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# Roughness perception during the rubber hand illusion

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ABSTRACT

Watching a rubber hand being stroked by a paintbrush while feeling identical stroking of one's own occluded hand can create a compelling illusion that the seen hand becomes part of one's own body. It has been suggested that this so-called rubber hand illusion (RHI) does not simply reflect a bottom–up multisensory integration process but that the illusion is also modulated by top–down, cognitive factors. Here we investigated for the first time whether the conceptual interpretation of the sensory quality of the visuotactile stimulation in terms of roughness can influence the occurrence of the illusion and vice versa, whether the presence of the RHI can modulate the perceived sensory quality of a given tactile stimulus (i.e., in terms of roughness). We used a classical RHI paradigm in which participants watched a rubber hand being stroked by either a piece of soft or rough fabric while they received synchronous or asynchronous tactile stimulation that was either congruent or incongruent with respect to the sensory quality of the material touching the rubber hand. (In)congruencies between the visual and tactile stimulation did neither affect the RHI on an implicit level nor on an explicit level, and the experience of the RHI in turn did not cause any modulations of the felt sensory quality of touch on participant's own hand. These findings first suggest that the RHI seems to be resistant to top–down knowledge in terms of a conceptual interpretation of tactile sensations. Second, they argue against the hypothesis that participants own hand tends to disappear during the illusion and that the rubber hand actively replaces it.



## 1. Introduction

Ten years ago Botvinick and Cohen (1998) reported an illusion in which participants attributed tactile sensations to a rubber hand and even felt that this fake hand became part of their body. In the classical experiment a rubber hand was placed in front of the participant in an anatomically plausible position with respect to the participant's body. The rubber hand and participant's own occluded hand were each stroked by a small paintbrush. Synchronous stroking, that is, correlated visual and tactile stimulation led to the experience of the illusion after a very short period of time. When the stroking was delivered asynchronously, however, "self-attribution" of the fake hand did not occur (e.g., Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). This phenomenon has meanwhile been replicated and further investigated in a number of studies (e.g., Armel & Ramachandran, 2003; Austen, Soto-Faraco, Enns, & Kingstone, 2004; Costantini & Haggard, 2007; Durgin, Evans, Dunphy, Klostermann, & Simmons, 2007; Ehrsson, Holmes, & Passingham, 2005; Ehrsson, Spence, & Passingham, 2004; Ehrsson, Wiech, Weiskopf, Dolan, & Passingham, 2007; Farnè, Pavani, Meneghello, & Làdavas, 2000; Holmes, Snijders, & Spence, 2006; Kanayama, Sato, & Ohira, 2007; Pavani, Spence, & Driver, 2000; Press, Heyes, Haggard, & Eimer, 2008; Rorden, Heutink, Greenfield, & Robertson, 1999; Schaefer, Flor, Heinze, & Rotte, 2006; Tsakiris & Haggard, 2005; Tsakiris, Hesse, Boy, Haggard, & Fink, 2007; Tsakiris, Prabhu, & Haggard, 2006; Walton & Spence, 2004) and is considered as an established paradigm to manipulate embodiment.

The rubber hand illusion (RHI) is thought to arise as a result of a multimodal conflict between vision, touch, and position sense as well as by visual capture of proprioceptive information (Botvinick & Cohen, 1998).[1] This leads to a re-location of the felt position of one's own hand towards the rubber hand (i.e., proprioceptive drift; participants judged their own hand as being closer to the rubber hand than it really was) and at the phenomenological level to the feeling of "like my hand". Both, the re-location of felt position of one's own hand and the phenomenological sensation of incorporation can be used as a quantitative and qualitative measure of the illusion, respectively, although their interrelation is not yet fully understood. Whereas Holmes et al. (2006), for example, reported that proprioceptive re-locations can occur also without an accompanying illusion of body ownership, Longo, Schüür, Kammers, Tsakiris, and Haggard (2008) recently found that the proprioceptive drift linked to the RHI does correlate selectively with questionnaire items

[1] It is well-known that vision usually dominates touch and proprioception (Ernst & Banks, 2002). For instance, distorted views of the body can improve the spatial resolution of touch (Haggard, Taylor-Clarke, & Kennett, 2003; Kennett, Taylor-Clarke, & Haggard, 2001; see also Section 4).

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relating to the rubber hand being the participant's hand (i.e., embodiment of rubber hand).

It is now widely accepted that not only synchronicity but also spatial congruency between visual and tactile stimulation is a necessary condition for a successful induction of the illusion. For example, the RHI is reduced or even abolished when there is a mismatch between the subject's hand posture and the posture of the rubber hand (Costantini & Haggard, 2007; Graziano, Cook, & Taylor, 2000; Tsakiris & Haggard, 2005) and when the identity of the rubber hand (i.e., left or right hand) is incongruent with that of the participant's own hand (Graziano et al., 2000; Tsakiris & Haggard, 2005) or finally, when participants watch a neutral object instead of hand being stroked synchronously with their own hand (Graziano et al., 2000; Tsakiris & Haggard, 2005; but see Armel & Ramachandran, 2003). These findings suggest that the RHI is mediated by both a bottom–up process of multisensory integration and a mapping of the viewed object onto a general representation of one's own body. That latter has been interpreted as being a top–down process (Tsakiris & Haggard, 2005). Top–down processes refer to information processing that is guided by an individual's higher-level knowledge and expectations, whereas bottom–up processes are those that take sensory information from the environment and transform it into neural impulses without recourse to an individual's prior knowledge.

Although the correlated local multisensory input is a necessary condition for the illusion to occur, it is important to stress that the RHI also causes a profound change in a more higher-order body representation (Holmes & Spence, 2007; Tsakiris & Haggard, 2005). Participants consciously experience that the seen fake hand becomes part of their body as validated by questionnaire responses. This clearly goes beyond a pure bottom–up multisensory integration process but leads to the question what actually happens during the RHI. How and to what extent does the presence of the RHI alter the representation of the bodily self? One possibility is that participants incorporate an extra limb as an additional part of their body. However, this assumption is not in line with previous findings suggesting that the visual input is mapped onto a pre-existing representation of the body that normally does not contain extra limbs (e.g., Tsakiris & Haggard, 2005). On the other hand, the illusionary experience of supernumery limbs has been reported in neurological patients (e.g., McGonigle et al., 2002) and recently in healthy controls too (Schaefer, in press). Schaefer et al. (in press) had participants to wear a special shirt with an artificial rubber arm that was in this way "connected" to participants' body between their own left and right arm. Interestingly, participants not only had the visual impression to have an extra arm but they also reported that they *felt* having three arms. In contrast, feelings of ownership of a supernumery limb could not be evoked by simply placing the rubber arm in front of participants without "connecting" it to their body. As another possibility participants may incorporate the fake hand in their body representation in a way they can incorporate tools to extent the physical body structure and also the action space (for a review see Graziano & Botvinick, 2002; Makin, Holmes, & Ehrsson, 2008; Maravita & Iriki, 2004). Finally, a third possibility would be that the rubber hand is not only incorporated but displaces or substitutes participant's own hand (cf. Longo et al., 2008). By conducting a principal component analysis Longo et al. (2008) identified "loss of own hand" as one of four major components of the subjective experience during the RHI. However, it should be mentioned that the component "loss of own hand" was identified as being a less present experience than for example the component "embodiment of the rubber hand". Interestingly, a recent study reported that the RHI is accompanied by a significant drop in skin temperature for the real hand (Moseley, Olthoff, Venema, et al., 2008). Furthermore, this study shows that during synchronous visual–tactile stimulation participants gave less weight to processing tactile information from their real hand, that is, they showed less perceptual sensitivity in tactile temporal order judgements than in a control condition or during asynchronous stimulation. These results may in fact be interpreted in the sense that – to some extent – the real hand is being replaced by its artificial counterpart.

### 1.1. The present study

The present study aimed at investigating the influence of the RHI on the representation of the bodily self. More precisely, we sought at finding out whether or not the conceptual interpretation of the sensory quality of visual and tactile sensations influences the occurrence of the illusion. This sheds further light on the possible role of top–down influences in this self-attribution process. Furthermore, we aimed at studying whether the rubber hand is incorporated into one's own body representation or whether it replaces one's own hand. To this end we conducted an experiment following the classical RHI paradigm in which we manipulated the sensory quality of the visual and tactile stimulation. That is, participants watched a rubber hand being stroked by a piece of soft material (i.e., a piece of cotton) or by a piece of rough material (i.e., a piece of sponge) while they received (a) synchronous tactile stimulation by a material that was either congruent or incongruent with respect to the sensory quality (i.e., soft or rough) of the material touching the rubber hand.

Perceived roughness is related to the spatial density of the features on a material's surface, which is being processed in specific receptive fields in the primary sensory cortex of the human brain (for an overview see Lederman & Klatzky, 2004). However, spatial density is not identical to perceived roughness. That is, roughness is also a subjective perception which shows interindividual variability (see e.g., Bergmann Tiest & Kappers, 2007), and thus requires a more conceptual interpretation. A number of studies have provided evidence suggesting that there is a close relationship between visually and haptically perceived roughness (e.g., Björkman, 1967; Guest & Spence, 2003; Lederman & Abbott, 1981). In the visual modality the recognition or perception of a certain material as being soft or rough has to be retrieved from memory.

If conceptual interpretations, that is, top–down factors are generally important (cf. Tsakiris & Haggard, 2005), we expected the RHI to occur only in those conditions in which the visual and tactile stimulation are congruent not only with respect to the timing but also with respect to the tactile property of the material the stimulation is conducted by. Furthermore, if the real hand is being replaced when the illusion is established, participants should start sensing the touch on the embodied rubber hand. This sensation then takes over the perceived tactile stimulation delivered to their own hand (cf. Moseley et al., 2008) so that participants start interpreting touch by a rough material on their own hand as being softer when they observe a rubber hand being stroked in synchrony with a soft material and vice versa. In other words, participants should adjust their interpretation of roughness on their own hand according to the perceived visual stimulation of the rubber hand.

## 2. Methods

### 2.1. Participants

A total of 29 neurologically healthy participants (18–30 years of age, 15 female, 4 left-handed and 1 two-handed as assessed by self-report) took part in a single session of about 50 min. All participants were naive with respect to the purpose of the study and received a small reimbursement for their participation. Informed written consent was obtained from each participant prior to the experiment.