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No consistent cooling of the real hand in the rubber hand illusion

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ABSTRACT

In the rubber hand illusion (RHI), participants view a rubber hand that is stroked synchronously with their real, hidden hand. This procedure results in experiencing an increased sense of ownership over the rubber hand and demonstrates how multisensory information (vision, touch) can influence the sense of body ownership. However, it has also been suggested that a (lack of) sense of ownership over an own body part may in turn influence bodily processes. This suggestion has previously been supported by the observation that a decrease in skin temperature in the real hand correlated with ownership over the rubber hand. However, this finding has not been consistently replicated. Our lab has conducted several studies in which we recorded temperature of the hands during the RHI using various measures and in different circumstances, including continuous temperature measurements in a temperature-controlled room. An overall analysis of our results, covering five attempts to replicate the traditional RHI experiment and totalling 167 participants, does not show a reliable cooling of the real hand during the RHI. We discuss this failure to replicate and consider several possible explanations for inconsistencies between reports of hand temperature during the RHI.

1. Introduction

Consider a simple task such as walking towards another person – say, this huge big shot you noticed at a conference – and shaking hands. Your brain is charged with the challenging mission of walking, while making an appropriate arm movement, without knocking other things over, shaking the wrong hand, colliding forcefully with the target hand, or crushing it if you managed to reach it without accidents. Also, among this sea of moving limbs you will need to keep track of which ones are yours, so you can walk away again without making a complete fool out of yourself. To do so, your brain needs to know which parts of the world are “you” and which parts are not. To no surprise, the concept of body ownership, or recognition that your body indeed is your own, has received ample attention (De Vignemont, 2011; Ehrsson, Spence, & Passingham, 2004; Kilteni, Maselli, Kording, & Slater, 2015; Serino et al., 2013; Tsakiris, 2010, 2016; Tsakiris, Hesse, Boy, Haggard, & Fink, 2007).

While body ownership is considered a basic part of the sense of the self (Blanke, 2012; Gallagher, 2000; Serino et al., 2013), various illusions have shown that body ownership is surprisingly malleable (Alimardani, Nishio, & Ishiguro, 2016; Botvinick & Cohen, 1998; Ehrsson, 2007; Newport, Pearce, & Preston, 2010; Petkova & Ehrsson, 2008; Slater, Spanlang, Sanchez-Vives, & Blanke, 2010; van der Hoort, Guterstam, & Ehrsson, 2011). In these illusions, healthy participants are made to feel that an artificial object (Botvinick & Cohen, 1998; Ma & Hommel, 2015; Pasqualotto & Proulx, 2015) (or even artificial body such as a complete mannequin) (Maselli & Slater, 2013; Petkova & Ehrsson, 2008; Petkova, Khoshnevis, & Ehrsson, 2011; Salomon, Lim, Pfeiffer, Gassert, & Blanke, 2013; Slater et al., 2010) is part of their body by providing “false” multisensory information. In the most widely used version, the rubber hand illusion (RHI), a rubber hand is being stroked synchronously with one's own unseen hand. This causes integration of the visual and tactile input about the stroking which is felt on the rubber hand. This leads to the experience that the rubber hand feels like the own real hand (Botvinick & Cohen, 1998). Apart from the subjective changes assessed with questionnaires, the estimated position of the real hand is drifted towards the rubber hand (proprioceptive drift).

This illusion reveals that the brain's ability to integrate bottom-up multisensory input (vision, touch) heavily influences the sense of body ownership. Interestingly, gaining ownership of a foreign hand has consequences for the perception of the own “replaced” hand. Indeed, it has been suggested that the hand for which the illusion is evoked is somewhat disowned (Lane, Yeh, Tseng, & Chang, 2017; Lewis & Lloyd, 2010; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008; Preston, 2013; Valenzuela Moguillansky, O'Regan, & Petitmengin, 2013)

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(However see De Vignemont, 2011; Folegatti, de Vignemont, Pavani, Rossetti, & Farné, 2009; Schütz-Bosbach, Tausche, & Weiss, 2009). This may in turn influence various physiological processes. For example, Barnsley et al. (2011) showed that histamine reactivity was increased after conducting the RHI, an effect that was only present for the stimulated, "replaced" arm. Hegedüs et al. (2014) reported higher pain thresholds of the real hand after RHI induction (although it should be noted that Mohan et al. (2012) did not find any influence on pain ratings of noxious heat stimuli). Moreover, it has been suggested that the RHI leads to slower processing of tactile stimuli on the "replaced" arm (Moseley et al., 2008).

One influential and widely cited effect of the RHI is a drop in skin temperature for the replaced own hand (Moseley et al., 2008). Moseley et al. (2008) observed that many pathological conditions (e.g. anorexia nervosa, complex regional pain, stroke) are characterised by both body ownership problems and a disturbed thermoregulation. They hypothesised that these symptoms are related, which could explain why disruption of temperature regulation can be restricted to a specific limb. This would imply that body ownership is not only a cognitive phenomenon that arises from having to control a body and bodily processes, but may in turn influence physiological processing in the body. Using the traditional RHI, Moseley et al. (2008) showed a relative decrease in skin temperature in the real "replaced" hand of about 0.2 °C–0.8 °C that correlated with ownership over the rubber hand. Most importantly, in their Experiment 3 they compared synchronous with asynchronous stroking and showed that the hand temperature after a 7–8 min stroking period was lower with synchronous than with asynchronous stroking on the test hand, whereas no difference was found on the non-stimulated hand. This suggests that the cooling is related to the illusionary disowning of the real hand in favour of the rubber substitute.

However, replication of this effect has been inconsistent. To our knowledge, since the study by Moseley et al. (2008), eight studies have published results on hand temperature measurements during the traditional RHI in healthy participants (David, Fiori, & Aglioti, 2014; Grynberg & Pollatos, 2015; Kammers, Rose, & Haggard, 2011; Paton, Hohwy, & Enticott, 2012; Rohde, Wold, Karnath, & Ernst, 2013; Thakkar, Nichols, McIntosh, & Park, 2011; Tsakiris, Tajadura-Jiménez, & Costantini, 2011; Van Stralen et al., 2014). Only three of them could replicate the RHI related temperature drop. Kammers et al. (2011) showed a relative cooling of the hand in synchronous compared to asynchronous conditions in the RHI. They provide additional evidence for the link between the RHI and local temperature changes, as artificially lowering the hand temperature increased proprioceptive drift in the RHI, while increasing the hand temperature decreases proprioceptive drift. Hand temperature manipulation did not influence subjective ratings of body ownership, but it has been shown before that proprioceptive drift and body ownership questionnaires measure different aspects of the RHI (Abdulkarim & Ehrsson, 2016; Blanke, 2012; Fiorio et al., 2011; Rohde, Luca, & Ernst, 2011). Tsakiris et al. (2011) also found a lower hand temperature in synchronous compared to asynchronous stroking in the RHI, however only in participants with relatively low interoceptive sensitivity, and it appeared to be more related to the proprioceptive drift outcomes than the subjective ratings of the RHI. Also, hand temperature change only showed a very small correlation with the level of interoceptive sensitivity, so it seems not entirely clear what was causing most of the temperature change in this experiment. Finally, a study from our lab (Van Stralen et al., 2014) reported a RHI-related hand temperature drop with slower stroking velocities in the RHI, which elicit an affective touch sensation and increases the effect of the RHI. However, a second experiment in the same study and using the same methods, did not replicate the temperature change (while it did replicate the increase in proprioceptive drift with slower stroking). This therefore might suggest that affective, pleasant stoking may be linked to temperature changes of the hand. Indeed, literature on affective touch shows that stroking with a velocity around 3 cm/s activated C-tactile fibres that project to the posterior insula and is associated with a pleasant feeling. Interestingly, the posterior insula has also been linked to interoception, for instance of body temperature (Craig, 2002).

In studies using variations on the RHI or related bodily illusions, skin temperature drop has also occasionally been replicated. Hohwy and Paton (2010) showed a hand temperature change related to the synchrony of stroking using some variants of the (in this case virtual) rubber hand illusion, but did not find any temperature changes in other variations on the RHI (although these variations did elicit the changes in sense of ownership). Salomon et al. (2013) found a very small temperature decrease of on average around 0.010–0.015 °C after about half a minute of stroking (see their Supplementary Fig. S1) on the leg and back in congruent conditions of a full body illusion, in which illusionary ownership over a complete fake body was generated by the use of a virtual reality setup. Macauda et al. (2015) used visual and vestibular input to create a full body illusion and also reported a small but significant drop in hand and neck temperature in the congruent full body illusion condition.

However, many other studies report a failure of replication of the temperature drop in the RHI either finding no temperature changes, or temperature changes that are independent of stroking synchrony, so unrelated to the illusion of body ownership. Paton et al. (2012) found no cooling of the test hand in the RHI using sensitive temperature measurements (0.01 °C accuracy, 2 Hz sampling over 15 s) in either participants with autism spectrum disorder or healthy controls. Grynberg and Pollatos (2015) also found no relative cooling of the hand in the RHI in a study investigating possible links between RHI susceptibility and lower awareness of emotional and non-emotional internal bodily signals. Other studies did find a drop in hand temperature, but independent of the synchrony of stroking (David et al., 2014; Thakkar et al., 2011). A case study in our lab in a patient with problems in ownership of her left arm showed a temperature drop in the left arm as a result of the RHI procedure but not in the right arm, but this was again independent of stroking synchrony (van Stralen, van Zandvoort, Kappelle, & Dijkerman, 2013). One study specifically set out to investigate the relative cooling of the test hand in the RHI. Rohde et al. (2013) used a robot arm to apply the stroking and did not find any temperature changes over the course of a 3.3 min stroking period, nor after 5–7 min of continuous stroking, while subjective ratings of the illusion and proprioceptive drift were in the range generally reported in RHI literature. When reverting to manual stroking and mimicking the procedure of Moseley et al. (Moseley et al., 2008) as closely as possible, Rohde et al. (2013) found a significant drop in hand temperature of the stimulated hand, but this drop was independent of synchrony of stroking (although there was a trend) and did not correlate with vividness of the illusion. Also, subjective ratings of the illusion and proprioceptive drift did not differ between the automatically applied and manually applied conditions. Therefore, the authors suggested that uncontrolled low level properties of the stimuli applied in the traditional RHI rather than subjectively felt ownership may cause temperature changes in some studies but not others.

Overall, these studies raise the question whether hand temperature really is a reliable objective measure of hand disownership during the RHI, especially given the known publication bias for positive findings (Franco, Malhotra, & Simonovits, 2014). Unfortunately, the literature that reports hand temperature in the rubber hand illusion in healthy participants is limited and quite diverse in their analyses and coverage, making a meta-analysis problematic. Over the years, several studies in our lab have included hand temperature as a dependent variable in their design. As mentioned above, we did find an effect of the RHI on hand temperature in one experiment (Van Stralen et al., 2014). Other studies in our lab have recorded temperature of the hands during the RHI with various measures and in different circumstances, but on a single study level did not find any illusion-related changes in hand temperature. This made us question the reliability of hand temperature