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Shifting Perceptions: Exploring with the Rubber Hand Illusion

by

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Abstract

In two experiments, we explored the boundary conditions for evoking the rubber hand illusion (RHI). In the first study, we hypothesized that we could elicit more vivid RHI experiences using personal cell phones than using wooden blocks as external objects because we interact with our phones and they are familiar objects. The cell phone condition elicited a weak illusory experience but it did not significantly differ from the wooden block condition. In the second study, we hypothesized that manipulating the size of rubber hands used for the illusion would affect size estimates of objects. Participants who experienced a strong RHI with a large rubber hand underestimated the size of small objects more than participants who did not vividly experience the illusion. However, this underestimation bias was stronger before experiencing the illusion rather than afterwards, suggesting that just visual size comparison might affect size estimates rather than experiencing the multisensory RHI. These findings contribute to our knowledge of the RHI by demonstrating that the conditions necessary to evoke the RHI extend to cell phones and rubber hands of different sizes.

Keywords: rubber hand illusion, body image, proprioception, body ownership, perceptions

Shifting Perceptions: Exploring with the Rubber Hand Illusion

The rubber hand illusion (RHI) is a phenomenon in which temporary feelings of ownership over a rubber hand are elicited. The illusion is evoked when the rubber hand is stroked in synchrony with one's own hand, but only the rubber hand is in view. The illusion is prompted by the interplay between visual cues, tactile sensations, and proprioception (Botvinick & Cohen, 1998). Over 100 papers have been published about the rubber hand illusion in the last two decades (Ferri, Chiarelli, Merla, Gallese & Costatini, 2013), demonstrating the ability to produce the multisensory experience among different individuals. While it is clear that the rubber hand illusion can be elicited, recent research has sought to determine specific boundaries and limitations of the illusion as well as how to apply the RHI as a tool for research questions across subfields of psychology. The goal of our first study was to explore the possibility of eliciting the RHI with cell phones to expand our knowledge of the conditions in which the RHI can be elicited. Our goal with the second study was to apply the RHI as a technique for manipulating perception of object sizes by doing a variation of the RHI with large rubber hands and small rubber hands.

Measures of the RHI

The illusion is typically measured by retrospective self-report of the illusory experience and proprioceptive drift distance. Botvinick and Cohen (1998) developed a questionnaire that has been used as a measure of subjective illusory experience. Other researchers have adapted these nine items according to their research question (Longo, Schuur, Kammers, Tsakiris & Haggard, 2008; Farmer, Tajadura-Jimenez & Tsakiris, 2012; Schaefer, Konczak, Heinze, & Rotte, 2013). Updating the questionnaire is supported by evidence suggesting that the first three self-report questions elicit stronger and more relevant responses indicative of illusory experience (Haans, Kaiser, Bouwhuis & IJsselstein, 2012; Peled, Ritsner, Hirschmann, Geva & Modai, 2000) than the remaining items. The first three items respectively measure illusory experience in terms of location (the touch came from the location where the paintbrush touched the rubber hand), causation (the touch came from the paintbrush touching the rubber hand), and embodiment (the rubber hand felt like my own). Higher scores on these questions are indicative of a more vivid illusory experience.

Proprioceptive drift, the second common measure of RHI experience, is typically the difference between where an individual's real hand is located and where the individual perceives her hand to be after experiencing the RHI. Proprioception is the knowledge of one's own body location in space. Botvinick and Cohen (1998) demonstrated how experiencing the RHI causes discontinuity in proprioception, typically resulting in individuals perceiving that their actual hand is closer to the rubber hand than its true location. This discrepancy between actual hand location and perceived hand location is measured and described as proprioceptive drift.

The use of proprioceptive drift as a measure of the rubber hand illusion has become more controversial as more RHI research is conducted. Some researchers have found that proprioceptive drift is consistent with subjective reports of the illusory experience, suggesting that proprioception is a valid measure of the illusion (Botvinick & Cohen, 1998; Ide, 2013; Schaefer et al., 2013) and ownership (Longo et al., 2008). Other research has found that proprioceptive drift is independent of subjective illusory ownership reports (Holmes, Snijders & Spence, 2006; Seiryte & Rusconi, 2015), which suggests that while proprioceptive drift is a valid measure for experiencing the illusion, subjective reports are necessary to conclude any illusory feelings of body ownership (Holle, McLatchie, Maurer & Ward, 2011; Rohde, Di Luca & Ernst, 2011). While there is still debate over the extent of what proprioception measures, evidence shows general consensus for using proprioceptive drift as at least a supplemental measure of the rubber hand illusion even if it is independent of subjective experience (Farmer et al., 2012; Holle et al., 2011; Seiryte & Rusconi, 2014; Haggard & Jundi, 2009).

Although self-report and proprioceptive drift are the two most common measures for assessing experience of the RHI, other techniques have been introduced since the original publication of the RHI (Botvinick & Cohen, 1998). Multiple researchers have looked at participant responses to the rubber hand being injured after inducing the illusion (Armel & Ramachandran, 2003; Yuan & Steed, 2010). Armel and Ramachandran (2003) used skin conductance response (SCR) to measure the level of stress among participants when a finger on the rubber hand was bent backwards. Although no real fingers were injured, participants who experienced the illusion more vividly tended to have higher SCR scores, showing a physiological response to a perceived threat to a rubber hand (Armel & Ramachandran, 2003). Hand temperature has also been used as a measure of RHI experience. Moseley et al. (2008) found that the temperature of an individual's real hand would decrease while the illusion was elicited, even though temperature was constant for the rest of the body. They speculated that temporary ownership over a rubber hand leads to a disruption in feelings of ownership for the real hand, which leads to the decreased temperature in that limb (Moseley et al., 2008). However, Rohde, Wold, Karnath, and Ernst (2013) tried to replicate this finding and while hand temperature did decrease during the RHI, they concluded that temperature change was independent of subjective feelings of body ownership during the illusion. Exploring these newer measures of the RHI is critical for better understanding the illusion as well as the validity of the questionnaire items and proprioceptive drift techniques commonly used.

Variations of the RHI

These measures of the RHI have been used to learn more about the RHI and the conditions necessary to elicit the illusory effect. Mainly, visual input (Armel & Ramachandran, 2003; Farmer et al., 2012; Hohwy & Paton, 2010) and anatomical congruency (Ferri et al., 2013; Ide, 2013) influence the degree to which individuals feel the illusion. More recently, researchers have also explored how virtual images and virtual reality affect the vividness of the RHI (Pavani & Zampini, 2007; Slater, Perez-Marcos, Ehrsson & Sanchez-Vives, 2008; Slater, Perez-Marcos, Ehrsson & Sanchez-Vives, 2009; Slater, Spanlang, Sanchez-Vives & Blanke, 2010). Comparing the results of such different manipulations to the RHI contributes to a better understanding of body image malleability.

By comparing multiple studies that manipulate the visual input during the RHI, we see that the visual component of the RHI does not override the multisensory experience as a whole. Instead, while likeness of the rubber hand to a participant's real hand does correlate with degree of illusion (Farmer et al., 2012; Holmes et al., 2006), it is possible to elicit at least a weak version of the RHI using rubber hands or other objects that do not appear similar to the individual's real hand. For instance, using a rubber hand that appears to belong to the same racial group of an individual typically elicits a significantly more vivid illusion than any other external object but individuals have still been found to experience illusory feelings of ownership over rubber hands of outgroup racial appearance while receiving synchronous tactile sensation (Farmer et al., 2012). Since participants have reported feeling body-ownership even in rubber hands that appear to belong to a different racial group, this supports the claim that visual cues and similarity in appearance do not override multisensory experience in affecting body-ownership (Farmer et al., 2012). This evidence supports previous findings that perceived similarity of one's own hand does not affect the subjective experience of the illusion (Longo, Schuur, Kammers, Tsakiris &

Haggard, 2009).

The rubber hand illusion has been reproduced with a variety of external objects to better understand how visual cues affect the multisensory experience. Armel and Ramachandran (2003) observed that even though generating the RHI with a rubber hand was most effective in shifting body image, participants still experienced the illusion when a wooden table was used in place of a rubber hand. Holmes et al. (2006) found similar results when using a wooden block in place of a rubber hand. Hohwy and Paton (2010) used a cardboard box to test the same idea and found that the RHI worked for participants who had already been exposed to the RHI with a rubber hand as the external object. Evidence that the RHI works with a variety of external objects supports the idea that body ownership is malleable and is at least partially independent of visual input. However, it is still unclear what exact conditions of the illusion or underlying features of the external objects are necessary for producing the experience of the RHI.

The anatomical congruency between a rubber hand and an individual's real hand has also been examined as a factor of illusion strength. Typically, placing the rubber hand parallel to the real hand with matching posture will elicit the strongest illusion (Ehrsson, Spence & Passingham, 2004; Holmes et al., 2006). However, participants have still experienced the rubber hand illusion even when the rubber hand was placed three feet away from the real hand (Armel & Ramachandran, 2003) and when the rubber hand was placed on a separate table directly above the real hand (Ferri et al., 2013). Ide (2013) has shown evidence that the anatomical plausibility of the rubber hand placement does correlate with the vividness of the RHI. Taken together, this evidence suggests that anatomical plausibility does affect body image malleability to at least some extent.

In light of newer technology, real-time videos and virtual reality environments can also be used to elicit the RHI and subsequent manipulations on the illusion. Pavani and Zampini (2007) used a real-time video of participants' hands rather than using a rubber hand, which allowed them to manipulate the size of the visible hand to participants during the illusion. Slater et al. (2008) found that participants who focused on a virtual arm that appeared to come out of their shoulder in a plausible position did experience the illusion but only when the tactile sensation was synchronous, suggesting that visual input does not override the multisensory integration even in virtual environments (VE). Since then, this work has been extended to show how a full body illusory effect can be elicited using VE (Slater et al., 2009; Slater et al., 2010).

Taking these different manipulations of the RHI into consideration, we can conclude that although placing a rubber hand (with physical likeliness to the participant) in proximity to the individual's body will elicit the strongest illusion, body image seems to be malleable enough that it is possible to elicit the illusion in less plausible conditions. However, since slightly different results have been found from study to study, we still cannot conclude any concrete rules for when the RHI will work or will not work. Using this general understanding of the conditions in which the illusion is elicited, recent research has applied the RHI as a technique for comparing how different populations differ in experiencing the RHI and the consequential implications for body image malleability in these populations.

Applications of the RHI

Specifically, the RHI has been used a tool for evaluating body image malleability in various clinical populations. Mussap and Salton (2006) found that individuals with eating disorders, such as bulimia and anorexia nervosa, are more susceptible to experiencing the RHI than individuals without a history of eating disorders. This intuitively suggests that individuals suffering from an eating disorder have more unstable body images than a control population and could provide insight into which individuals might be most receptive to cognitive therapy as it concerns body image (Mussap & Salton, 2006). Conversely, individuals on the autism spectrum are less susceptible to the RHI than individuals in a control group (Palmer, Paton, Kirkovski, Enticott & Hohwy, 2015; Schauder, Mash, Bryant & Cascio, 2015). Schauder et al. (2015) concluded that this shows individuals on the ASD spectrum are more likely to focus on internal cues than incorporating contextual information (such as the visuotactile sensation from the RHI) into perceptions of the self. Although it hardly seems conceivable that susceptibility to the RHI could ever be used as a diagnostic tool or predictor of susceptibility to eating disorders, these studies show how the application of the RHI across populations can contribute to our understanding of how individuals differ, such as in terms of body image stability and use of contextual information.

The RHI can also be used as a tool in cognitive psychology, specifically within an embodied cognition framework, to learn more about perception. Various methodologies have shown that body size influences perception of external object sizes (Proffitt, 2013; Stefanucci & Geuss, 2009) and that body size is assumed to be a constant size when using it as an ecological reference (Linkenauger et al., 2014). Findings from variations of body-scaling studies suggest that eliciting the RHI with an extremely large or small hand will create underestimations or overestimations of object sizes respectively (Linkenauger, Ramenzoni & Proffitt, 2010; Berlot, 2013; Linkenauger, Leyrer, Bulthoff & Mohler, 2013). The tendency to underestimate an object size after experiencing the rubber hand illusion with an unusually large rubber hand suggests that temporary body ownership of a rubber hand leads to using that hand as an ecological reference for size judgments of objects. In other words, we tend to use our hands as references for making size judgments since hand size is relatively stable. So if our “hand” is temporarily larger than usual, we are still prone to using it as a reference, resulting in underestimating the size of nearby objects. Conversely, using immersive virtual reality to create a first-person perspective of being in a small child's body (Banakou, Groten & Slater, 2013) or even smaller, a doll-size body (van der Hoort, Guterstam & Ehrsson, 2011), leads to overestimation of object sizes. However, it is still unclear whether this effect is equally large when using a large rubber hand and a small rubber hand to manipulate perceptions of object size. Additionally, it is unclear whether these biases in object size estimations are caused by experiencing the illusion or from the visual input of a rubber hand and using that visual input as a perceptual metric.

Our second study is an extension of Berlot's (2013) work showing that manipulating the size of rubber hands and eliciting an illusion will lead to biases in object size estimation. Berlot (2013) found that participants who experienced the RHI with a larger than average rubber hand would significantly underestimate the size of small objects. Participants who experienced the RHI with an average-sized hand had the most accurate size biases and participants who experienced the RHI with a small rubber hand tended to overestimate the size of small objects (Berlot, 2013). However, it is important to note that participants' estimates from the small hand condition did not significantly differ from the estimates of participants in the average-sized hand condition. Critically, Berlot's (2013) design cannot account for whether these estimation biases are a result of experiencing the RHI and assimilating the rubber hand into body image or if size estimation biases are merely a product of using visual input from the rubber hand. Our second study intends to answer this question.

Study Overviews

The goal of our first study was to gain a better understanding of the conditions necessary for the RHI to work. Specifically, we extended upon the work of Holmes et al. (2006) to compare RHI experience using different external objects. While other materials have been used to successfully produce the RHI, forms of electronic technology have yet to be tested. Rubber hands, tables and cardboard boxes are all objects that do not respond when acted on and have no assumed personal attachment value yet they still work as external objects during the rubber hand illusion (Armel & Ramachandran, 2003; Holmes et al., 2006). However, cell phones respond to touch-based commands, tend to hold an added attachment value (Thorsteinsson & Page, 2014), and affect our cognitive and emotional processing (Clayton, Lesher & Almond, 2015). The different interaction experience between non-electronic objects versus electronic objects could affect the vividness of the illusion when a cell phone is used in place of a rubber hand if interaction is an underlying factor of the illusion. Likewise, any pre-existing attachment to the external object could affect the vividness of the illusion. If this is the case, then cell phones could elicit a stronger illusory experience than a random object that doesn't hold any attachment value or visual similarity to a hand. Consequently, replacing the rubber hand with a personal cell phone could potentially heighten the RHI vividness if underlying features such as pre-existing attachment or object-interaction influence body ownership and self-attribution. We hypothesize that using a personal cell phone in place of a rubber hand will produce a Rubber Hand Illusion. Additionally, we hypothesize that while a rubber hand will create the strongest RHI, personal cell phones will elicit a stronger RHI than non-electronic objects such as a block of wood.

Our second study aims to replicate Berlot's (2013) findings of size estimation biases as a function of rubber hand size and assess whether or not these biases are caused by experiencing the RHI or by using the visual input of an unusually-sized hand as an ecological reference for size estimates. Our methodology is fairly similar to Berlot's (2013), with the exception that we did not include an average-sized hand condition. In addition to Berlot's (2013) procedure, we are also analyzing object size estimates when the rubber hand (large or small) is in view but before the illusion has been elicited. Comparing size estimates from before the RHI and after the RHI will show how size perceptions are affected by illusory experience but also visual input. We hypothesized that participants in the large hand condition would underestimate object sizes, and that this bias would increase after experiencing the RHI. Conversely, we hypothesized that participants in the small hand condition would overestimate object sizes, and that this bias would increase after experiencing the RHI. Lastly, we expected to find that self-report of illusory experience would moderate the bias in each condition. We hypothesized that individuals who reported more vivid illusory experiences in each hand condition would be more biased in their size estimates of objects.

Study 1

Method

Participants

Forty University of Richmond students were recruited for participation through online Spiderbytes during the summer of 2014. All participants received monetary compensation for their time.

Materials and Procedure

Subjects participated in a 30-minute, within-subjects design study that measured the effect of the Rubber Hand Illusion in three conditions. After giving informed consent, participants placed their left hand palm-up inside a box with cutouts on either end. The box served as a partition to hide the participant’s hand from view while leaving the external object in the participant’s visual field. The external object was placed parallel to the participant’s left hand within an anatomically plausible distance from the participant’s body. The hypothesis-blind researcher delivered synchronized tactile sensation to both the left hand and the external object with the eraser ends of pencils for a total of 2.5 minutes to allow time for the RHI to emerge (Armel & Ramachandran, 2003) during each trial. While stroking alone has been found to be more effective than tapping alone to elicit the illusion (Haans et al., 2012), we decided to use a combination of tactile sensation throughout each condition.

The three conditions included a rubber hand, a block of wood, and the participant's personal cell phone as the external objects (see Figure 1). A commercially available rubber hand, roughly 11cm by 8cm, was used as the first external object. After the rubber hand condition, the participant's personal cell phone and a white 11.5cm x 6cm x 1.5cm block of wood (comparable in size and shape to an iPhone 4) were used in a pre-randomized, counterbalanced order across participants. These two conditions were counterbalanced across participants to ensure that any sign of the RHI is from assimilation to body ownership rather than by chance or due to exposure in previous trials.

The effectiveness of the Rubber Hand Illusion had two measures. First, we measured for proprioceptive drift after each trial. Preceding the first trial and at the conclusion of each 2.5 minute trial, participants were asked to close their eyes and slide their right hand along a straightedge perpendicular to their left arm until they marked the location where they believed their right index finger was lined up with their left index knuckle (Yuan & Steed, 2010). The distance between the pre-trial estimate and each post-trial estimate was recorded and compared across conditions to look for any rightward biases towards the rubber hand. Afterwards, participants were asked to complete a 9-item questionnaire for each trial that measures the retrospective subjective experience of the illusion on a 7-point scale (adapted from Botvinick & Cohen, 1998; see Table 1). The 7-point scale ranged from -3 to 3, with -3 referring to "strongly disagree" and 3 referring to "strongly agree." The measures provide behavioral and subjective data that reflects the extent of the illusion, including illusory feelings of body ownership, across the multiple mediums used as external objects.

Results

Prior to looking at the results, we culled seven missing cases for the proprioceptive drift measure. Average proprioceptive drift for the rubber hand (*M* = 1.04 in, *SD* = 1.41), wood (*M* = 1.20 in, *SD* = 1.59) and phone (*M* = 1.23 in, *SD* = 1.80) were all similar. We ran a 2 x2 repeated measures ANOVA in R statistical program to compare the effect of order (phone first or wooden block first) and condition (wood or phone) on proprioceptive drift. Since we were interested in the comparison between the wooden block and phone conditions, we did not compare the rubber hand condition in any of our statistical analyses. Wooden block and phone proprioceptive drifts did not significantly differ across conditions for order $F(1) = 0.32$, $p = 0.57$, or condition, $F(1) = 0.16$, $p = 0.69$.

As shown in Figure 2, we averaged the scores from questionnaire items to compare subjective illusory experience. Participants in the rubber hand condition (*M* = 0.20, *SD* = 1.11) reported slightly higher feelings of the illusion compare to participants in the wood (*M* = -0.95, *SD* = 1.27) or phone condition (*M* = -1.05, *SD* = 1.25). A paired samples t-test between the wooden block condition questionnaire averages and phone condition averages scores did not significantly differ, $t(36) = 0.52$, $p = 0.61$.

Additionally, since the first three items of the questionnaire have been found to generate the strongest responses for experiencing the RHI (Botvinick & Cohen, 1998; Haans et al., 2012), we compared responses for the first three items (see Table 2). The rubber hand condition (*M* = 2.20, *SD* = 1.20) generated slightly higher responses to the first question than the wood condition

(*M* = 0.75, *SD* = 1.92) and the phone condition (*M* = 0.88, *SD* = 2.14). A paired samples t-test showed the scores between wooden block and phone condition were not significantly different, $t(36) = -0.77$, $p = 0.45$. The rubber hand condition (*M* = 1.35, *SD* = 1.56) also generated slightly higher responses than the wood condition (*M* = 0.05, *SD* = 2.16) and the phone condition (*M* = -0.13, *SD* = 2.03) for the second questionnaire item. These scores were not significantly different between the wooden block and phone condition, $t(36) = 0.17$, $p = 0.86$. Responses to the third question followed the same pattern with the rubber hand condition (M=1.25) eliciting slightly higher responses than the wood (*M* = -1.15, *SD* = 1.86) and phone (*M* = -1.15, S*D* = 1.79) conditions but without significant difference between the wooden block and phone conditions in a paired samples t-test, $t(36) = -0.34$, $p = 0.74$.

Study 2

Method

Participants

We recruited 61 University of Richmond students through the Introduction to Psychological Sciences course. Participants received partial course credit as compensation for their time.

Materials and Procedure

Subjects participated in a ten-minute, between-subjects design study that measured perception of object sizes before and after being exposed to the RHI as well as a retrospective self-report of illusory experience. We randomly pre-assigned participants to either the large rubber hand condition or the small rubber hand condition (see Figure 3) with the same procedure in each condition.

In order to construct an unusually large rubber hand and an unusually small rubber hand, we used two blue, High Five latex gloves. We stretched an extra-large glove and stuffed it with cotton. From the bottom of the palm to the tip of the middle finger, the large hand measured 21cm. The hand spanned 17cm from the widest point on the thumb to the widest point on the fifth finger. For the small hand, we cut about an inch off of the fingers on a small glove, taped the ends to round the tips then stuffed the glove with cotton. From the base of the palm to the tip of the middle finger, the small hand measured 13cm. From the widest point on the thumb to the widest point on the fifth finger, the small hand spanned 12.5cm. Lastly, to make the appearances of the hands as similar as possible, we taped the tips of each finger on the large hand to match the tape on the fingers of the small hand.

Upon arrival, we confirmed that participants did not have a latex allergy and reviewed the consent form before continuing. Participants placed a Hygloss Craft Glove For Adults on their left hand, were seated at a table and asked to rest their left arm on the table to the left of a partition. We devised a 25cm high partition to obstruct the view of participants' left hands so they would focus on the rubber hand placed directly in front of them on the table. The rubber hand was placed an anatomically-plausible distance from the participant's body. To increase the visual sensation of the illusion, we draped a black sheet from the wrist of the rubber hand to the participant's shoulder, to remove the visual reminder that the rubber hand was not connected to the participant in any way.

We conducted all measurements in millimeters so once seated, the hypothesis-blind researcher showed each participant a ruler and indicated the length of a millimeter. The researcher then proceeded to place three small objects in front of the participant one-by-one in a randomized order, roughly 5cm away from the pointer finger of the rubber hand (see Figure 4).

The objects were small, round, green translucent stones with diameters of 25mm, 29mm, and 31mm. When the researcher placed each green stone on the table, participants were asked to make a verbal judgment of each diameter. The diameters were drawn across each stone in red marker to avoid any confusion.

The researcher then conducted a 3-minute trial of the rubber hand illusion using the ends of paintbrushes to deliver synchronized tactile sensation to the rubber hand and the participant's hand simultaneously. Participants were reminded to focus on the rubber hand and to keep their left hand still during the trial until further instructed. Immediately following the trial, the researcher placed three small blue stones in front of the participant one-by-one in a randomized order, roughly 5cm from the pointer finger of the rubber hand. These blue stones were comparable to the green stones used before the trial in shape and size. When the researcher placed each blue stone on the table, participants were asked to make a verbal judgment of each diameter drawn across each stone.

After showing each blue stone, participants were allowed to move their left hand and filled out a three-item questionnaire about their experience during the RHI trial (see Table 3). We adopted the self-report items from the original RHI questionnaire (Botvinick & Cohen, 1998) and used an 8-point Likert scale where 0 indicated "disagree strongly" and 7 indicated "agree strongly." Participants indicated whether "during the experiment there were times when 1) it seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand touched 2) it seemed as though the touch I felt was caused by the paintbrush touching the rubber hand and 3) I felt as if the rubber hand were my hand." We chose to use these three items based on the empirical evidence suggesting that this items are the most indicative of illusory experience (Haans, Kaiser, Bouwhuis & IJsselstein, 2012; Peled, Ritsner, Hirschmann, Geva & Modai, 2000).

Following completion of the questionnaire, participants threw away the latex glove and were debriefed about the purpose of our study.

Results

Before analyzing the data, we culled one participant's data on the grounds that it was unclear which condition the subject was in (large or small hand), leaving 59 participants. After accounting for this, we ended up with 30 subjects in the large hand condition and 29 subjects in the small hand condition. We calculated bias as the size estimate (mm) minus actual object size (mm) for each of the six judgments across participants (354 observations). We calculated illusory strength as the average of the three questions in the questionnaire for each participant.

We performed a linear mixed-effects model fit by maximum likelihood analysis in R statistical program. Condition (large or small hand) and block (before or after experiencing the RHI) were included as fixed factors, illusory strength was entered as a covariate and participant was included as a random factor. All interaction terms were also included in the model.

We found a main effect of block, b = -9.83, SE = 3.25, t(291) = -3.02, p = .003, 95% CI: (-16.17, -3.50). Participants underestimated object size more in block one (M = -1.27 mm, SD = 14.65) than in block two (M = -0.32 mm, SD = 14.59).

As shown in Figure 5, we found an interaction between block and condition, b = 11.04, SE = 4.06, t(291) = 2.72, p = .007, 95% CI: (-8.07, 0.43). To explore this interaction, we performed separate mixed effects models for the large hand condition and the small hand condition. The large hand significantly changed in bias from block one (M = -2.08mm, SD = 13.96) to block two (M = -0.94mm, SD = 13.37), b = -9.83, SE = 2.94, t(148) = -3.34, p = .001, but there was no significant difference from block one (M= -0.44mm, SD = 15.36) to block two

(M = 0.33mm, SD = 15.80) for the small hand condition, b = 1.21, SE = 2.65, $t(143)$ = 0.45, p = 0.64.

We found a block by illusion interaction, b = 2.23, SE = 0.64, $t(291)$ = 3.47, p = .0006, 95% CI: (0.98, 3.48). By performing a separate mixed effects model for each block, we found that illusory strength resulted in greater underestimation biases but this effect was stronger for block one, b = -3.82, SE = 2.14, $t(55)$ = -1.78, p = .08, than block two, b = -1.59, SE = 2.18, $t(55)$ = -0.73, p = 0.47.

This is qualified by the three-way interaction between block, condition and illusory strength, b = -2.32, SE = 0.80, $t(291)$ = -2.90, p = .004, 95% CI: (-3.86, -0.76). The interaction between block and illusion was only significant for the large hand condition, b = 2.23, SE = 0.58, $t(148)$ = 3.84, p = .0002.

Discussion

In Study 1, while the phone condition did not elicit very strong responses to any illusory effects, self-report responses indicate ambiguous experiences of the RHI, which suggests that the phone did elicit a weak rubber hand illusion. However, the results do not support our second hypothesis since there were no considerable illusory effect differences between the phone condition and the wood condition.

The first study did have multiple limitations. By using a manual stroking method rather than an automated method, individual differences might have arisen between trials and conditions. We also did not account for subjective feelings towards personal cell phones so there is no way to tell if attachment did influence the illusory experience. Proprioceptive drift was also recorded on a blank sheet of paper and then measured by the researcher rather than having participants estimate their hand position along a ruler (Botvinick & Cohen, 1998). Using our method could have led to some variance in measurement.

Our first study does support prior research on the rubber hand illusion. Namely, participants reported strong feelings of the experience under the original conditions with a rubber hand as the external object. Additionally, since there were no significant differences between proprioceptive drifts across conditions although the rubber hand condition elicited stronger self-report responses, this study supports prior research that suggests proprioceptive drift is independent of illusory ownership (Holle et al., 2011; Holmes et al., 2006; Rohde et al., 2011). Although our hypothesis that a personal cell phone would produce a more vivid illusion than a non-electronic object was not supported, both the wooden block and the cell phone conditions elicited ambiguous responses that indicate weak but present illusions can be produced using other objects than a rubber hand (Armel & Ramachandran, 2003; Hohwy & Paton, 2010).

It is still unclear whether the rubber hand illusion is a product of top-down (Holmes et al., 2006; Longo et al., 2009; Moseley, Olthof, Venema, Don, Wijers, Gallace & Spence, 2008) or bottom-up (Armel & Ramachandran, 2003) processing or which mechanism is more influential in eliciting the illusion. However, the first study provides evidence to support top-down processing as the more influential mechanism behind the rubber hand illusion since the external objects that did not previously fit into a body schema, the phone and wooden block, produced much weaker illusions than the rubber hand.

In Study 2, our hypothesis that participants in the large hand condition would underestimate object sizes was only supported before participants experienced the RHI. This bias was affected by illusory self-report which supported our hypothesis that participants who experienced a strong RHI would estimate more biased size perceptions than individuals who reported a weak illusory experience. Our hypothesis that participants in the small hand condition would overestimate object sizes was not supported.

Our second study had two major limitations. Our research question, does manipulating perceived hand size affect perceived size of objects, hinged on eliciting the RHI in hands that were either way too large or too small to belong to the participant. However, we did not take participant hand size into account. So, if a participant's hand was similar to the size of the hand in their condition, it is possible that no bias in size perception was elicited because the size of the rubber hand might not have been extreme enough to convince the participant that her hand was temporarily a different size. The individual differences in hand size could have affected the amount of overall bias that we found in object size estimations. Additionally, our rubber hands were stuffed, blue latex gloves. Although participants wore latex gloves to create comparable tactile sensation during the illusion, the visual input might have weakened the illusory experience for some participants.

The second study supports past research demonstrating that manipulating perceived hand size will affect perceptions of other object sizes (Berlot, 2013; Haggard & Jundi, 2009). Berlot (2013) found that experiencing the RHI with a large rubber hand resulted in underestimation of glove sizes, consistent with our findings. Berlot (2013) did not find significant overestimations of object size with the small hand condition which is also consistent with our results. However, our findings suggest a slightly different conclusion than previous work (Berlot, 2013). Berlot (2013) concluded that participants' representation of their own hand size is assimilated to the rubber hand which then acts as a calibrator for size estimates. Berlot (2013) implies that assimilation to the rubber hand is through experiencing the RHI. Our findings do suggest that hand size becomes assimilated to the rubber hand which serves as an ecological reference but not as the result of experiencing the RHI. Since our results show that bias actually decreased after participants experienced the RHI, it seems plausible that assimilating hand size to the rubber hand is a result of visual input rather than the multisensory experience of the illusion.

Future research should continue to examine the boundaries of the rubber hand illusion and the underlying mechanisms behind the RHI and body-ownership that could contribute to individual differences of illusory experience. To further explore the conditions in which we can evoke the illusion, future work should see if we can extend our current findings from Study 1 to other electronic objects in case being able to interact with an object makes it easier to incorporate it into our body image. Similarly, we can further explore the hypothesis that attachment to objects might play a role in illusory experience. In both studies, some participants reported strong illusory experiences while others reported little to no sense of the illusion and there is a gap in the RHI literature to explain what factors affect an individual's susceptibility to the RHI. Specifically, continuing to develop a Rasch model for predicting individual rubber hand illusion experiences (Haans et al., 2012) could provide more insight as to why some of the illusion aspects require more cognitive demand than others and how these cognitive demands affect body ownership malleability. Additionally, future versions of this model could incorporate other factors that cause individual differences aside from cognitive demand of each RHI task. For instance, future research could examine whether there is a connection between spatial cognition tasks and strength of RHI.

The first study contributes to our understanding of the rubber hand illusion by providing added evidence for previously addressed questions such as whether or not proprioceptive drift measures illusory ownership and whether or not individuals can experience the illusion with an object other than a rubber hand after experiencing the illusion with a rubber hand. Additionally, our study provides evidence to suggest that the rubber hand illusion is the interplay between visual cues, tactile sensations, and proprioception, without being significantly influenced by underlying features of an object such as familiarity or attachment. Our second study replicates previous evidence that we can elicit an RHI using a large rubber hand and that assimilating hand size to a large rubber hand will affect size perceptions. However, our study is the first to suggest that object size perceptions can be influenced by just seeing a large rubber hand rather than experiencing the RHI. Since bias decreased from the first block to the second block, we can speculate that habituation to the rubber hand size occurs over the course of the illusion or that an aspect of the illusion diffuses the effect of hand size on perception of object sizes.

By continuing to study the rubber hand illusion, we are gaining a better understanding of how body-ownership, perceptions of ourselves, and perceptions of external objects are shaped and affected. This knowledge can contribute to our understanding and potential treatment for individuals with clinical disorders, such as schizophrenia (Peled, Ritsner, Hirschmann, Geva, & Modai, 2000) and eating disorders (Mussap & Salton, 2006), who may differ in subjective experience of body-ownership and self-attribution. Developing a better understanding of the factors and individual differences that contribute to body-ownership may also have significant implications for how to effectively use the RHI for social projects like spreading empathy (Maister, Slater, Sanchez-Vives & Tsakiris, 2015; Seiryte & Rusconi, 2015). By studying the rubber hand illusion, we can use it as a tool to understand broader concepts about body-ownership malleability and shifting perceptions.

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Table 1. Questionnaire used in Study 1 to assess subjective experience with the RHI (adapted from Botvinick & Cohen, 1998).

Questionnaire Items
1. It seemed as if I were feeling the touch of the paintbrush in the location where I saw the external object touched.
2. It seemed as though the touch I felt was caused by the paintbrush touching the external object.
3. I felt as if the external object were my hand.
4. It felt as if my (real) hand were drifting towards the right (towards the external object).
5. It seemed as if I might have more than one left hand or arm.
6. It seemed as if the touch I was feeling came from somewhere between my own hand and the external object.
7. It felt as if my (real) hand were turning into the same material as the external object.
8. It appeared (visually) as if the external object were drifting towards the left (towards my hand).
9. The external object began to resemble my own (real) hand in terms of shape, skin tone, freckles or some other visual feature.

Note. Participants responded to these items on a scale of -3 (disagree strongly) to 3 (agree strongly).

Table 2. The average responses to questionnaire items in Study 1, as well as the overall questionnaire average across the three conditions.

Question	Rubber Hand	Wooden Block	Cell Phone
1. It seemed as if I were feeling the touch of the pencil in the location where I saw the external object touched.	2.20	0.75	0.88
2. It seemed as though the touch I felt was caused by the pencil touching the external object.	1.35	0.05	-0.13
3. I felt as if the external object were my hand.	1.25	-1.15	-1.15
Questionnaire Average	0.20	-0.95	-1.05

Note. Participants responded to these items on a scale of -3 (disagree strongly) to 3 (agree strongly).

Table 3. The items used for self-report in Study 2 (adapted from questionnaire items in Study 1).

Questionnaire Items
1. It seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand touched.
2. It seemed as though the touch I felt was caused by the paintbrush touching the rubber hand.
3. I felt as if the rubber hand were my hand.

Note. Participants responded to these items on a scale of 0 (disagree strongly) to 7 (agree strongly).

Figure 1. The stimuli used in Study 1 for the rubber hand condition and the wooden block condition.

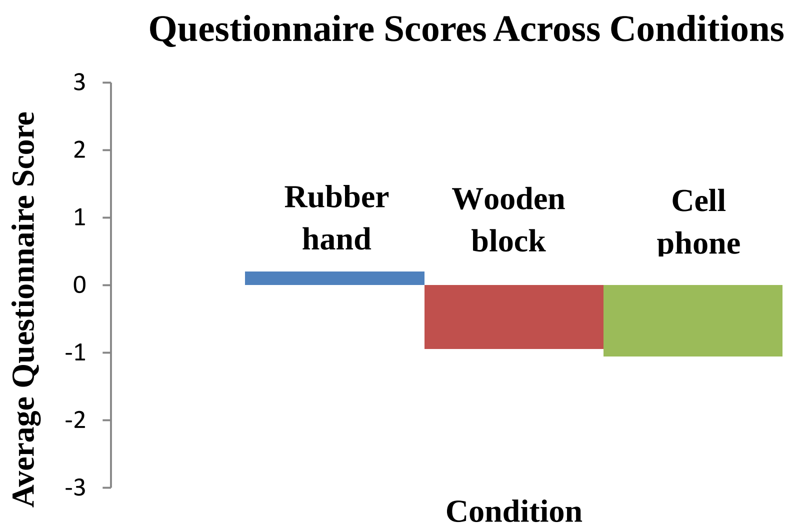

Figure 2. The average responses for the questionnaire items for each condition in Study 1. No significant differences were found between the wooden block and cell phone condition.

Figure 3. The stimuli used in Study 2 for the small rubber hand condition and the large rubber hand condition.

Figure 4. Example of a small stones used for size judgments and placement for each object relative to rubber hand position.

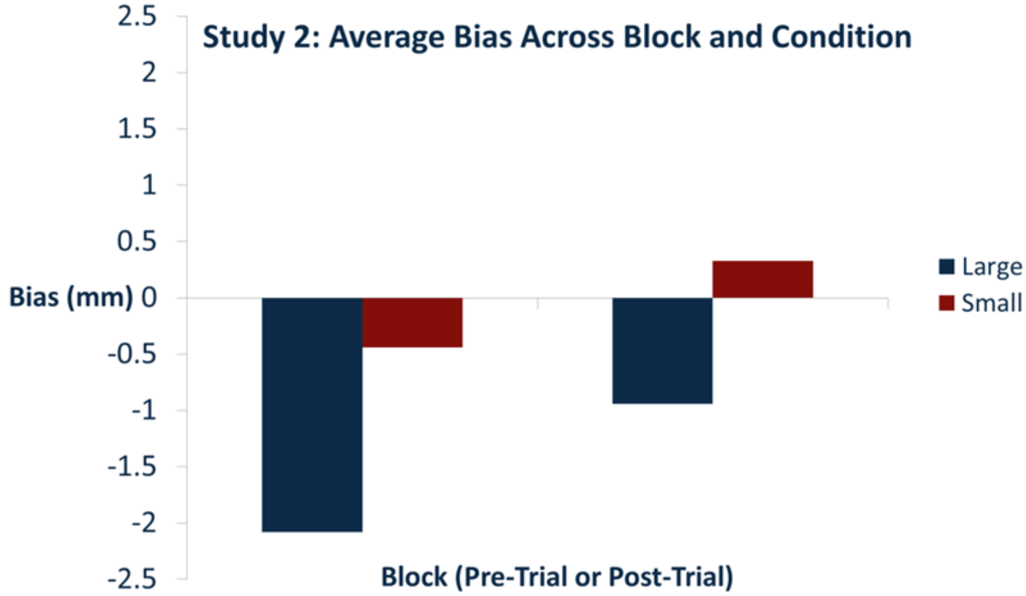

Figure 5. The interaction between condition and block in Study 2. Participants in the larger hand condition underestimated object size significantly more than participants in the small hand condition but only in the first block, prior to experiencing the RHI.