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The use of realistic and mechanical hands in the rubber hand illusion, and the relationship to hemispheric differences

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ABSTRACT

Embodiment, as measured through the rubber-hand illusion (RHI), depends on the similarity between object to be embodied and part of the body it replaces. We compared a fake hand similar to a real hand, and one matched in size but made of wires (mechanical). Left and right versions were tested to investigate whether the effect of appearance was stronger in the left hand. We found that the mechanical hand induced embodiment, though to a reduced degree relative to the realistic hand ($N = 120$). Left and right versions of the mechanical hand did not differ in strength of the illusion. However, with the left realistic hand there was a stronger relationship between drift (an objective measure of the illusion) and agreement on the questionnaire (subjective experience). With the mechanical hand, objective and subjective measures were unrelated. We discuss the results in relation to factors that influence the RHI and hemispheric differences.

1. Introduction

The rubber hand illusion (RHI) plays a key role in the study of how the inner representation of one's body changes over time based on experience. In the standard procedure, one's hand is hidden, and a fake hand is visible. When both hands are stimulated at the same time, for instance by a paintbrush, the visual experience of seeing the fake hand touched is combined with the corresponding tactual sensation. After less than a minute, most participants experience a sense of ownership of the fake hand, including a sense that the fake hand feels the touch (Botvinick & Cohen, 1998, for a review see Serino & Haggard, 2010). The illusion is strongest following synchronous stroking, weaker with asynchronous stroking, and weaker with only visual exposure to the fake hand and no stimulation (e.g. Longo, Cardozo, & Haggard, 2008; Rohde, Di Luca, & Ernst, 2011).

The conditions necessary for the illusion have been debated in the literature. Some authors have suggested that the correlation between vision and touch is sufficient for inducing the experience of ownership of objects totally different from a hand, for instance a table (Armel & Ramachandran, 2003). Other authors, however, have concluded that the fake hand has to have a plausible appearance, and be placed in a plausible relationship to the body. We review this literature below, and next we consider reasons to predict a difference in the strength of the illusion when the left hand or the right hand is stimulated (Ocklenburg, Rüther, Peterburs, Pinnow, & Güntürkün, 2011), and how this might relate to the appearance of the fake hand. Our study addresses both the role of appearance, by using two types of hands, and the role of laterality, by testing both left and right hands of each participant.

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2. The appearance of the fake hand

In our study, we revisited the role of the appearance of the hand. In particular, we compared hands that looked like human hands, and hands that had the size and shape of a hand, including the presence of fingers, but were clearly non-biological. There is empirical evidence that the plausibility of the hand determines the strength of the illusion. Tsakiris and Haggard (2005) compared fake hands with wooden sticks, and the latter failed to elicit the illusion. A rectangular wooden block has been used as a control condition and it does not elicit an illusion (Bertamini, Berselli, Bode, Lawson, & Wong, 2011, but see Hohwy & Paton, 2010, for a discussion of the role of previous experience). Even when cuts of wood have been made to look hand-like, they fail to elicit the illusion (Tsakiris, Carpenter, James, & Fotopoulou, 2010). In contrast, gloves that can be worn on real hands do not interfere with the illusion (Haans, Ijsselsteijn, & de Kort, 2008). Similarly the illusion can be produced with a left fake hand placed on the right when the right biological hand is stimulated (Petkova & Ehrsson, 2009).

A different but related phenomenon provides some indication that appearance of the hand may be less important for some measures of the illusion. It is known that observers mislocalise a tactile stimulus delivered to an unseen hand if lights near a fake hand are perceived to flash in synchrony with the tactile stimulus (Pavani, Spence, & Driver, 2000). This effect survived when there was no match in the texture, or the visual material of the fake and the real hands, and even when a green alien hand was used (Austen, Soto-Faraco, Enns, & Kingstone, 2004). More salient contextual cues may therefore bias perception in favor of accepting a fake hand.

Other cues that influence the induction of the illusion include the degree to which the fake hand fits a biologically plausible orientation relative to the body (Costantini & Haggard, 2007; Ehrsson, Spence, & Passingham, 2004; Tsakiris & Haggard, 2005), and the distance between the fake and hidden hands (Lloyd, 2007). There is conflicting evidence as to how much the relative size of the fake hand matters in the strength of the illusion produced. There is some suggestion that larger, but not smaller, fake hands, relative to average, will illicit an illusion of ownership (Pavani & Zampini, 2007), but other evidence that the size does not matter to the strength of the illusion (Bruno & Bertamini, 2010), but size of the fake hand influences subsequent haptic perception of size.

In our study the fake hands matched the size of the average hand, and were placed in a biologically plausible orientation. Hands appeared to exit the sleeve of a shirt that the participant was wearing. We tried to optimize conditions that would be conducive to the illusion and focused the analysis on comparing two specific types of hands (realistic and mechanical). The mechanical hand is different from other non-hand objects that have been tested before. For instance placing a glove on a fake hand may change the texture of a hand (Haans et al., 2008) but it may still be seen as a biological hand. A mechanical hand has the shape of a hand but because it is made of wires it has no biological plausibility.

3. Hemispheric differences and body representation

The right hemisphere has been connected to a stronger awareness of the physical and mental self, with evidence coming from neurological patients and neurophysiological techniques (Feinberg & Keenan, 2005; Karnath & Baier, 2010; Keenan, Nelson, O'Connor, & Pascual-Leone, 2001). Recently, differences in representations related to self have been addressed through the RHI. There is evidence that the right hemisphere accepts a fake hand more easily than the left hemisphere. Skin conductance response to the fake hand being threatened with a syringe is stronger when the RHI is induced through the left hand relative to the right (Ocklenburg et al., 2011), suggesting that the representation of the left hand was updated more fully. In addition to a stronger skin conductance response, the same participants reported a stronger feeling of ownership when the illusion was induced through the left hand (Ocklenburg et al., 2011; Reinersmann et al., 2013).

Other evidence suggests that one's subjective perception of the body may draw on inter-hemispheric cross talk. Increased mixed handedness, reflective of the strength of influence of the right hemisphere over the left, is positively related to a stronger perception of the illusion when induced through the left hand, suggesting that, while the right hemisphere can facilitate the updating of the representation of the illuded hand more easily, inter-hemispheric cross talk influences subjective perception (Niebauer, Aselage, & Schutte, 2002).

Consistent with the potential for inter-hemispheric cross talk to influence embodiment, the illusion can be induced in the right hand when it is illuded, but the unhidden left hand is being stroked along with the rubber hand mimicking the right hand (Petkova & Ehrsson, 2009; objective and subjective measures were included). Moreover, fMRI data of the illusion being induced in the left hand show *bilateral* activity in premotor cortex that correlates with the subjective perception of the illusion (Ehrsson et al., 2004). However, both hemispheres may be making separable contributions, as an objective measure of the illusion was shown to correlate more with the right posterior insula and the right frontal operculum, even though the illusion was induced through the right hand (Tsakiris, Hesse, Boy, Haggard, & Fink, 2007). The posterior insula is related to interoceptive awareness; thus the right hemisphere may have a stronger awareness of self. Additionally, TMS induced disruption of the right temporo-parietal junction reduced subjective measures of the illusion (Tsakiris, Costantini, & Haggard, 2008), consistent with the right hemisphere making a unique contribution.

Alternatively, a laterality effect in the RHI may relate to other differences across the hemispheres that are not specifically related to representing the *self*. Both cerebral hemispheres make unique contributions in multiple domains of cognition, including memory, decision-making, and attention. With regard to memory, priming experiments have shown that primes activate specific associates in the left hemisphere, and a more dense quantity of semantic associates on the basis of feature