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Crossmodal congruency measures of lateral distance effects on the rubber hand illusion

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ABSTRACT

Body ownership for an artificial hand and the perceived position of one's own hand can be manipulated in the so-called rubber hand illusion. To induce this illusion, typically an artificial hand is placed next to the participant's body and stroked in synchrony with the real hand, which is hidden from view. Our first aim was to test if the crossmodal congruency task could be used to obtain a measure for the strength of body ownership in the rubber hand illusion. In this speeded location discrimination task participants responded to tactile targets presented to their index or middle finger, while trying to ignore irrelevant visual distracters placed on the artificial hand either on the congruent finger or on the incongruent finger. The difference between performance on congruent and incongruent trials (crossmodal congruency effect, CCE) indicates the amount of multisensory interactions between tactile targets and visual distracters. In order to investigate if changes in body ownership influence the CCE, we manipulated ownership for an artificial hand by synchronous and asynchronous stroking before the crossmodal congruency task (blocked design) in Experiment 1 and during the crossmodal congruency task (interleaved trial-by-trial design) in Experiment 2. Modulations of the CCE by ownership for an artificial hand were apparent in the interleaved trial-by-trial design. These findings suggest that the CCE can be used as an objective measure for body ownership. Secondly, we tested the hypothesis that the lateral spatial distance between the real hand and artificial hand limits the rubber hand illusion. We found no lateral spatial limits for the rubber hand illusion created by synchronous stroking within reaching distances. In conclusion, the sense of ownership seems to be related to modulations of multisensory interactions possibly through peripersonal space mechanisms, and these modulations do not appear to be limited by an increase in distance between artificial hand and real hand.

1. Introduction

Walking along a busy street, our bodies are surrounded by many different objects and other human bodies. In order to coordinate our bodily movements and sensory experiences while interacting in such a complex environment, it is important to identify the current position of our body-parts and which body-parts belong to us. The existence of a sense for body-part ownership in addition to a sense for body-part position seems surprising. However, interestingly there are examples of disturbed body ownership (see Moseley et al., 2008 for a list). One such example is somatoparaphrenia—a monothematic delusion where body ownership for a part of the body is denied and which can occur in patients after stroke (see Vallar & Ronchi, 2009 for a review).

The perceived position of our arms relies on the integration of proprioceptive, visual and auditory information (Lackner & DiZio, 2000). This multisensory integration uses positional information from each modality, weighted differently depending on the given situation (van Beers, Wolpert, & Haggard, 2002). To specify the influence of each modality on position coding, in several studies spatial differences between visual and proprioceptive information were introduced using, for example, prisms, mirrors, and artificial hands (Graziano, Cooke, & Taylor, 2000; Holmes, Snijders, & Spence, 2006; Mon-Williams, Wann, Jenkinson, & Rushton, 1997). In the study by Holmes et al. (2006) participants were asked to perform reaching movements with their left hand which was placed behind a mirror and could not be seen. Just before a reaching movement, participants saw the mirrored reflection of their own right hand, of an artificial right hand, or of a wooden block. The visual image was projected to a position in space different from the covered left hand, thus creating a conflict between visual and proprioceptive information. The authors found that the felt hand position prior to reaching movements was biased towards the visual information when a hand was seen (real or artificial) as compared to a wooden block or a misaligned rotated artificial hand. This suggests that the position of a hand is encoded relative to what is felt *and* what is

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seen which can lead to errors if 'misleading' visual information is given.

What can contribute to the resolution of these conflicts and determine where one's own arms and hands are perceived? One possibility is that additional multisensory input is used to determine perceived hand position and perceived hand ownership. This possibility has been investigated using the so-called "rubber hand illusion" (Botvinick & Cohen, 1998). Again, a spatial difference between visual and proprioceptive information is introduced by placing an artificial rubber hand in front of the participant while the participant's real hand is hidden from view. Both hands are now stroked with brushes simultaneously. When asked after the brushing most participants report the perceived position of the real hand (i.e., what is felt) to be closer to the artificial hand (i.e., what is seen) (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). Importantly, this drift in perceived position depends on the simultaneity of the prior multisensory input: For synchronous brushing larger position drifts were found as compared to asynchronous stroking. Note that to date it is has not been resolved whether synchronous brushing increases position drift, or asynchronous brushing decreases position drift, or both. Many participants report the subjective experience that the felt touch of the brush is located where the seen artificial hand is touched and that the felt touch is caused by the brush touching the artificial hand. Furthermore, many participants feel as if the artificial hand is their own hand. It therefore seems that the synchronicity of tactile and visual input produced by objects touching the hand can further modulate the multisensory integration for hand position together with changes in the perceived localisation of touch and the sense of body ownership. However, the multisensory and/or sensory-motor processes involved still need to be explained.

Neurons that are specialized in the encoding of multisensory information concerning body-parts have been studied in the monkey brain. Electrophysiological studies suggest that multisensory information regarding hand position modulates cortical activity in parietal and frontal brain areas (Graziano, 1999; Graziano et al., 2000). Furthermore, in some parietal and frontal brain areas multisensory maps of space around a body-part in a body-part-centred frame of reference is encoded in addition to a representation of body-part position; for example, in the ventral intraparietal area (VIP) and the premotor cortex (or more precisely the polysensory zone in the precentral gyrus) in the monkey brain (see Graziano & Cooke, 2006 for a review). Some neurons in these areas have visual receptive fields that cover the area around the body-part and move with the body-part when it changes position. These multisensory neurons thus map the near space around body-parts which is known as "peripersonal space" (Rizzolatti, Fadiga, Fogassi, & Gallese, 1997).

In humans, brain areas have been identified that are specialized in the representation of visual stimuli within peripersonal space around the arm. In a functional magnetic resonance imaging (fMRI) study tactile activation *and* significant differences in visual activation for the visual appearance of a ball appearing near versus far from the participant's hand have been found in the anterior intraparietal sulcus (IPS) and premotor cortex (Makin, Holmes, & Zohary, 2007). Interestingly, very similar areas have been related to the conditions that may lead to illusory ownership for an artificial rubber hand and the reported feelings of body-part ownership itself in human fMRI studies (Ehrsson, Holmes, & Passingham, 2005; Ehrsson, Spence, & Passingham, 2004; Ehrsson, Wiech, Weiskopf, Dolan, & Passingham, 2007). Based on the above studies, common mechanisms have been suggested to play a role in the representation of body-part position, body-part ownership, and peripersonal space (Ehrsson et al., 2004; Lloyd, 2007; Makin, Holmes, & Ehrsson, 2008). In this present study, we investigated two questions regarding the rubber hand illusion that are related to these aspects of body representation.

1.1. Crossmodal congruency effect as a measure of the rubber hand illusion

Our first aim for the present study was to obtain an objective measure of changes of body ownership in the rubber hand illusion. Many previous studies have used rating scales, position judgements, or skin conductance responses to measure the differences in illusion strength (Armel & Ramachandran, 2003; Botvinick & Cohen, 1998; Lloyd, 2007; Longo, Schuur, Kammers, Tsakiris, & Haggard, 2008; Tsakiris & Haggard, 2005). We tested if the crossmodal congruency task might be used to obtain an indirect measure of the rubber hand illusion which is probably less susceptible to observer and experimenter biases. The crossmodal congruency task is a speeded location discrimination task for which, for example, tactile targets as well as visual distracters are presented to one of two different locations on the hand (see Spence, Pavani, Maravita, & Holmes, 2004, 2008, for reviews). The location of target and distracter can be congruent (same finger) or incongruent (different finger). The difference in performance between incongruent and congruent trials, known as the crossmodal congruency effect (CCE), specifies the influence of the visual distracter on discriminating the tactile target location and thus indicates multisensory interaction. Importantly, the CCE is modulated by the distance between the tactile and visual stimuli: Visual stimuli near the body-part receiving tactile stimuli lead to a larger CCE compared with more distant visual stimuli. Thus, the task can be used to investigate multisensory interactions with respect to peripersonal space in humans.

This task has been used to obtain an online measure for changes in 'global body self-consciousness' (Aspell, Lenggenhager, & Blanke, 2009). Participants saw their own back from 2 m behind. In a 'synchronous' condition the backs of the participants were brushed and participants could see the brushing on their own backs. In an 'asynchronous' condition a delay was introduced between felt and seen brushing. In the synchronous condition (but not in the asynchronous condition), participants reported experiencing that the felt touch was in the location where the seen body was touched, that the 'virtual body' was their own body, and a significant drift of perceived body position towards the seen body. Furthermore, an adapted version of the crossmodal congruency task was used in which tactile targets and visual distracters were attached to the upper back. CCEs for stimuli presented on the same side of the back were larger in a condition in which changes in 'global body self-consciousness' were induced by synchronous stroking, compared with the asynchronous stroking condition.

Findings from a previous study conducted by Pavani, Spence, and Driver (2000) suggest that the amount of CCE and the strength of ownership for an artificial body-part are also related (see also Walton & Spence, 2004, for related findings). The authors investigated the effect of conflicting visual and proprioceptive information regarding arm position on multisensory interactions in peripersonal space as measured by the CCE. Participants received tactile targets to their covered real hands, while visual distracters were placed next to artificial hands that were positioned above the real hands. Pavani and colleagues found that the presence of artificial hands next to visual distracters led to an increased CCE compared with the absence of artificial hands or misaligned rotated artificial hands; this occurred only for visual and tactile stimuli presented on the same side of space (on/near the same hand). The authors argued that the tactile targets are perceived closer to the visual distracters when artificial hands are present and aligned with the position of the participants' own hands. Although no brushing was used in this study to induce the rubber hand illusion, participants experienced the rubber hand illusion more (but overall, not very strongly) when