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# The spatial distance rule in the moving and classical rubber hand illusions

Andreas Kalckert *, H. Henrik Ehrsson

*Brain, Body & Self Laboratory, Department of Neuroscience, Karolinska Institutet, Retzius väg 8, SE-171 77 Stockholm, Sweden*

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ABSTRACT

The rubber hand illusion (RHI) is a perceptual illusion in which participants perceive a model hand as part of their own body. Here, through the use of one questionnaire experiment and two proprioceptive drift experiments, we investigated the effect of distance (12, 27.5, and 43 cm) in the vertical plane on both the moving and classical RHI. In both versions of the illusion, we found an effect of distance on ownership of the rubber hand for both measures tested. Our results further suggested that the moving RHI might follow a narrower spatial rule. Finally, whereas ownership of the moving rubber hand was affected by distance, this was not the case for agency, which was present at all distances tested. In sum, the present results generalize the spatial distance rule in terms of ownership to the vertical plane of space and demonstrate that also the moving RHI obeys this rule.


## 1. Introduction

In the rubber hand illusion, participants perceive a model hand as part of their own body (Botvinick & Cohen, 1998). This bodily illusion can be induced by touching the rubber hand, which is presented in full view in front of the participant, in synchrony with touches applied to the participant's hand, which is hidden from view behind a screen. When experiencing this visual and tactile stimulation for a short period, sometimes even less than 10 s, the majority of participants starts to sense the touch as originating from the model hand (referral of touch) and experience that the rubber hand feels like their own hand (sense of ownership). To understand the basic processes that mediate this illusion (and thereby, learning something about how body self-perception works under more natural conditions), it is important to identify the basic rules that determine this illusion. Thus, several studies have set out to identify the basic constraints that govern the rubber hand illusion. These studies have shown that visual and tactile stimulation must occur in synchrony (Botvinick & Cohen, 1998; Ehrsson, Spence, & Passingham, 2004; Tsakiris & Haggard, 2005), in the same direction (Costantini & Haggard, 2007; Gentile, Guterstam, Brozzoli, & Ehrsson, 2013) and sufficiently close in space (Lloyd, 2007) for the illusion to be elicited. If the visuo-tactile stimulation is applied asynchronously, if it is applied in opposing directions on the hands, or if the visually stimulated rubber hand is placed far from the participant's hand, then the illusion is not elicited. Moreover, the model hand must be placed in an anatomically plausible position that matches the posture of the real hand (Ehrsson et al., 2004; Ide, 2013; Tsakiris & Haggard, 2005). All of these findings fit well within a theoretical framework in which body-self perception arises as a consequence of multisensory integration and continuous dynamic updating of the central body representation (Ehrsson, 2012; Graziano & Botvinick, 2002).

* Corresponding author.
*E-mail address:* andreas.kalckert@gmail.com (A. Kalckert).

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In previous literature, there are relatively few studies that have examined the spatial constraints of the rubber hand illusion. This is particularly surprising given the importance of this constraint to the question of the kind of process that is responsible for the illusion. For example, Lloyd (2007) found that the strength of the illusion, as measured by a subjective rating of the illusion (referral of touch), decreases significantly when the rubber hand is placed more than 27.5 cm away from the participant's hand. Zopf, Savage, and Williams (2009) re-examined the effect of distance and found somewhat mixed results, whereby the illusion appeared to be inducible at a distance of 45 cm. Armel and Ramachandran (2003) claimed that the illusion could be elicited beyond the participant's reaching space and at a distance of 91 cm from the participant; however, their questionnaire data actually suggested a substantial reduction of the effect at this distance. More recently, Preston (2013) found that the absolute distance between the rubber hand and the participant's hand, as well as the distance of the model hand relative to the participant's trunk and whether the model hand is placed laterally or medially in regard to the participant́s hand, matters. All these previous studies investigated the effect of distance in the horizontal plane so we do not know if the effect holds true in other planes of space. Demonstrating a generalization of this rule to a different plane of space would support the view that the spatial distance rule corresponds to a fundamental principle determining the illusion.

Recently, we introduced a version of the rubber hand illusion that was based on finger movement instead of externally applied touches. In this version, the participant moves his or her finger and the model hand's finger either moves synchronously or asynchronously with respect to the participant's movements (Kalckert & Ehrsson, 2012). When the movements of the participant's finger and the model's finger are synchronous, participants report a vivid feeling of ownership of the model hand and report experiencing somatic sensations from the location where they see the model finger move (see also, Dummer, Picot-Annand, Neal, & Moore, 2009; Sanchez-Vives, Spanlang, Frisoli, Bergamasco, & Slater, 2010; Tsakiris, Prabhu, & Haggard, 2006). This illusion seems to work equally well for active and passive finger movements (Kalckert & Ehrsson, 2012, 2014; Tsakiris et al., 2006), although in the case of active movements, the participants also experience a strong sense of agency (David, Newen, & Vogeley, 2008; Jeannerod, 2003), that is, the sense of being the one to generate the model's finger movements (Kalckert & Ehrsson, 2012). In the moving rubber hand illusion paradigm, the ownership-illusion effect is elicited by matching somatosensory and visual feedback from the fingers. Sense of agency, by contrast, arises as a consequence of the match between the intention to move and the visual and somatosensory feedback from the model hand that matches those intentions (Kalckert & Ehrsson, 2012). Despite the procedural differences and differences in the types of somatosensory submodalities involved with respect to the classical version, the moving rubber hand illusion seems to involve a highly similar illusory experience of owning the model hand. This is reflected in high questionnaire ratings of ownership and a significant proprioceptive drift toward to model hand, which quantifies the degree to which participants experience their hand to be closer to the model's hand (Kalckert & Ehrsson, 2012; Riemer, Kleinböhl, Hölzl, & Trojan, 2013; Tsakiris et al., 2006). Moreover, when testing the classical rubber hand illusion and the moving rubber hand illusion with the same group of participants, these measures were correlated, indicating that the strength of the moving rubber hand illusion can be predicted from the strength of the classical illusion (Kalckert & Ehrsson, 2014). When violating the temporal synchronicity of the seen and felt finger movements (Dummer et al., 2009; Tsakiris et al., 2006) or the anatomical plausibility of the model hand (Kalckert & Ehrsson, 2012; Tsakiris & Haggard, 2005), the rubber hand illusion is not induced, which is consistent with the rules of the classical version of the illusion. However, the important question of whether the spatial distance rule also applies to the moving rubber hand illusion has not yet been investigated. Demonstrating this would support the hypothesis that the moving rubber hand illusion obeys the same fundamental constraints as the classical rubber hand illusion, which in turn would suggest the involvement of similar multisensory processes (Ehrsson, 2012; Kalckert & Ehrsson, 2012).

In the present study, we compare the moving (visuo-motor) and classical (visuo-tactile) versions of the rubber hand illusion by using different distances between the model hand and the participant's hand (12, 27.5, and 43 cm) in the vertical plane. In particular, we are testing the hypothesis that the moving rubber hand illusion will obey a spatial rule that is similar to that of the classical illusion, which means that we expect to find a diminishing effect of the illusion when the hands are further apart. Second, we expect to find an effect of spatial distance for the sense of ownership, but we do not expect to find this effect for the sense of agency. This hypothesis is grounded in the notion that only ownership will depend on the multisensory integration of body-part centered spatial reference frames (Ehrsson, 2012), thereby restricting the model hand to a space near the hand within one's peripersonal space (Brozzoli, Ehrsson, & Farnè, 2013). However, agency involves a process of matching motor intention to sensory feedback that is not expected to be constrained to the body or to a space near a body part (Kalckert & Ehrsson, 2012).

## 2. Methods and results

### 2.1. General procedures

Participants sat on a chair next to a table on which a wooden box with the measures of 30 × 20 × 12 cm had been placed. A life-size, wooden model of a right hand was placed on top of the box in the participant's direct view. The box onto which the model hand was placed was freely movable along the vertical axis and could, thus, easily be positioned at different heights. The participant's right hand was underneath the box and on the table (see Fig. 1). The model hand measured 20 cm in length (from wrist end to the tip of the middle finger) and was covered with a latex glove. Participants wore