match the closest value. The assumptions of normality, homogeneity of variances and covariances were met. There was a significant main effect of held tool length, $F(1, 44) = 4.53$, $p = .039$, $\eta_p^2 = .093$, with the participants that held the long tool ($M = 5.21$, $SD = .56$) reporting more drift than those that held the short tool ($M = 3.85$, $SD = .54$). However, there was no significant main effect of observed tool length, $F(1, 44) = .91$, $p > .34$, $\eta_p^2 = .020$, and tool task, $F(1, 44) = 1.83$, $p > .18$, $\eta_p^2 = .040$. None of the two-way interactions were significant, with following results: held tool length and observed tool length, $F(1, 44) = 3.04$, $p = .088$, $\eta_p^2 = .065$; held tool length and tool task, $F(1, 44) = .11$, $p > .73$, $\eta_p^2 = .003$; and observed tool length 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-tool ($M = 48.89$, $SD = 2.04$) and different-tool ($M =$

50.59, $SD = 1.59$) conditions where participants held the short tool following tool-use, $p > .39$. The same comparison for the long tool condition following tool-use was also not significant, $p > .94$.

These results suggested that active tool-use prior to a tool-holding RHI procedure does not change the proprioceptive drift results. Additionally, planned comparisons revealed that after tool-use, observing a longer or shorter tool during RHI does not affect proprioceptive drift either. So, we can conclude that the significant main effect of held tool length was neither due to the observed tool length being different from held tool length nor was it due to the elongation effect from prior tool-use. Additionally, the lack of interaction between held tool length and tool task means that this effect occurs independently of the motoric embodiment of the tool provided with active tool use. However, the absence of this effect in Experiment 2 suggests it is not very robust.

5.4.3 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 length* (same and different) and *tool task* (tool-use and tool-hold) were between-subjects variables, while *held tool length* (short and long) was the within-subjects variable. Homogeneity of covariances assumption was violated, and since the only questionnaire component of interest was “embodiment,” other components were excluded from the analysis. After this exclusion, there were no outliers, and the assumptions of normality, homogeneity of variances and covariances were met. There was no significant main effect of held tool length, $F(1, 44) = .52$, $p > .47$, $\eta_p^2 = .012$, observed tool length, $F(1, 44) = 2.69$, $p > .10$, $\eta_p^2 = .058$, and tool task, $F(1, 44) = .001$, $p > .98$, $\eta_p^2 < .001$. None of the two-way interactions were significant, with following results: held tool length and observed tool length, $F(1, 44) = 1.44$, $p > .23$, $\eta_p^2 = .032$; held tool length and tool task, $F(1, 44) = .55$, $p > .46$, $\eta_p^2 = .012$; and observed tool length 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-tool ($M = 1.36$, $SD = .44$) and different-tool ($M = .27$, $SD = .44$) conditions where participants held the short tool following tool-use, $p = .089$. 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 a robust measure of BI unaffected by the changes in BS. Moreover, as expected, embodiment ratings were positively correlated with proprioceptive drift measurements.

5.4.4 Forearm bisection pre/post RHI on pooled E1 & E2 & E3 data

Since there was no asynchronous condition in Experiment 3, forearm bisections results pre and post RHI 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 RHI with pooled data of synchronous conditions of all experiments. *Observed tool length* (same and different) and *tool task* (tool-use and tool-hold) were between-subjects variables, while *held tool length* (short and long) was the within-subjects variable. A lower outlier in the "long tool & same tool & tool-use" cell was winsorized to match closest value. The assumptions of normality, homogeneity of variances and covariances were met. There was no significant main effect of tool task, $F(1, 44) = .66$, $p > .42$, $\eta_p^2 = .015$, observed tool length, $F(1, 44) = .058$, $p > .81$, $\eta_p^2 = .001$, and held tool length, $F(1, 44) = 3.14$, $p = .083$, $\eta_p^2 = .067$. There was also no significant interaction between tool task and held tool length, $F(1, 44) = .074$, $p > .78$, $\eta_p^2 = .002$, and between tool task and observed tool length $F(1, 44) = .008$, $p > .92$, $\eta_p^2 < .001$. However, there was a significant interaction between held and observed tool length, $F(1, 44) = 5.41$, $p = .025$, $\eta_p^2 = .11$, as Bonferroni-adjusted post-hoc tests revealed a significant difference only between the conditions where participants held 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 held tool length, observed tool length 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 holding 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 22). The same comparison for the tool-hold condition was not significant, $p > .56$.

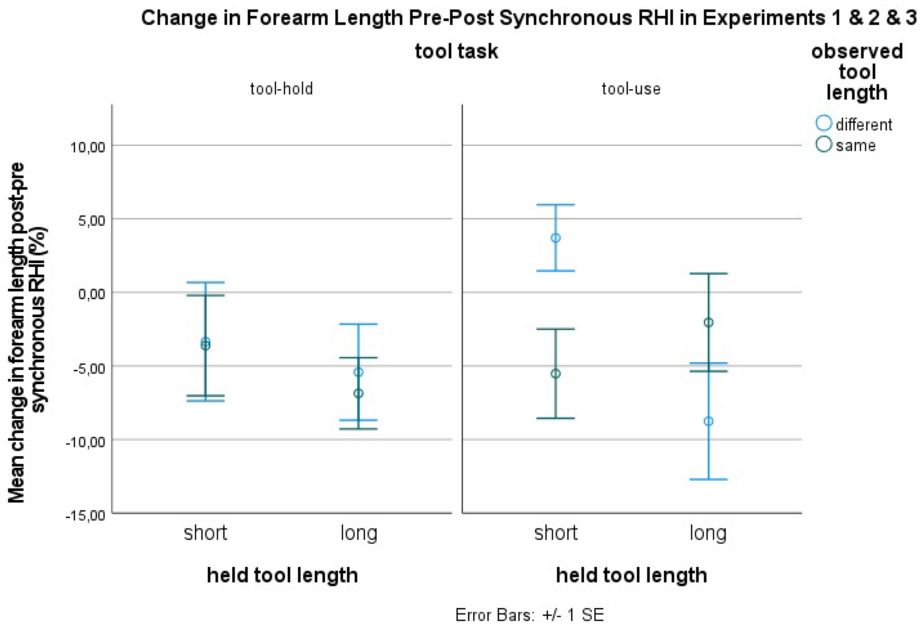

Figure 22. Three-way interaction between held tool length, observed tool length, and tool task on the change in forearm length after RHI in pooled data of synchronous conditions of Experiments 1 & 2 & 3

These results indicated that prior active tool use moderates the elongation effect that occurred while observing a longer tool during RHI. The three-way interaction shows that tool-use moderates the significant interaction between held and observed tool length. Thus, confirming our fourth hypothesis, we could conclude that modification of BS through changes induced in BI via RHI 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 RHI, 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 RHI.

5.4.5 Pain scores

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 held tool length. 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 suggested that the amount of pain/numbness/tingling caused by the short and long tools was not different in Experiment 3.

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 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 revealed that the amount of pain/numbness/tingling caused by the tool-hold and the tool-use tasks was not different.

5.4.6 Tool task duration

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 held tool length. 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.

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. An upper outlier in the tool-use cell was winsorized to match the closest value. The assumptions of normality and homogeneity were met. The result suggested that there was no significant effect of task type on duration, $t(142) = .30$, $p > .76$, $d = .052$. Thus, we concluded that the amount of time it took to complete the tool-hold and the tool-use tasks were not different.

CHAPTER 6

DISCUSSION AND CONCLUSION

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 the purposes of action or perception. However, there has been a substantial disconnect in the field due to the lack of experimental work on the interaction of these representations. This thesis bridges the gap between the two bodies of literature by comparing the effect of these paradigms on BS and BI in a single experimental setup.

6.1 General discussion

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 BS measures, while synchronous RHI resulted in an embodiment of and drift towards the tool-holding rubber hand in BI measures. Thus, the experimental basis for the intended comparison of BS and BI was established.

Next, the influence of tool-use on RHI was investigated to reveal how BS-related changes modified BI. Interestingly, tool-related factors did not influence RHI measures in any meaningful way. There was a slight tendency for increased proprioceptive drift while participants wielded 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 others evaluated the BI measures in the presence or absence of the task. Thus, our results might reflect an additional effect of familiarity with the tool. Altogether, these observations indicate that as long as the tool is functional, it is seamlessly integrated into the body representations. Preceding active use is unnecessary to reinforce its embodiment through BI, and this embodiment is strong enough to endure an incongruency in the length of the held and observed tools.

More importantly, we inspected the influence of BI on BS by examining how manipulation of the observed tool's length during RHI changed the representational length of the forearm. After the tool was embodied through BS via active tool-use, observing a longer tool during synchronous RHI increased the BS measure of forearm length. Crucially, this effect was absent if the tool was not actively used prior to RHI or not embodied through BI due to asynchronous stimulation. This finding was novel and notable for several reasons.

Firstly, this thesis was the first (to our knowledge) to investigate how BS measures of limb size were affected by tactile RHI. Previous studies that reported an effect on BS after tactile induction had measured changes in limb location (Kalckert & Ehrsson, 2014; Riemer et al., 2013). However, measurements that reflect a change in limb size were the most common method of studying BS in the tool-use paradigm and might involve different subprocesses to that of location.

Secondly, the experimental design of this thesis enabled the first empirical comparison of BS and BI through the combined procedure of tool-use and RHI paradigms. While this design provides a novel framework for studying the interaction of body representations, it also allows further inspection of factors that modify this interaction. We were able to control for the effects of fatigue and task duration, but future studies might systematically introduce these factors into the same design to reveal if they change this interaction effect.

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 and reinforces the significance of the forearm elongation effect.

6.2 Limitations and suggestions for future research

While the results of the thesis confirmed our hypotheses, there were nonetheless some limitations. In the forearm bisection task, we did not record the time for pointing movements, so we could not quantitatively confirm the ballistic characteristic of the movements. Additionally, the precision of the measurement could be improved by placing kinematic sensors on the tip of the left index finger, right middle finger, and right elbow. This alteration would also solve the previous limitation as it would provide the positional information in a temporal resolution of milliseconds. We did not employ this measurement for practical and financial reasons, but this absence was not vital since we could still observe the effect.

Another limitation was the control of different force profiles on hand muscles that resulted from the dynamic movement of short and long tools. Although we controlled the perceived torque by adding some weight to the short tool's distal tip in a static condition, there was a discernable difference when the participants actively moved the tool. In the preliminary tests conducted in our lab, a blindfolded person could not differentiate which tool was which while they simply held both tools in their hands. However, after a few seconds of active movement, the difference became apparent. Moreover, adding weight to balance the perceived torque compounded the fatigue effect that resulted from actively wielding the tools for the duration of the tool task. While the responses in VAS pain ratings showed comparable levels for the short and long tools, the mean ratings were much higher than those previously reported (Sposito et al., 2012). Lastly, to match the fatigue effect between the tool-use and tool-hold tasks, participants were asked to press on the lever as they executed the task with their left hands. However, this manipulation most likely replicated the fatigue effect in hand and forearm muscles, but not in upper arm or shoulder muscles. While we did not observe any effect in forearm bisection measures due to this distal shift in muscle recruitment (as described in Romano et al., 2019), this is still a critical factor that should be adequately controlled. Future studies should modify the task to induce less fatigue in arm muscles.

A criticism of the tool-use task we conducted might argue that the change in perceived forearm length might be contaminated by modifications of PPS rather than purely observing BS-related changes. This concern was addressed in the study of Cardinali, Frassinetti, et al. (2009) as they designed the tool task in a way that using the tool did not extend reachable space. However, the same study also used more precise methods (kinematic sensors) to find much smaller changes (in the order of millimeters). On the other hand, Sposito et al. (2012) observed much larger effects (in the order of centimeters) after participants extended their reachable space with a 60-cm-long tool. Since we would not be able to demonstrate a significant effect that was observable in the millimeter range without kinematic sensors, we preferred to design a task that extended the reachable space at the risk of this criticism. A future investigation that employs more precise measurements and a tool task that does not expand reachable space might provide a solution to this criticism.

After these experiments, we could not investigate the main effect of observed tool length during RHI in terms of the tool being short or long. Rather, we could only observe this effect in interactions. This limitation was due to the design of our experiments, as we determined the congruency of the observed tool length to the held tool length (same or different) to be a between-subjects factor in the experiments instead. Thus, the length of the tool held by the rubber hand (short or long) changed both within-subjects and between-subjects. Future experiments where the between-subjects factor is the length of the observed tool rather than the congruency of it to the held tool would satisfy the necessary design to investigate such an effect and fill the remaining gap.

Lastly, 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 RHI, which was the only condition that resulted in an elongation effect. We could not attribute this effect to the decay in the prior elongation effect from tool-use since the short tool conditions also displayed comparable contraction. Another potential explanation was that the forearm bisection task also reflected a rolling average of the forearm midpoint position. However, since the effect persisted in Experiment 3 even though the position of the tool-holding forearm was very similar in the tool-hold task and RHI, this explanation was also disregarded. While we were unable to reveal the factor that caused such an effect empirically, we suspect it might be due to the continuous stimulation of the elbow during RHI. Unlike the tool tasks, participants rested their right elbow on a platform during RHI to prevent uncontrolled arm motion that might affect proprioceptive drift results. This continuous tactile stimulation on the elbow that only occurred during RHI might have resulted in a bias towards forearm contraction compared to the tool tasks. Future experiments should administer the whole procedure while the participant is situated in the same position to control such random confounding effects.

6.3 Concluding remarks

All in all, our results support the theoretical approach that BS and BI 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 ballistic 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 BS and BI, which would, in turn, help consolidate decades of disconnected findings in tool-use and RHI paradigms under a coherent theory of body representation.

APPENDIX A

SUBJECTIVE EXPERIENCE QUESTIONNAIRE

Plastik El İllüzyonu Anketinin Alet Tutan El Versiyonu

Aşağıdaki ifadeler için -3 "kesinlikle katılmıyorum", +3 "kesinlikle katılıyorum", 0 ise "ne katılıyorum ne katılmıyorum" anlamına gelmektedir. Lütfen aşağıdaki ifadeleri, biraz önceki illüzyon deneyiminize dayanarak -3 ila +3 arasındaki ölçekte cevaplayınız.

	-3	-2	-1	0	+1	+2	+3
1) Plastik elin aleti tutmasını değil, doğrudan kendi elimin aleti tutmasını izliyor gibiydim.	☐	☐	☐	☐	☐	☐	☐
2) Tuttuğum alet, plastik el tarafından tutulan aletin konumunda gibiydi.	☐	☐	☐	☐	☐	☐	☐
3) Aleti tutan plastik el, benim elime doğru hareket ediyor gibiydi.	☐	☐	☐	☐	☐	☐	☐
4) Aleti tutan plastik el, benim elim gibiydi.	☐	☐	☐	☐	☐	☐	☐
5) Üç elim var gibiydi.	☐	☐	☐	☐	☐	☐	☐
6) Aleti tutan plastik el bedenimin parçası gibiydi.	☐	☐	☐	☐	☐	☐	☐
7) Elimde karıncalanma hissi oluştu.	☐	☐	☐	☐	☐	☐	☐
8) Aleti tutan plastik el, elimin bulunduğu konumda gibiydi.	☐	☐	☐	☐	☐	☐	☐
9) Aleti tutan plastik el bana ait gibiydi.	☐	☐	☐	☐	☐	☐	☐
10) Bu deneyimi ilginç buldum.	☐	☐	☐	☐	☐	☐	☐
11) Eğer istersem, plastik elin tuttuğu aleti hareket ettirebilecek gibiydim.	☐	☐	☐	☐	☐	☐	☐
12) Elim plastikleşmiş gibiydi.	☐	☐	☐	☐	☐	☐	☐
13) Elimdeki aleti hareket ettiremiyor gibiydim.	☐	☐	☐	☐	☐	☐	☐
14) Elim ortadan kaybolmuş gibiydi.	☐	☐	☐	☐	☐	☐	☐
15) Fırçanın tuttuğum alete değmesi keyifli bir his uyandırdı.	☐	☐	☐	☐	☐	☐	☐
16) Elim kontrolümün dışında gibiydi.	☐	☐	☐	☐	☐	☐	☐
17) Bu deneyimi keyifli buldum.	☐	☐	☐	☐	☐	☐	☐
18) Eğer istersem, elimdeki aleti hareket ettirebilecek gibiydim.	☐	☐	☐	☐	☐	☐	☐
19) Elim, aleti tutan plastik ele doğru hareket ediyor gibiydi.	☐	☐	☐	☐	☐	☐	☐
20) Plastik elin tuttuğu alet benim kontrolümdeymiş gibiydi.	☐	☐	☐	☐	☐	☐	☐
21) Elimin nerede olduğunu gerçekten söyleyemeyecek gibiydim.	☐	☐	☐	☐	☐	☐	☐
22) Ellerimin hissiyatı normalden daha az canlı gibiydi.	☐	☐	☐	☐	☐	☐	☐
23) Elimde uyuşma hissi oluştu.	☐	☐	☐	☐	☐	☐	☐
24) Hissettiğim dokunuşa, plastik elin tuttuğu alete dokunan fırça neden olmuş gibiydi.	☐	☐	☐	☐	☐	☐	☐
25) Plastik el, gerçek elime benzemeye başlamış gibiydi.	☐	☐	☐	☐	☐	☐	☐

English translation of the questionnaire:

Tool-holding Version of the Rubber Hand 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 recent experience of the illusion in a scale from -3 to +3.

	-3	-2	-1	0	+1	+2	+3
1) It seemed like I was watching my own hand holding the tool, not the rubber hand.	☐	☐	☐	☐	☐	☐	☐
2) It seemed like the tool I held was in the position of the tool held by the rubber hand.	☐	☐	☐	☐	☐	☐	☐
3) It seemed like the rubber hand holding the tool was moving towards my own hand.	☐	☐	☐	☐	☐	☐	☐
4) It seemed like the rubber hand holding the tool was my own hand.	☐	☐	☐	☐	☐	☐	☐
5) It seemed like I had three hands.	☐	☐	☐	☐	☐	☐	☐
6) It seemed like the rubber hand holding 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 holding the tool was in the position of my own hand.	☐	☐	☐	☐	☐	☐	☐
9) It seemed like the rubber hand holding the tool belonged to me.	☐	☐	☐	☐	☐	☐	☐
10) I found this experience interesting.	☐	☐	☐	☐	☐	☐	☐
11) It seemed like I could move the tool held 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 held.	☐	☐	☐	☐	☐	☐	☐
14) It seemed like my own hand disappeared.	☐	☐	☐	☐	☐	☐	☐
15) The touch of the brush on the tool I held 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 held if I wanted to.	☐	☐	☐	☐	☐	☐	☐
19) It seemed like my hand was moving towards the rubber hand holding the tool.	☐	☐	☐	☐	☐	☐	☐
20) It seemed like the tool held 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 held by the rubber hand.	☐	☐	☐	☐	☐	☐	☐
25) It seemed like the rubber hand started to resemble my own hand.	☐	☐	☐	☐	☐	☐	☐

APPENDIX B

ETHICS COMMITTEE APPROVAL

Evrak Tarih ve Sayısı: 23.06.2021-18473

T.C.
BOĞAZİÇİ ÜNİVERSİTESİ
SOSYAL VE BEŞERİ BİLİMLER YÜKSEK LİSANS VE DOKTORA TEZLERİ ETİK İNCELEME KOMİSYONU
TOPLANTI TUTANAĞI

Toplantı Sayısı	:	18
Toplantı Tarihi	:	17.06.2021
Toplantı Saati	:	13:00
Toplantı Yeri	:	Zoom Sanal Toplantı
Bulunanlar	:	Dr. Öğr. Üyesi Yasemin Sohtorik İlkmen, Prof. Dr. Ebru Kaya, Prof. Dr. Fatma Nevra Seggie
Bulunmayanlar	:	

Alp Erkent

Bilişsel Bilim

Sayın Araştırmacı,

"Alet Kullanımı ve Plastik El İllüzyonunun Dayandığı Beden Temsillerinin Karşılıklı İlişkileri" başlıklı projeniz ile ilgili olarak yaptığınız SBB-EAK 2021/39 sayılı başvuru komisyonumuz tarafından 17 Haziran 2021 tarihli toplantıda incelenmiş ve uygun bulunmuştur.

Bu karar tüm üyelerin toplantıya çevrimiçi olarak katılımı ve oybirliği ile alınmıştır. COVID-19 önlemleri kapsamında kurul üyelerinden ıslak imza alınamadığı için bu onay mektubu üye ve raportör olarak Ebru Kaya tarafından bütün üyeler adına e-imzalanmıştır.

Saygılarımızla, bilgilerinizi rica ederiz.

Prof. Dr. Ebru KAYA
ÜYE

e-imzalıdır
Prof. Dr.Ebru KAYA
Raportör

SOBETİK 18 17.06.2021

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