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The rubber hand illusion in a mirror

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ABSTRACT

In the rubber hand illusion (RHI) one's hand is hidden, and a fake hand is visible. We explored the situation in which visual information was available indirectly in a mirror. In the mirror condition, compared to the standard condition (fake hand visible directly), we found no reduction of the RHI following synchronised stimulation, as measured by crossmanual pointing and by a questionnaire. We replicated the finding with a smaller mirror that prevented visibility of the face. The RHI was eliminated when a wooden block replaced the fake hand, or when the hand belonged to another person or mannequin. We conclude that awareness of the reflection is the critical variable, despite the distant visual localisation of the hand in a mirror and the third-person perspective. Stimuli seen in a mirror activate the same response as stimuli seen in peripersonal space, through knowledge that they are near one's body.

1. Introduction

1.1. Mirrors and self-recognition

Most people have daily experience of seeing themselves reflected in a mirror. In the modern environment mirrors are familiar objects and people have learned to use them for a number of tasks. In terms of visual information, when we look at ourselves in a mirror what we see is a copy of our own body. Here we limit our discussion to the case of a single plane mirror; by contrast it has been suggested that using two mirrors it is possible to look at the second virtual image and "stand outside oneself" (Altschuler & Ramachandran, 2007). With a single mirror we can see a copy of our body through an aperture, but our conscious experience is not that of a body double (or an out-of-body phenomenon). Instead we immediately relate this visual information back to ourselves. Indeed, many studies have used mirrors as a tool to test for self-recognition (Gallup, 1977). Few other species share with humans this ability to recognise themselves in a mirror and, therefore, relate the information from the mirror to themselves (for a review see Parker, Mitchell, & Boccia, 2006). In humans this self-recognition ability starts in the first few years of life (about 18 months, Anderson, 1984).

Imagine a person sitting at a table with their hands resting on its surface. If a plane mirror were placed in front of the person then they would see their virtual image opposite themselves and mirror reversed. The virtual copy of their left hand, for instance, would be located directly in front of the person's left hand but it would be the right hand of the virtual person and the tips of the fingers of these two hands would face the opposite way. Thus, even though they see the image as belonging to themselves, in terms of visual information they have a third-person perspective of their own body.

People rely on visual information to update an internal model of their own body (for a recent review, see Serino & Haggard, 2010). Given this, we tested whether such adjustments would occur when visual information came exclusively from seeing a reflection in a mirror rather than from seeing one's own body directly.

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1.2. The rubber hand illusion

When a fake hand is stimulated at the same time as one's real but hidden hand, this person may experience a sense of ownership of the fake hand and a sense that the fake hand feels the stimulation. This phenomenon is known as the rubber hand illusion (RHI, Botvinick & Cohen, 1998) and can be used to study how people perceive their own body and how they maintain and update an internal representation of their body. Neuroimaging studies of the sense of body ownership have also harnessed this illusion (e.g. Tsakiris, Longo, & Haggard, 2010).

A necessary condition for the RHI is for the fake and real hands to have a similar orientation. Specifically, Ehrsson, Spence, and Passingham (2004), and Tsakiris and Haggard (2005) found that the illusion was abolished when the fake hand was at 180° and 90° to the subject's own hand. Costantini and Haggard (2007) used smaller rotations (10°, 20° and 30°) and found that the illusion was preserved as long as the stimulation was consistent in a hand-centred frame of reference. More recently, Guterstam, Petkova, and Ehrsson (2011) used a rotation by 180° as a control condition for a new version of the illusion in which participants experience the ownership of a third hand (but not when rotated). In addition to orientation, location and size of the hand are also important. Lloyd (2007) found that the strength of the illusion decayed significantly when the fake hand was over 30 cm from the real hand. Pavani and Zampini (2007) found that size modulated the illusion. The RHI was present for veridical and enlarged images of the hand, but absent when the image of the hand was reduced. However, Bruno and Bertamini (2010) obtained the RHI with realistic fake hands that were either slightly smaller or slightly larger than the hand of the participant. They also found that the size of the fake hand affected the haptic estimation of the size of an object.

Petkova and Ehrsson (2008) have reported an extension of the RHI phenomenon to a whole other body. Participants adopted the visual perspective of a mannequin using a CCTV camera recording from the mannequin's viewpoint. This, in combination with the receipt of correlated multisensory information, triggered the illusion that the mannequin's body was their own. Petkova and Ehrsson concluded that first-person perspective is an important factor in this illusion. Note that this conclusion is consistent with the importance of the orientation of the hand for the RHI because when the fake hand is rotated this is inconsistent with our (usual) first-person perspective of our own hand (we rarely see our own hand rotated 90° or 180°, i.e. with the tip of the fingers towards us). More recently, Petkova, Khoshnevis, and Ehrsson (2011) compared the strength of this full body illusion from the perspective of a first or third person. They concluded that the first-person perspective is essential, and that the multisensory process underlying the sense of self operates in an egocentric reference frame.

We have listed a series of studies showing important constraints on the conditions necessary to induce the RHI. By contrast, Armel and Ramachandran (2003) have suggested that a correlation between vision and touch can induce experiences of ownership of objects completely different from a hand, for instance a table. This view has been criticised because it is incompatible with empirical findings, for instance those reported by Tsakiris and Haggard (2005). Recently, Hohwy and Paton (2010) have suggested a possible resolution. They found that the RHI persists through periods of no tactile stimulation when the real and the fake hand are aligned in personal space. They also reported experiences of touch felt on a cardboard box rather than a fake hand, but only after the basic illusion was established. Without prior onset of the illusion there was no difference between reports of a RHI-like illusion for a cardboard box during synchronous or asynchronous touch. Hohwy and Paton argue that information is treated differently depending on context because of the underlying inferential process. The system is engaged in "explaining away" the incoming evidence.

With respect to the key role of alignment of the real and fake arm, Hohwy and Paton's (2010) results are consistent with Petkova and Ehrsson's (2008) results in so far that the alignment in personal space meant that the participant had a first-person perspective of the hand (as well as of the cardboard box).

1.3. Cross-modal congruency data

Maravita, Spence, Sergent, and Driver (2002) have studied a situation in which participants perceived stimuli only indirectly in a mirror placed in front of them. The task was to respond to tactile stimulation; in this paradigm the interference caused by incongruent visual stimuli is called the cross-modal congruency effect. Stronger interference was produced by visual stimuli located near to the stimulated hand, even when these stimuli were only seen indirectly as mirror reflections. This visual-tactile interference for stimuli seen in a mirror implies that the information from the mirror is not treated as belonging to the virtual location, inside the mirror. Instead this information is related to the location where the objects reflected are physically located, near the hand. The study by Maravita et al. (2002) is an example of how visual information gathered directly or indirectly through a mirror may be treated as equivalent.

There have been many studies on the cross-modal congruency effect, and some of them are relevant because, even though they did not involve a mirror, a third-person perspective was used. For instance, Heed, Habets, Sebanz, and Knoblich (2010) found that crossmodal processing in peripersonal space is reduced for perceptual events that another person acts upon. This third person was sitting across a table from the participant and in one condition acted within the visual stimuli present in the participant's peripersonal space. These effects suggest that some congruency modulation does not require a first-person perspective.

A different but related phenomenon has been reported by Pavani, Spence, and Driver (2000). Observers mislocalised a tactile stimulus delivered to an unseen hand if there were lights near a fake hand that flashed in correlation with the tactile stimulus. Pavani et al. (2000) did not find the effect when the hand was rotated by 90°. Austen, Soto-Faraco, Enns, and