Consciousness and Cognition 21 (2012) 799–812

Contents lists available at SciVerse ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

# The Rubber Hand Illusion: Two's a company, but three's a crowd

A. Folegatti [a,b,*], A. Farnè [a,c,d], R. Salemme [a,c,d], F. de Vignemont [e]

[a] INSERM U1028, CNRS UMR5292, Lyon Neuroscience Research Center, ImpAct Team, F-69000 Lyon, France[1]
[b] Dipartimento di Psicologia, Università degli Studi di Torino, Italy
[c] University Lyon 1, F-69000 Lyon, France
[d] Hospices Civils de Lyon, Hôpital Neurologique, Mouvement et Handicap, Lyon, France
[e] Institut Jean Nicod, EHESS–ENS–CNRS, Paris, France

ARTICLE INFO

*Article history:*
Received 24 May 2011
Available online 15 March 2012

*Keywords:*
Rubber Hand Illusion
Embodiment
Body ownership
Limb duplication
Body model
Body boundaries

ABSTRACT

On the one hand, it is often assumed that the Rubber Hand Illusion (RHI) is constrained by a structural body model so that one cannot implement supernumerary limbs. On the other hand, several recent studies reported illusory duplication of the right hand in subjects exposed to two adjacent rubber hands. The present study tested whether spatial constraints may affect the possibility of inducing the sense of ownership to two rubber hands located side by side to the left of the subject's hand. We found that only the closest rubber hand appeared both objectively (proprioceptive drift) and subjectively (ownership rating) embodied. Crucially, synchronous touch of a second, but farther, rubber hand disrupted the objective measure of the RHI, but not the subjective one. We concluded that, in order to elicit a genuine RHI for multiple rubber hands, the two rubber hands must be at the same distance from the subject's hand/body.



## 1. Introduction

Since its (re)discovery by Botvinick and Cohen (1998), the Rubber Hand Illusion (RHI) has become the experimental tool for investigating the sense of body ownership. But why do we feel ownership towards the rubber hand in the RHI? Our only access to the rubber hand is visual. We do not even see the rubber hand in contiguity with our body. It could be anybody's hand. The only difference between anybody's hand and this specific rubber hand is the spatio-temporal correlation between the observed stroking of the rubber hand and the felt stroking of our biological hand. It has been argued that it is precisely multisensory correlation that is at the source of the sense of body ownership (Botvinick & Cohen, 1998; Ehrsson, Holmes, & Passingham, 2005; Makin, Holmes, & Ehrsson, 2008; Morgan & Rochat, 1997; Rochat, 1998).

However, as it stands, the hypothesis of intermodal matching leaves many questions unanswered. In particular, the sense of body ownership cannot derive from any kind of intermodal correlation. Imagine that you see and hear two hands clapping. Despite visuo-auditory correlation, you do not feel these hands as your own. You also need visuo-auditory information to correlate with proprioceptive and tactile information indicating that you, and nobody else, are clapping your hands. In other words, there must be information that is self-specific (e.g. somatosensory information) for intermodal correlation to play a role for ownership. Yet, even the involvement of self-specific information does not always suffice, as shown by a series of recent RHI studies (see Table 1).

* Corresponding author at: INSERM U1028, CNRS UMR5292, Lyon Neuroscience Research Center, ImpAct Team, F-69000 Lyon, France. Fax: +33 (0)4 72 91 34 01.
*E-mail address:* alessiafolegatti@gmail.com (A. Folegatti).
[1] http://u864.lyon.inserm.fr/ImpAct.

1053-8100/$ - see front matter © 2012 Elsevier Inc. All rights reserved.
doi:10.1016/j.concog.2012.02.008

**Table 1**
Constraints that lay upon intermodal matching in the RHI.

| Factors | That prevent the RHI | That do not prevent the RHI |
|---|---|---|
| Temporal | Asynchronous stimulation Cf. Botvinick and Cohen (1998) | |
| Spatial | Mismatch in direction of strokes (in hand-centered frame) Cf. Costantini and Haggard (2007)<br>Mismatch in posture (orientation) Cf. Pavani, Spence, and Driver (2000), Tsakiris and Haggard (2005), Guterstam et al. (2011)<br>Mismatch in location (distance from the torso) Cf. Armel and Ramachandran (2003), Lloyd (2007) | |
| Anatomical | Mismatch in anatomical shape (hand-shaped) Cf. Tsakiris et al. (2010) | Mismatch in visual appearance (monstrous arms, skin tone, etc.) Cf. Austen, Soto-Faraco, Enns, and Kingstone (2004); Longo, Cardozo, and Haggard (2008) |
| | Mismatch in hand laterality with mismatch in hand location (e.g., left RH on the left with right biological hand) Cf. Tsakiris and Haggard (2005) | Mismatch in hand laterality with no mismatch in hand location (e.g., left RH on the right with right biological hand) Cf. Petkova and Ehrsson (2009) |
| | Mismatch in size if rubber hand is smaller Cf. Pavani and Zampini (2007) | Mismatch in size if rubber hand is bigger Cf. Pavani and Zampini (2007) |

Another counterexample is mirror reflection. When you look at your reflection in the mirror while combing your hair, you have self-specific somatosensory information that matches visual information. Yet, one may doubt that you really feel ownership towards the hand in the mirror in the same way that you feel ownership towards the rubber hand in the RHI. You know this is the reflection of your own hand, but the phenomenology does not seem to include a kind of primitive immediate feeling of mineness. What is then the difference between the RHI and mirror recognition? There is one striking difference between the rubber hand and your body reflection in the mirror: you feel tactile sensations on the rubber hand; you do not feel tactile sensations on the head that you see in the mirror when you comb your hair. One may then suggest that the ownership feeling of the rubber hand is grounded in the spatial content of tactile sensation. On this view, it is because touch is experienced as being located on the rubber hand that the rubber hand is experienced as your own. On the other hand, if the body in the mirror is not experienced as your own, it is because no sensation is experienced as being located there. This interpretation of the RHI is in line with a dominant theoretical approach to body ownership, also known as the spatial account of ownership (de Vignemont, 2007), which highlights the importance of the spatiality of bodily sensations.

There are several versions of the spatial account. Martin (1995) reduces the sense of ownership to the awareness of the boundaries of one's own body. He argues that the spatial structure of bodily experiences is such that sensations are necessarily experienced within the boundaries of one's own body. Indeed, in bodily sensations, there is nothing that does not fall within the limits of the bodily space. By contrast, the boundaries of the object that I see are not co-extensive with the visual field. Consequently, the body that I see does not bear the "indelible stamp of ownership" (Brewer, 1995). Martin's spatial account is exclusively at the phenomenological level. Alternatively, one may defend a representationalist view of body ownership, which aims at singling out the specific type of representation of the bodily space that grounds the sense of ownership (e.g., Carruthers, 2008; de Vignemont, 2007; Tsakiris, 2010).

For example, Tsakiris (2010) defends the view that ownership is constrained by what he calls a body model, defined as a "reference description of the visual, anatomical and structural properties of the body". However, a number of questions about the body model remain open. Does it represent the human body in general or more specifically, the subject's individual bodily parameters? Is there only a single model of the body as a whole or several models of parts of the body? How fine-grained is it? The answers to these questions are of importance. The body model is indeed supposed to determine what can or cannot be experienced as one's own. In other words, only objects that meet the description "given" in the body model can be processed as if they were parts of one's body. If the body model depicts anatomical properties and if it plays a role in the RHI, and thus in the sense of body ownership, then one can make the following predictions: (i) one can experience as one's own only objects that look like body parts (i.e. body part constraint); (ii) one can experience as one's own only bodily shape objects of identical laterality (i.e. laterality constraint); (iii) one can experience ownership only for two hands, and not more (i.e. two-hand constraint). The first prediction received so far some support. It was found that one could not induce the RHI with objects that do not present the visual appearance of a body part (Haans, Ijsselsteijn, & de Kort, 2008; Tsakiris, Carpenter, James, & Fotopoulou, 2010; Tsakiris & Haggard, 2005). The laterality constraint, however, is more controversial. On the one hand, Tsakiris and Haggard (2005) found no RHI when a right rubber hand was visually presented close to the stroked left biological hand. However, Petkova and Ehrsson (2009) were recently able to induce the RHI with a difference in hand laterality by introducing spatial separation between the stroked biological hand and the rubber hand. A right rubber hand was placed on the table, while the right biological hand was hidden behind a screen. The left biological hand was placed in full view, but participants were instructed to look at the rubber hand. Both the left biological hand and the right rubber hand were stroked. Despite the incongruence between the hands laterality, participants reported feeling touch on the