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The Rubber Hand Illusion and Skin-to-Skin Touch: Does the Touch of Others Matter for Feeling Like Me?

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Abstract. In this study we investigated if skin-to-skin touch moderates the effect of the Rubber Hand Illusion. Twenty participants (all right-handed) took part in the experiment. The participants' own hands (hidden from view) were either stroked in synchrony (should induce the illusion) or asynchrony (control condition) with a rubber hand, using the experimenter's own hand, a wide brush or a small brush. We found no significant difference for the stimulation types for the proprioceptive drift $F(2, 19) = .33$, $p = .72$ or for the subjective rating, $F(2, 19) = .43$, $p = .65$. However, both outcome measures showed the same trend (that the skin-to-skin touch induced the strongest illusion) and therefore we neither conclusively rejected nor confirmed our hypothesis.

The sense of self, the feeling of being "me", stems greatly from the fact that we feel that our body is our own. In the words of French phenomenologist philosopher Maurice Merleau-Ponty (1962, p. 169): "The body is our general medium for having a world".

The fact that the sense of agency seems to be so greatly intertwined with the subjective feeling of being a self, was for long thought of as a great obstacle to the study of the phenomenon of embodiment. This sense of agency is something that is hard to separate from the other aspects of embodiment in day-to-day life, as we almost always have a feeling of control over our own body (Jeannerod, 2003). When we interact with the world we have the experience of being a discrete entity that is independent from other objects. We do not typically mistake something as alien as a lamp or a flowerpot for being part of our own body. Although under the right circumstances it is possible to transform this percept, so as to include different kinds of objects and also to feel limbs that have been lost to amputation (phantom limbs). The pioneering works by scientists such as Ramachandran (1998) on phantom pains have offered us insight into how this process works and shown that our body image is significantly more malleable than previously thought.

Experiences such as voluntary self touch (Hara et al., 2015), the velocity of touch (Crucianelli, Metcalf, Fotopoulou & Jenkinson, 2013) and damage to the nervous system (such as in the syndrome somatoparaphrenia, where the patient do not feel ownership over certain body parts) (Vallar & Ronchi, 2008) have all been linked to changes in the system of body perception. Recent studies have also uncovered associated disturbances in different parts of this complex system (most crucially interoceptive awareness) in disorders of body perception, such as anorexia nervosa (Crucianelli, Cardi, Treasure, Jenkinson & Fotopoulou, 2016; Emanuelsen, Drew & Köteles, 2014; Eshkevari, Rieger, Longo, Haggard, & Treasure, 2011). In this study we seek to investigate the social factors that might contribute to our sense of embodiment (more specifically – tactile human interaction). This is something that, to our knowledge, has not yet been investigated in relation to the Rubber Hand Illusion (RHI).

The Rubber Hand Illusion

The rubber hand illusion paradigm offers one of the few recognized ways to investigate how we represent and create the image of our body – separate from the sense of agency (Botvinick & Cohen, 1998). This paradigm has given us important clues as to how information from our different senses is unified and has been used in a number of ways to show how this representation can be manipulated – allowing even for the incorporation of an artificial limb, drawn on a piece of paper (Pasqualotto & Proulx, 2015; Shibuya, Unenaka & Ohki, 2015).

The illusion consists of letting the participants observe a rubber hand being stroked in synchrony with their real hand while the latter is hidden from view. This procedure gives rise to a proprioceptive drift (the feeling of where their own hands is positioned) towards the rubber hand and also elicits a subjective feeling of embodiment of the rubber hand. The classic, and most common, explanation of the illusion is that when providing the participant with conflicting sensory information (where the visual signal is dominant) she solves this conflict by incorporating the rubber hand into her own body, thus giving rise to the illusion (Aimola Davies, White, Thew, Aimola & Davies 2010; Pavani, Spence & Driver, 2000).

A different explanation of the RHI is offered from the relatively new perspective on human cognition called the "Bayesian Brain Hypothesis" (Friston, 2012; Hahn, 2014). According to this idea the brain constantly generates a representation of the world from the information it has access to (memories, senses etc.). The brain is essentially seen as a probability machine, where the factors are calculated according to Bayesian principles, that is, by estimating the probable cause of the data (the posterior) by the observed probabilities (bottom-up signals) and prior beliefs/expectations (top-down signals) about the causes (Seth, 2013).

The RHI paradigm has been well researched, outlining both the temporal conditions of synchronicity required to elicit the illusion (Shimada, Fukuda & Hiraki, 2009) and the maximum boundary distance between the real and the artificial limb (Zopf, Savage & Williams, 2010), as well as other crucial factors, such as colour and shape of the rubber hand (Haans, IJsselsteijn & de Kort, 2008) and the posture of the subjects real hand (Longo, Schüür, Kammers, Tsakiris & Haggard, 2008; Pozeg, Rognini, Salomon & Blanke, 2014; Walsh, Moseley, Taylor, & Gandevia, 2011). Even though there seem to be some general requirements to elicit the illusion, it also exists a large individual variation in malleability to the illusion. Some people perceive the fake rubber hand as their own just by watching it (while their real hands are hidden from view) while others experience the illusion only vaguely or not at all. An average of around 25% do not feel the illusion according to earlier studies (Ehrsson, 2005; Lloyd, 2007).

The majority of studies, using the RHI paradigm to this date, have mainly focused on examining the exteroceptive part of the illusion (DeWitt, Ketcherside, McQueeny, Dunlop & Filbey, 2015). This is the system that conveys the body's own position, motion and state and also includes the traditional five senses, as well as proprioception, pain and balance. Considerably fewer studies have examined the role of the interoceptive system, which consists of the senses that perceive internal sensations, such as affective touch and signals from the internal organs (Craig, 2002).

Regarding the interoceptive influences on the RHI; the effects of the velocity of the brushing (Crucianelli et al., 2013), the perception of roughness (Schütz-Bosbach, Tausche & Weiss, 2009) and even more specifically the role of activation of affective afferents, so called tactile C-low threshold mechanoreceptors (CT-fibres) (van Stralen et al., 2014), have recently been studied. Even though some significant findings were made in these studies, the results varied and it remains unclear whether or not pleasant touch/type of touch moderates only the subjective part of the illusion or the objective measure (proprioceptive drift) as well (Dempsey-Jones & Kritikos, 2014; Lloyd, Gillis, Lewis, Farrell & Morrison, 2013; Rohde, Di Luca and Ernst, 2011).

When it comes to areas of the brain associated with the RHI, one of the first functional magnetic resonance imaging (fMRI) studies (Ehrsson, 2005) found correlated activity in multisensory areas such as vPM (ventral premotor cortices) and the LIP (intraparietal cortices) in participants experiencing the illusion. In a later study, Tsakiris, Hesse, Boy, Haggard and Fink (2006) found a positive correlation with proprioceptive drift in the right posterior insula and the right frontal operculum, but also a significant negative correlation with activity in the left somatosensory cortex and the contralateral parietal cortex. In another study by Ehrsson, Wiech, Weiskopf, Dolan and Passingham (2007) investigating the response when threatening the rubber hand, findings indicated associated activity in the anterior cingulate cortex (ACC) and the left insular cortex. This activity was also correlated with the degree of experienced ownership of the rubber hand, with higher rated ownership generating a stronger neural response.

The Interoceptive System and the Insular Cortex

When it comes to interoception, a central role has been ascribed to the insular cortex (a region of the brain associated with functions such as regulating homeostasis, emotions and the sense of self). The insular cortex is bilateral and is located beneath the temporal and frontal lobe and is connected with the parietal, frontal and limbic regions of the brain (Deen, Pitskel and Pelphrey, 2010).

One study, investigating the role of agency during hand movement, found activation in the bilateral mid insula during hand movement (Farrer et al., 2003). A later study by Tsakiris et al. (2006) found similar activation during experience of the RHI, which made the authors postulate that activity in the mid insula during movement might represent a sense of embodiment rather than agency.

Other studies have also found activation of the anterior insular cortex (AIC) when participants were shown their own image (Devue et al., 2007) with concurring activity in the ACC and the inferior frontal gyrus (IFG). The majority of the studies have found this conjoint activity in the AIC and ACC when studying emotion (Craig, 2009; Devue et al., 2007). This has in turn made some scientists, like Craig (2009), suggest that the AIC might play a role not only when it comes to subjective feelings regarding the body, but subjective feelings in general.

It is also interesting, for the purpose of this study, to note that a special type of neurons, called Von Economo neurons, have a particular high density in the AIC and the ACC (Allman et al., 2010). These spindle type neurons have been suggested to be an evolutionary convergent trait in animals with large enough brains, allowing for rapid communication. They have been found in animals (Hakeem et al., 2009) that show signs of some kind of self awareness, where these animals perform better than those that do not have these type of neurons in self awareness tests, like the dot-mirror-test (Gallup, 1970).

The Importance of Touch

The most prominent of the senses when it comes to the interoceptive system is touch. Of all the senses, our tactile sense is perhaps the least explored. Only as recently as the early 1990's scientists discovered the CT-fibres (Vallbo, Olausson, Westberg & Norrsell, 1993), a type of unmyelinated nerve fibre involved in the transduction of afferent touch. Interestingly, these types of fibres project to the posterior insula cortex (Olausson et al., 2002), which has been found to play a role in body ownership (see above). This system is distinct from that of discriminative touch; both in the specific pathways from the periphery, but also in the areas of the brain involved in processing the signals (Vallbo et al., 1993).

Affective touch has many functions, not earlier recognised, and has been found to influence several aspects of human life. It increases coupling between romantic partners (Chatel-Goldman, Congedo, Jutten & Schwartz, 2014), makes sports teams more successful (Kraus, Huang, & Keltner, 2010), makes children more happy (Field, 2010) and also has cognitive effects – such as customers being more compliant when shopping, after receiving affective touch (Hornik, 1992a; Hornik, 1992b). It has even been suggested that affective touch may play a major role in social development and subsequently in normal development of the brain and nervous system (Ardiel & Rankin, 2010; Barnett, 2005; Crucianelli et al., 2013)

When it comes to the brain and the system of affective touch, stimulus related activation has been found to be elicited in the mid to posterior insula, while anticipatory activation was recorded mostly in the posterior insula. Moreover, the degree of activation in the anterior insula was correlated with the experienced intensity of the touch (Lovero, Simmons, Aron & Paulus, 2009). One study also found a role for the primary somatosensory cortex in discriminating the affective significance in social touch, stating that the response in primary somatosensory cortex is modified by the perceived sex of the person performing the caress, suggesting that these tactile systems interact (Gazzola et al., 2012).

Even though the physiology and psychology of touch have seen a great surge in interest as of late, very few studies have looked at the difference between being touched directly by another human being (skin-to-skin touch) versus being touch by an inanimate object such as a brush (indirect touch).

In one of the few studies on the subject Kress, Minati, Ferraro and Critchley (2011) found a discrepancy in how the particular types of touch are processed in the brain. Most notably, skin-to-skin touch were found to elicit a larger response in the contralateral primary and secondary somatosensory areas, as well as in the posterior insula when compared to a velvet stick.

Mindfulness and the RHI

Mindfulness was defined by Marlatt and Kristeller (referred to in Dobson, 2009, p. 348) as: "bringing one's complete attention to the present experience on a moment-to-moment basis". Interoceptive awareness plays a central part for mindfulness practises (Farb et al., 2015) and interoceptive sensitivity has been seen to correlate with RHI susceptibility, so that people with low interoceptive sensitivity experienced a stronger illusion (Tsakiris, Jimenez, & Costantini, 2011). Kirk et al. (2014) showed how top-down processes influenced people in an art-viewing paradigm, and that these top-down processes affected the participants less after mindfulness training. The RHI is also dependent on top-down processes and therefore we hypothesised that the RHI and mindfulness could be correlated.

The only study that explicitly has investigated how mindfulness correlates with the RHI (Palomo et al., 2015) found a positive correlation with Emotional Awareness on the Multidimensional Assessment of Interoceptive Awareness-scale. In our study we have instead chosen to correlate the RHI with mindfulness, as measured by the Mindful Attention Awareness Scale.

In the present study we wanted to compare the effects of skin-to-skin touch on moderating the RHI. Our hypothesis was that touch by an inanimate object is not ecologically valid and can not be directly generalized to human touch and therefore could elicit a different outcome when it comes to moderating the illusion. This hypothesis is grounded in the fact that a direct interpersonal touch (skin-to-skin touch) has been found to elicit a different neural response in the specific parts of the brain that correlate with the perception of body ownership. Therefore it is possible that it could involve a different afferent channel adding to the interoceptive information. Direct skin-to-skin touch also involves distinctly different top-down factors not present when being touched by an inanimate object such as a soft paintbrush or a velvet stick, something that may affect body ownership. In addition we wanted to replicate earlier findings (Rohde et al. 2011) and investigate if the RHI could be induced visually (before the stimulation).

In conjunction we wanted to examine if the degree of mindfulness correlates with susceptibility to the RHI. In general we took an explorative approach, considering the difficulty of investigating this kind of social interaction.

Our independent variables were stimulation type (hand, wide brush, small brush) and synchronicity (synchronous, asynchronous). In experiments on the RHI a small brush is commonly used (Asai, Mao, Sugimori & Tanno, 2011; Dempsey-Jones & Kritikos, 2014; van Stralen et al. 2014). We also chose to perform the stimulation with a wide brush, so as to be able to rule out the width of the stimulation as a potential confound. The dependent variables were proprioceptive drift and the subjective rating of the illusion.

Method

Participants

Twelve women and eight men took part in the experiment (age range = 18-65, M = 31.3, SD = 11.7). The participants were recruited via the University of Gothenburg and social media using a convenience sample. We excluded left-handed people since left-handedness has been seen to correlate negatively with the RHI (Niebauer, Aselage & Schutte, 2002). Handedness was assessed using a Swedish translation of the Edinburgh Handedness Inventory (Oldfield, 1971), which showed that 19 of the participants were right-handed and that one was ambidextrous (M = 77.7, SD 23.1). The participants received a small reward in the form of a lottery ticket, worth approximately 30 SEK. The experiment was conducted in accordance with the declaration of Helsinki and the participants signed a form of written consent, informing them that they had the right to withdraw, anytime during the experiment, without any consequences. All the participants were naïve as to the purpose of the study.

Apparatus and Materials

The Framework. We placed a wooden framework (see *Figure 1*), with the measurements 75 cm × 50 cm × 25 cm, on a desk in front of the participants. A moveable board with the same measurements as the bottom (75 cm × 50 cm), could either be placed vertically between the rubber hand and the participants' right hands, so as to conceal the participants' right hands, or horizontally on top of the framework, in order to cover both the participants' own hands and the rubber hand (when they were to judge the location of their index fingers). The longest sides of the framework were open, except for two wooden strips at the upper part. On the participants' side a half folded black cloth hanged from one of the wooden strips and covered the space where the participants were to put their hands. On the opposite side a ruler (only visible to the experimenter) was attached. On the bottom of the framework there were three markings. Seen from the left side (the experimenter's perspective) these were: 12.8 cm (the participants' right index fingers), 27.8 cm (the rubber hand's index finger), 60.8 cm (the participants' left index fingers). The distance between the participants' right index fingers and the rubber hand's index finger were 15 cm. The set-up was adapted from Kammers, Vignemont, Verhagen and Dijkerman (2009).

The Rubber Hand. We used a fair-skinned rubber hand (KI-RHANDARM, bought at Killer Ink) with the length 37 cm and the width 13 cm. We made two markings with a pen on the upper left forearm of the rubber hand. The first marking was made 4 cm from the knuckle of the index finger and the second 18 cm from the previous marking.

The Brushes and the Hand. The stimulation was done with the experimenter's own hands and two different types of brushes. When the experimenter did the stimulation with her own hands she used all fingers except for the thumb, to make the stimulation on the rubber hand and the participants' hands as congruent as possible. The stimulation was done with the experimenter's hands parallel to the participants' hands and the rubber hand (see *Figure 2*). On average, this stimulation was 7.5 cm wide. The brushes were both made of goat hair. The wide brush (KICKS Professional Kabuki Brush) measured approximately 6.5 cm during the stimulation. The small brush (Åhléns Blush Brush no. 7) measured about 4 cm during the stimulation.

The Rubber Hand Illusion Questionnaire. The questionnaire adapted from Botvinick and Cohen (1998) and Kammers et al. (2009) was translated into Swedish and consists of ten statements, on a ten-point Likert scale, where 1 means " I strongly disagree" and 10 means "I strongly agree". The first three statements measure the illusion, whereas the statements 4-10 serve as control questions (controlling for effects such as acquiescence bias). The three illusion-related questions are: "It felt as if I was feeling the stroking touch in the location where I saw the rubber hand touched", "It felt as if the rubber hand were my hand" and "It seemed as though the touch I felt was caused by the touching on the rubber hand". If the mean value for the answers on the first three questions exceeds 5 it confirms that the participant has experienced the illusion (van Stralen et.al., 2014).

Pleasantness and Intensity Ratings. We used two 10 cm visual analogue scales, for ratings of pleasantness and intensity, where 0 meant very unpleasant/not at all intensive and 10 meant very pleasant/very intensive. These ratings were used to further distinguish between the different types of stimulation.

Mindful Attention Awareness Scale. The Mindful Attention Awareness Scale (MAAS) (Brown & Ryan, 2003) consists of 15 statements, measured on a six-point Likert scale, where 1 means "Almost always" and 6 means "Almost never". Examples of the questions are: "I could be experiencing some emotion and not be conscious of it until some time later", "I break or spill things because of carelessness, not paying attention, or thinking of something else" and "I find it difficult to stay focused on what's happening in the present".

Figure 1. The experimental set-up.

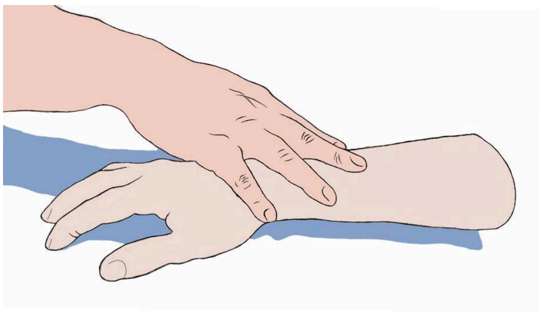

Figure 2. How the stimulation with the experimenter's hand was induced.

Procedure

The experiment took place at the Department of Psychology at the University of Gothenburg and the duration of the experiment was approximately two hours, with the duration varying slightly between the participants.

The participants were seated in an office chair with adjustable height, straight in front of the desk, in order for them to be able to see the entire length of the rubber hand. They were asked to remove all jewellery on their right hands and pull up their sleeves. We made the same markings on their right hands, as on the rubber hand (see *Apparatus and Material*). They placed their index fingers on the markings and were asked to hold their right hands in a congruent position with the rubber hand and be as still as possible.

They were asked to close their eyes as the board was placed on top of the framework, concealing both their own hands and the rubber hand. This was different to other studies (e.g. Kammers et al., 2009; van Stralen et al. 2014), which only made the participants close their eyes when the board was placed on top of the framework before the second judgement of the finger location. Because of this, in addition, we received a measure of the visual illusion. A recent study (Rohde et al. 2011) showed that vision only, could induce the RHI as strongly as the synchronous stimulation.

The participants were told that they could open their eyes again. The experimenter then moved a long needle from the left side to the right (seen from the experimenter's side) along the upper part of the wooden strip. She asked the participants to say "stop" when they felt that the needle was directly in front of the perceived position of their right index fingers. They were asked to draw a "mental line" between the needle and their own fingers. The board was then put back, in the vertical position.

During the stimulation period the participants received stimulation either with the experimenter's hand, the small brush or the wide brush. The stroking began at the 18 cm marking and continued downward the dorsal side of the arm and ended four cm from the knuckle. The stimulation could either be synchronous (the rubber hand and the participants' hands were stroked in temporal synchrony) or asynchronous (there was a one second delay between the stimulation of the rubber hand and the participants' hands). The asynchronous stimulation serve as a control and is not supposed to elicit the illusion (Botvinick & Cohen, 1998). The participants were asked to stay as still as possible and focus their attention on the rubber hand, during the stimulation period. In total we had six different trials (i.e. hand – synchronous, hand – asynchronous, wide brush – synchronous, wide brush – asynchronous, small brush – synchronous, small brush – asynchronous) and these were counterbalanced between the participants using Latin Squares. The participants were informed of which type of stimulation that would be administered next, but not if the stimulation were to be synchronous or asynchronous.

We used a stroking speed of 3 cm/s (i.e. the length of 18 cm took six seconds, followed by a two seconds pause between the stimulations) and the entire stimulation period was two minutes. This is in the range (1 cm/s-10 cm/s) for the optimal speed for pleasant touch that activates the C-tactile fibres (Löken, Vessberg, Morrison, McGlone & Olausson, 2009). To keep the speed constant the experimenter listened to a recording with a tone that signalised the seconds. The pressure was about 0.4 N (the same as Triscoli, Olausson, Sailer, Ignell & Croy, 2013). Fifteen minutes before each new participant the experimenter practiced the brushing technique on a scale to make sure that the pressure would be in the right range for all of the participants. If the stimulation was to be done with the experimenter's hand the experimenter warmed her hand on a heating pad, set at the highest level (Beurer, HK Comfort), so as to avoid the temperature of the hand acting as a confound.

After the stimulation period was over the participants yet again were asked to close their eyes and the board was placed horizontally. The participants made a new judgement on the location of their right index fingers', using the same procedure as described above. The participants were then asked to pull out their hands and look at them. They thereafter filled out the rubber hand illusion questionnaire and the pleasantness and intensity ratings.

When this was done we asked the participants to do a Stroop-test (Stroop, 1935) for two minutes, to avoid carry-over effects. The participants were naïve as to the purpose of this procedure.

The Stroop-test marked the end of each trial, and afterwards the entire procedure was repeated. When the six trials were completed the participant's were asked to fill out the MAAS-questionnaire. As the final step we held a short debriefing session, informing the participants about the purpose of the study and asked them if they had been able to guess it. In conjunction with the debriefing the participants were offered to take part of the results of the study.

Outcome Measures

The Objective Rating (Proprioceptive Drift). The proprioceptive drift is measured as the difference between the judgement of the index finger's location after the stimulation and the judgement of the index finger's location before stimulation, i.e. location after - location before

Visual Illusion. This is measured as the distance between the first judgement of the index finger's location (before the stimulation period) and the actual location of the finger (12.8 cm), i.e. location before - 12.8.

The Subjective Rating (Questionnaire). The subjective rating of the illusion is measured as the mean value for the three first questions (which measures the illusion on a Likert-scale from 1 to 10, where a score exceeding 5 indicates susceptibility to the RHI) in the rubber hand illusion questionnaire.

Pleasantness/Intensity Ratings. The score for the pleasantness rating and the intensity rating, measured separately (on a ten cm visual-analogue scale, where a high score signified high degree of pleasantness or intensity).

Mindfulness Rating. The mean value for the 15 questions in the MAAS-questionnaire (which assesses the degree of mindfulness on a scale from 1 to 6, where a high score indicates a high degree of mindfulness).

Results

Our hypothesis was that touch by an inanimate object is not ecologically valid and can not be directly generalized to human touch and therefore should elicit a different outcome when it comes to modulating the effect of the illusion. We also intended to replicate the results of other studies in order to investigate if just looking at the rubber hand could induce the illusion. In addition we wanted to examine the relationship between the degree of mindfulness and the RHI. In general we took an explorative approach considering the difficulty of investigating this kind of social interaction.

The design consisted of a 2 × 3 within subjects design, with synchronicity (synchronous, asynchronous) and stimulation type (hand, wide brush, small brush) as independent variables and proprioceptive drift (the difference between the perceived location of the index finger before stimulation and the perceived location of the index finger after stimulation) and the subjective rating of the illusion as dependent variables, although we chose to analyse the outcome for the dependent variables separately. The conducted analyses were two-tailed with a significant level of $p < 0.05$.

Main analyses

The objective outcome measure

Proprioceptive Drift for all Stimulation Types. We conducted a two-way repeated measures analysis of variance (ANOVA) for proprioceptive drift. Since Mauchly's test of Sphericity was significant for stimulation type ($p < .05$) we corrected the degrees of freedom using Greenhouse-Geisser. The results showed that there were no significant difference for stimulation type, $F(1.4, 19) = 2.05$, $p = .16$. We found a marginal, but not statistical significant, effect for the difference between synchronous and asynchronous stimulation, $F(1, 19) = 3.40$, $p = .08$, $\eta^2 = .15$. As expected, the synchronous stimulation induced a stronger illusion than the asynchronous and since the *p*-value was close to reaching significance we concluded that the paradigm worked. There was no significant interaction effect, $F(2, 19) = 2.00$, $p = .15$. These results are depicted in *Figure 3*.

The analysis is limited since the measure of stimulation type does not take into account the difference in synchronicity. The relationship between the synchronous and asynchronous stimulation was recognized by Botvinick and Cohen (1998) and the asynchronous stimulation has been used as a control condition in many studies, for example van Stralen et al. (2014), but none of these have administered the stimulation with a hand. Because of this and our explorative approach we decided to analyse the data further with two one-way ANOVA: s – one for the synchronous stimulation and one for the asynchronous stimulation. One further reason for this is that we did not find a statistical significant difference for synchronicity as expected, even if the *p*-value was close to .05.

Proprioceptive Drift for the Synchronous Stimulation. For the synchronous stimulation the hand induced the strongest illusion ($M = 1.9$, $SD = 2.5$), followed by the wide brush ($M = 1.7$, $SD = 1.6$) and the small brush ($M = 1.6$, $SD = 2.2$). We conducted a one-way ANOVA for the synchronous stimulation, but found no significant difference, $F(2, 19) = .33$, $p = .72$.

Proprioceptive Drift for the Asynchronous Stimulation. We did a one-way ANOVA for the asynchronous stimulation. Since Mauchly's test of Sphericity was significant for the stimulation type ($p < .05$) we corrected the degrees of freedom using Greenhouse-Geisser. With this correction we found a marginal, although not statistical significant, effect, $F(1.5, 19) = 2.85$, $p = .09$, $\eta^2 = .13$. Considering the tendency to a significant result and the fact that the effect size explains 13 % of the variance we decided to do a paired t-test for the asynchronous stimulation, in order to determine where the possible difference might lie.

We performed a paired t-test for the asynchronous stimulation for the hand ($M = 1.7$, $SD = 1.8$), the wide brush ($M = 0.2$, $SD = 2.0$) and the small brush ($M = 0.9$, $SD = 2.4$). Once corrected for multiple comparisons using Bonferroni, the hand tended to result in a stronger proprioceptive drift than the wide brush but no significant difference was found, $t(19) = 2.39$, $p = .07$. There was no significant difference between the hand and the small brush, $t(19) = 1.23$, $p = .68$ nor between the wide brush and the small brush, $t(19) = -1.16$, $p = .76$.

The Visual Illusion. We conducted a one sample t-test for the visual illusion ($M = 1.2$, $SD = 2.3$) and found a significant difference, $t(19) = -2.38$, $p < .05$, $d = -.53$. This result indicates that the participants perceived a visual illusion, i.e. that they experienced a significant proprioceptive drift just by looking at the rubber hand.

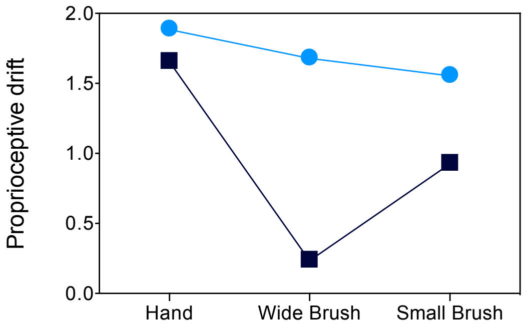

Figure 3. The objective rating of the illusion, as measured by proprioceptive drift. A higher score represents a stronger illusion.

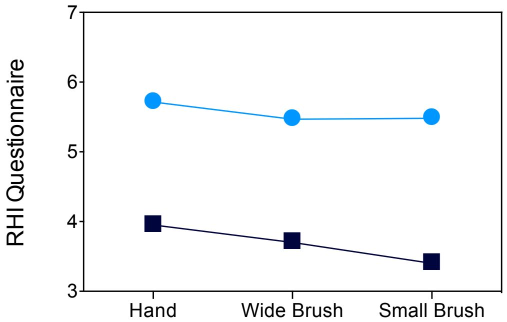

Figure 4. The subjective rating of the illusion, measured with the RHI Questionnaire. A higher score represents a stronger illusion.

The Subjective Outcome Measure

We performed a two-way repeated measures ANOVA, with stimulation type and synchronicity as independent variables and the subjective rating of the illusion as dependent variable. Mauchly's test of Sphericity was significant for stimulation type, $p < .05$ and we therefore corrected the degrees of freedom using Greenhouse-Geisser. We did not find any significant effect for the stimulation type, $F(1.5, 19) = 1.16$, $p = .32$. As anticipated we found a significant effect between the synchronous and the asynchronous stimulation, with a stronger RHI for the synchronous stimulation, $F(1, 19) = 20.31$, $p < .001$. We did not find any interaction effect, $F(2, 19) = .38$, $p = .69$. As for the objective measure we found a trend in the direction our hypotheses predicted. The hand induced the strongest illusion ($M = 5.7$, SD =2.9) followed by the small brush ($M = 5.5$, $SD = 3.1$) and the wide brush ($M = 5.5$, $SD = 3.0$). These results are shown in *Figure 4*.

For the same reasons as for the objective measure we can not draw any assumptions based on the p-value for stimulation type, since both the synchronous and asynchronous are measured as one. In this case though, since the difference between the synchronous and asynchronous conditions were found to be significant, we only made a one-way ANOVA for the synchronous conditions (which is supposed to elicit the illusion) and did not follow up and analyse the asynchronous conditions.

One-way ANOVA for the Synchronous Stimulation. We did not find any significant effect for the stimulation type, $F(2, 19) = .43$, $p = .65$.

Correlations

Between the MAAS-score and the Proprioceptive Drift. We found a significant positive correlation between mindfulness and proprioceptive drift for the small brush, but we also found an almost significant positive correlation between mindfulness and the wide brush. That the two factors are positively correlated means that people who were more mindful experienced a stronger illusion and vice versa. See Table 1.

Between the MAAS-score and the Subjective Rating. We found no significant correlation between mindfulness with any of the stimulation types. See Table 1.

Between the MAAS-score and The Visual Illusion. We found no significant correlation between mindfulness and the visual illusion. See Table 1.

Between the Objective and Subjective Measures. The stimulation types for proprioceptive drift were positively correlated with each other and the stimulation types for the subjective rating, likewise, showed positive correlations with each other. All of these reach significance. The subjective and objective measures were also positively correlated with each other, and all of them reached significance except for the subjective measure for skin-to-skin touch that did not correlate with the proprioceptive drift for the skin-to-skin touch or the proprioceptive drift for the wide brush; and the subjective measure for the wide brush that did not correlate with the proprioceptive drift for the skin-to-skin touch. See Table 1.

Table 1

The correlation between mindfulness, the objective and subjective measures and the visual drift, measured with Pearsons'r.

	Pd-hand	**Pd-wide**	**Pd-small**	**Sub-hand**	**Sub-wide**	**Sub-small**	**Visual**	**MAAS-rating**
Pd-hand	1							
Pd-wide	.73**	1						
Pd-small	.58**	.74**	1					
Sub-hand	.25	.44	.45*	1				
Sub-wide	.31	.47*	.46*	.93**	1			
Sub-small	.45*	.52*	.48*	.91**	.87**	1		
Visual	−.22	−.15	−.32	−.49*	−.45*	−.58**	1	
MAAS-rating	.27	.43	.49*	.21	.32	.25	-.24	1

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed). Pd = proprioceptive drift. Sub = subjective rating of the illusion.

Additional Analysis

We gathered data for pleasantness and intensity, to make sure that the participants experienced the illusion as pleasant. In addition to this we decided to examine if the stimulation types were experienced differently. Moreover, we analysed the control questions to confirm that the paradigm worked.

Pleasantness and Intensity

Pleasantness. We performed a two-way repeated measures ANOVA, with stimulation type and synchronicity as independent variables and rated pleasantness as dependent variable. We found a significant difference between pleasantness for the synchronous (M = 7.5, SD = 1.9) and asynchronous stimulation (M = 6.8, SD =1.7), F(1, 19) = 6.91, p < .05, η^2 = .27, i.e. the synchronous stimulation was rated as more pleasant than the asynchronous. We corrected the degrees of freedom using Greenhouse-Geisser since Mauchly's Test of Sphericity showed significance (p < .05), but found no effect for stimulation type, F(1.5, 19) = 1.67, p = .21) or any interaction effect, F(2, 19) = .17, p = .84). We did a one-way ANOVA for the synchronous stimulation for the hand (M = 7.2, SD = 2.2), wide brush (M = 7.7, SD = 1.9) and small brush (M = 7.6, SD = 1.6) (and corrected the degrees of freedom using Greenhouse-Geisser since sphericity was not assumed, p < .05) but found no significant difference F(1.5, 19) = 0.97, p = .37.

Intensity. We did a two-way repeated measures ANOVA with stimulation type and synchronicity as independent variables and rated intensity as dependent variable. We found a significant difference between intensity for synchronous (M = 5.7, SD = 2.3) and asynchronous (M = 5.2, SD = 2.3), F(1, 19) = 10.23, p < .01, η^2 = .35, i.e. the synchronous stimulation was rated as more intense. We discovered an effect that was close to significant for the stimulation type F(2, 19) = 2.82, p = .07, η^2 = .13. We found no interaction effect F(2, 19) = .54, p = .59. We did a one way ANOVA for the synchronous stimulation for the hand (M = 6.1, SD = 2.5), wide brush (M = 5.3, SD = 2.4) and small brush (M = 5.8, SD = 2.5) but found no significant difference F(2, 19) = 2.12, p = .13.

The Control Questions

None of the control questions (controlling for effects such as acquiescence bias) exceeded a mean value of 5 (which was in line with our expectations, since the control questions are not supposed to measure the illusion and a value over 5 indicates that the participants have experienced the question) for any of the stimulations types. Although when looking at the mean values; we found that question 7 ("It felt as if my real hand was turning rubbery") for the synchronous skin-to-skin touch (M = 4.8, SD = 3.6) had a higher mean value than the rest of the control questions. The mean value for the synchronous stimulation for the hand seemed in addition to be much higher than the mean value for the asynchronous stimulation for the hand (M = 3.9, SD = 3.4). Therefore we conducted a paired t-test across all control questions to compare the synchronous and asynchronous conditions for the different stimulation types (i.e. hand, wide brush, small brush) and discovered that the only significant difference was found in question 7, for the skin-to-skin touch $t(19) = 2.20$, $p < .05$.

We proceeded with doing a one-way ANOVA for the synchronous conditions. Mauchly's test of Sphericity was significant for stimulation type ($p < .01$) and therefore we corrected the degrees of freedom using Greenhouse-Geisser. We found a significant difference between the stimulation types: with a higher rating for the hand ($M = 4.8$, $SD = 3.6$) than the wide brush ($M = 2.9$, $SD = 2.8$) and the small brush ($M = 2.5$, $SD = 2.3$), $F(1.4, 19) = 7.02$, $p < .01$, $\eta^2 = .27$. The subsequent post-hoc test (corrected with Bonferroni for multiple comparisons) showed a significant difference between skin-to-skin touch and the wide brush, $t(19) = 2.90$, $p < .05$ and between skin-to-skin touch and the small brush, $t(19) = 3.51$, $p < .01$. No significant difference was found between the wide brush and the small brush, $t(19) = 0.61$ $p = 1.00$.

Summary of the Results

As expected, the synchronous stimulation induced a stronger illusion than the asynchronous for both outcome measures. In contrast to what we hypothesised, the stimulation type had no significant effect on neither the objective nor the subjective measure of the illusion. The pattern was however that the hand induced the strongest illusion, especially for the asynchronous condition, which is an unexpected finding. Moreover the participants experienced a visual illusion. We found a significant positive correlation between mindfulness and proprioceptive drift for the small brush but we also found an almost significant positive correlation between mindfulness and the wide brush. We found no significant correlation between mindfulness with any of the stimulation types for the subjective rating or the visual illusion. The subjective and objective measures where positively correlated with each other, and all of them reached significance except for the subjective measure for skin-to-skin touch that did not correlate with the proprioceptive drift for the skin-to-skin touch or the proprioceptive drift for the wide brush; and the subjective measure for the wide brush that did not correlate with the proprioceptive drift for the skin-to-skin touch. The synchronous stimulation was rated as significantly more pleasant and more intense than the asynchronous stimulation. There was a significant difference for question seven between synchronous and asynchronous stimulation for the hand. For question 7 the hand induced a significantly stronger rating than the other stimulation types.

Discussion

The main purpose for this study was to investigate if there is an effect of interpersonal touch on moderating the RHI, or if touch by an inanimate object can be directly generalized to skin-to-skin touch. We postulated that direct human touch might pose a unique influence on the sense of embodiment, not just by constituting a different bottom-up signal, but also by adding top-down influences. To test this hypothesis we used the well-established RHI-paradigm (Botvinick & Cohen, 1998).

The illusion was measured by the means of proprioceptive drift (objective measure) and the RHI-questionnaire (subjective measure) and in addition we obtained data for the visual illusion. We also gathered data for the perceived pleasantness and intensity, for the different types of touch, supposing that human touch would be perceived as different than the other types of touch. At the end of the experiment sessions we acquired the participant's score on the MAAS.

Discussion of the Results

Proprioceptive Drift. Our main hypothesis assumed that being touched by a human hand would elicit a different response to the illusion. This was not supported when it came to the outcome measure of proprioceptive drift. Even though the results did not show any significant difference, it is worth mentioning that the overall trend of the data was as hypothesised; with human touch receiving a higher mean score than both the wide and the small brush.

The difference between the synchronous and asynchronous conditions was close to reaching significance and since we found a significant difference between these conditions in the subjective measure we drew the conclusion that the paradigm worked and that the manipulation of temporal synchronicity was successful. The reason for why we did not reach significance for the difference between the synchronous and asynchronous conditions for the proprioceptive drift could depend on that the skin-to-skin touch induced a strong illusion for the asynchronous stimulation as well, generating a similar level of illusion to that of the synchronous stimulation.

The proprioceptive drift for the asynchronous skin-to-skin touch tended to be larger than touch by the wide brush, and a similar tendency was found between the wide brush and the small brush. No significant difference was found between either, after correcting for multiple comparisons. The reason for this might be that asynchronous stroking is not as good as a control condition as previously assumed. In a study by Lewis and Lloyd (2010) 84% of the participants did experience ownership in the asynchronous condition, as well as in the synchronous condition. Moguillansky, O'Regan & Petitmengin (2013) described how the participants experienced ownership of the rubber hand in the asynchronous condition, but continued to feel their own hand as well, i.e. there were no rejection of the real hand, as was the case in the synchronous condition. They postulated that this might reflect a difference between active and passive touch, and that the asynchronous stroking does not modify the active aspect of touch. They also described a phenomenon dubbed "phantom sensations" where the participants, in the asynchronous condition, feel the touch that is administered on the rubber hand as being located on their real hand, despite that they consciously notice this incongruence. This phenomenon has also been described by Durgin, Evans, Dunphy, Klostermann & Simmons (2007). An explanation for this is that the conflict between visual and tactile sensations is solved by sensing the touch given on the rubber hand on their real limb, i.e. vision dominates and induces the seen touch on the real hand (Press, Heyes, Haggard, & Eimer, 2008). This explanation is in line with the findings from another study, which showed that blind people do not perceive similar illusions in the same manner as seeing participants (Petkova, Zetterberg, & Ehrsson, 2012), thus further illuminating the importance of vision, as an integral part of the illusion.

Ellingsen et al. (2013) were able to enhance the experience of pleasant touch by giving participants an injection of a placebo nasal spray, said to enhance pleasantness, and found stronger activity in the primary- and secondary somatosensory cortex, as well as in the posterior insula. This suggests that top-down factors can effect how touch is perceived. We propose that a similar mechanism might explain our results. This might imply that top-down factors such as seeing the touch being performed by a human hand makes it more affectively significant (Gazzola et al., 2012), reducing the difference between the synchronous and asynchronous condition, by means of inducing a sense of passive touch in the asynchronous condition. Several of the participants in our experiment did remark on the asynchronous condition as being a bit “scary”, possibly because effects such as those described above induced a feeling of uncertainty, making them feel “deceived” by their own senses.

Subjective Rating. All of the subjective questions (and none of the control questions), on the RHI-questionnaire, reached a mean exceeding 5, which indicates that the experimental manipulation and paradigm was successful. We also found a significant effect for synchronicity, with higher scores in the synchronous condition, again replicating the results from earlier studies (Botvinick & Cohen, 1998; Crucianelli et al., 2013; Kammers et al., 2009; van Stralen et al., 2014).

Visual Illusion. We found a significant result for the visual illusion indicating that the participants did experience the illusion just by sitting down and seeing the rubber hand with their own hands occluded. This confirms the results of earlier studies (Rohde et al., 2011).

Pleasantness and Intensity. In conjunction with each trial a visual analogue scale was administered, on which the participants rated the perceived pleasantness and intensity of the touch. No significant effect for stimulation type was found for neither of the two measures. We did however find a significant difference for synchronicity, where the synchronous stimulation was perceived as more pleasant/intense than asynchronous stimulation. This is a peculiar finding that, to our knowledge, has not been reported in earlier studies. This difference in pleasantness/intensity might be one of the factors that contribute to a lesser degree of illusion in the asynchronous condition. This could, however, also be explained by “phantom sensations” (see above), where an incorporation of the seen touch is felt on the real hand in the asynchronous condition, potentially giving rise to a “strange” feeling that is not as pleasant as in the synchronous condition.

Correlations. Regarding the correlation between the MAAS-score and the two outcome measures (proprioceptive drift and the subjective rating) of the RHI and the visual illusion, we found a significant positive correlation with the amount of proprioceptive drift for touch with the small brush and a marginally significant positive correlation with the wide brush. This confirms the result from earlier studies (Palomo et al., 2015). However, we did not find any correlations between the MAAS and the subjective outcome measures of the illusion. The fact that no significant correlation was found for the skin-to-skin touch, but was found for the other two independent variables is indeed an interesting finding, adding to our belief that skin-to-skin touch is different from the other types of touch. The MAAS-score is for our purpose essentially seen as a crude measure of interoceptive sensitivity. This is usually quantified by some kind of heartbeat detection (Kleckner, Wormwood, Simmons, Barrett & Quigley, 2015) making our measure more subjective and possibly more imprecise.

We also found significant correlations between the majorities of the two outcome measures, although the skin-to-skin touch was resistant to this correlation. No definite consensus have been reached regarding the relationship between the two outcome measures and it has for example been reported that the outcome measure of proprioceptive drift seems to be resistant to the influence of top-down effects, but that such factors can modulate the subjective sense of embodiment (Dempsey-Jones & Kritikos, 2014).

A recent review-article (Christ & Reiner, 2014) listed the scores obtained for different methods to measure the proprioceptive drift. They concluded that if the proprioceptive drift is measured by letting the subjects actively point on the perceived position of their index finger it could potentially involve a different system for locating the position, than when using the more passive measure (as used in this experiment), where the participants vocally indicates the proprioceptive position.

Control Questions. None of the control questions reached a mean value exceeding 5 for any of the stimulations types, which indicates that the experimental manipulation was successful and that the paradigm worked. Question 7 for skin-to-skin touch had a higher mean value than the other control questions and was the only one of the control questions where we found a significant difference in synchronicity, suggesting that this effect might be due to the illusion and not just noise in the data. The phrasing of the question "It felt as if my real hand was turning 'rubbery'", might indicate another aspect of embodiment, not captured by questions 1-3 in the RHI-questionnaire. Several of the participants did also verbally note, during the experimental procedure, that touch by the hand felt "rubbery" and that their arm felt like rubber. This can both indicate that the question has been interpreted in the wrong way and might need to be revised if it is to be used as a control question in further studies, or that the participants in fact have been influenced by the perceived structure of the rubber arm in their perception of the touch.

Limitations of the Current Study

Although our results indicate that the paradigm did work and that the illusion was induced in a majority of the participants, some aspects of the conduction may be troublesome. Our intention in the planning stage was to deliver a touch as natural and ecologically valid as possible. This did however turn out to be more difficult than first thought. In a natural caress the thumb typically strokes the side of the forearm creating a clasping position of the hand of the person performing the caress. This kind of touch is impossible to perform in the experimental procedure we adopted (with only one experimenter). Instead we used one of the other fingers on each hand substituting for the wayward touch of the thumb (see *Figure 2*), i.e. the little finger on the experimenter's right hand acted as the index finger on her left hand. The two fingers have a similar contact surface, but the angle and exact mechanics of this type of touch is not identical to a natural caress. This is something that might potentially have influenced the results.

The experimenter did also experience problems with the underside of the wrist touching the participants' real arms from time to time, while performing the skin-to-skin touch. This kind of accidental touch could act as a factor contributing to less experience of the illusion. However, no such noise in either embodiment score or the proprioceptive drift could be seen in the relevant data. Overall, the skin-to-skin touch was harder to administer and significantly more challenging to keep constant, both across the synchronous and asynchronous conditions.

The first item on the RHI-questionnaire did also offer some problems initially. Participants found the question: "It felt as if I was feeling the stroking touch in the location where I saw the rubber hand touched" to be vaguely formulated and therefore we introduced a more rigid explanation, after participant number eight. To make sure that this difference in procedure did not affect the scores, we compared the mean for this question for the nine first participants (M = 5.46) with that of the following twelve (M = 5.41) and found no difference in the mean values.

The measurement of the visual illusion offers some troublesome aspects and could perhaps have been better designed. The design did not allow us to control for neither the temporal dimension (i.e. for how long the participants observed the rubber hand before the first judgement of their index finger) nor any potential individual differences in proprioceptive sensibility. A better option would have been to let the participants judge the position two times before the stimulation (one time before observing the rubber hand and one time after observing it) and to control for the temporal dimension.

Conclusion and Suggestions for Further Research

Our general conclusion from this study is rather conservative, as the data seem to neither conclusively confirm nor reject our hypothesis. Due to the nature of our hypothesis, this was expected as it is hard to isolate only one aspect when studying social interaction of this kind. Even though we did not find any significant difference between the stimulation types, the fact that both outcome measures did show a trend similar to what we predicted may indicate a small effect, that might be possible to investigate in more detail with another research design and a larger sample size.

Recent suggestions of the body image as being generated by a predictive coding model, using bayesian inference (Apps & Tsakiris, 2014; Suzuki, Garfinkel, Seth & Critchley, 2013), could perhaps assist in understanding the somewhat ambiguous data generated by our experiment. Integrating information and comparing bottom-up signals to prior top-down predictions generate this kind of representation of the self and the body. According to the free energy principle, to minimise the surprise, the mismatch in prediction and actual sensory data is ideally explained away, potentially giving rise to illusions such as the RHI (Nour & Nour, 2015). This theory has been tested (Samad, Chung, & Shams, 2015) and seems to predict the same kind of effects that occur in the RHI and similar phenomena, like phantom limbs (De Ridder, Vanneste, & Freeman, 2014). Input from different types of sensory data will in this type of reasoning (where the brain is seen as a probability machine) affect the outcome (the posterior i.e. what is most likely to perceived as being me) in distinct ways.

Besides from further investigating the effects of skin-to-skin touch on the illusion, future studies may wish to examine if different types of touch may induce the illusion in a different manner, taking up the approach of studies that have looked more closely at the discrete stages of the illusion, focusing on the participants' subjective experience (Lewis & Lloyd, 2010; Moguillansky et al., 2013). Results from other studies have also suggested that the experience of touch differs regarding to the sex of both the person receiving and the person performing the touch (Essick et al., 2010; Gazzola et al., 2012). This and similar social factors such as the emotional valence of a situation and other social top-down factors may introduce a different sense of embodiment and is something that should be investigated further.

Evaluating, and possibly finding, other objective measures of the illusion is also of importance, as the current measure of proprioceptive drift is problematic in several ways (see above). One suggestion for future studies might be to incorporate and use skin conductance response to measure the illusion in an objective way. The on-going development of virtual reality and similar techniques have already been utilised for the purpose of researching embodiment, but might yet still offer new possibilities to address the research problems in a better fashion.

It is important to continue researching how the mechanism of embodiment works, as it could be of great clinical importance for treating ailments like anorexia nervosa (Crucianelli et al., 2016; Eshkevari et al., 2011), OCD (Jalal, Krishnakumar & Ramachandran, 2015) and other similar conditions.

"Is the brain created for the body, or is it the other way around?" This is the beginning of a monologue of the main character of Jersild's (1980 p. 105) novel "A Living Soul", about a brain called Ypsilon living in a vat, separated from his former body. Ypsilon settles on concluding that the body is a worthless extension, "dumb as the root or the crown of a tree". However, all signs point to the opposite – that the brain would be a mere appendix without a body to supply it with raw data. For our purpose though, this question still remains very much alive, waiting for the details to be settled by the efforts of future science.

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