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Spatial limits on the nonvisual self-touch illusion and the visual rubber hand illusion: Subjective experience of the illusion and proprioceptive drift

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ABSTRACT

The nonvisual self-touch rubber hand paradigm elicits the compelling illusion that one is touching one's own hand even though the two hands are not in contact. In four experiments, we investigated spatial limits of distance (15 cm, 30 cm, 45 cm, 60 cm) and alignment (0°, 90° anti-clockwise) on the nonvisual self-touch illusion and the well-known visual rubber hand illusion. Common procedures (synchronous and asynchronous stimulation administered for 60 s with the prosthetic hand at body midline) and common assessment methods were used. Subjective experience of the illusion was assessed by agreement ratings for statements on a questionnaire and time of illusion onset. The nonvisual self-touch illusion was diminished though never abolished by distance and alignment manipulations, whereas the visual rubber hand illusion was more robust against these manipulations. We assessed proprioceptive drift, and implications of a double dissociation between subjective experience of the illusion and proprioceptive drift are discussed.

1. Introduction

In studies that use Botvinick and Cohen's (1998) visual rubber hand paradigm, the participant looks at a prosthetic hand as it is stroked with a paintbrush by the Examiner while at the same time the Examiner administers strokes with an identical paintbrush to the participant's hidden hand. When timing of stimulation on the viewed prosthetic hand is matched to timing of stimulation on the participant's hidden receptive hand, the participant experiences an illusion and seems to feel "the touch not of the hidden brush but that of the viewed brush, as if the rubber hand had sensed the touch" (Botvinick & Cohen, p. 756). It may seem to the participant that she feels touch at the location of the viewed prosthetic hand (visual capture of touch), that the felt touch is caused by the paintbrush touching the prosthetic hand (causation), and that the viewed prosthetic hand is her own hand (ownership). The visual rubber hand illusion (RHI) is commonly assessed using statements on a questionnaire, for which participants give agreement ratings. The illusion has also been assessed with a measure of proprioceptive drift – that is, the change in the proprioceptively perceived position of the participant's hidden receptive hand. In most rubber hand studies, this drift is toward the location of the viewed prosthetic hand and the magnitude of

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the drift is typically about 15–30% of the full distance between the receptive hand and the prosthetic hand (Makin, Holmes, & Ehrsson, 2008).

There is also a *nonvisual* self-touch rubber hand paradigm, and the illusion that it elicits is also assessed with agreement ratings and proprioceptive drift (Ehrsson, Holmes, & Passingham, 2005). In this paradigm, the participant – guided by the Examiner – administers stimulation with a paintbrush to a prosthetic hand while at the same time the Examiner administers stimulation with an identical paintbrush to the participant's other hand. When timing of stimulation on the prosthetic hand is matched to timing of stimulation on the participant's receptive hand, the participant experiences the illusion that she is touching her own hand: the self-touch illusion. It may seem to the participant that self-touch is occurring at the location of the prosthetic hand, where she herself is administering stimulation or, more commonly, that self-touch is occurring at the location of her receptive hand, which is receiving stimulation from the Examiner (see White, Aimola Davies, & Davies, 2011).

The nonvisual self-touch illusion (STI) provides a unique opportunity to investigate sensory integration in conditions that preclude vision, not only of the participant's own hands, but also of the prosthetic hand. Information about the position of the prosthetic hand is not provided by vision but by proprioception from the participant's hand that is administering stimulation to the prosthetic hand. Consequently, the nonvisual STI and the sensory integration it entails are quite different from the visual RHI and the sensory integration *it* entails (see also White et al., 2011). The visual RHI involves integration of sensory information from vision, proprioception, and touch. Visual information about the position of the prosthetic hand and about the brushstrokes administered to it, proprioceptive information about the position of the participant's receptive hand, and tactile information about the brushstrokes administered to the receptive hand are integrated in a single-event file – as if the seen brushstrokes were the felt brushstrokes. In the nonvisual STI, there is proprioceptive and tactile information about the position and action of the participant's hand administering touch to the prosthetic hand and there is proprioceptive and tactile information about the position of the participant's receptive hand and the touch administered to it. This information is integrated in a single-event file – as if the brushstrokes administered by the participant were the felt brushstrokes.

Our main interest is in conducting a systematic investigation (agreement ratings, time of illusion onset, and proprioceptive drift) of the spatial limits of distance (15 cm, 30 cm, 45 cm, 60 cm) and alignment (0°, 90° anti-clockwise) for the nonvisual STI. Manipulating the distance between the hands and the alignment of the hands with vision precluded will provide valuable evidence as to how sensory information is integrated when there is conflict between the position information provided by proprioception from the administering hand and from the receptive hand. Moreover, by independently manipulating distance and alignment, we can isolate the effect of each spatial manipulation.

No previous study has manipulated distance or alignment in the nonvisual self-touch rubber hand paradigm and our investigations were informed by studies using the visual rubber hand paradigm. The visual RHI has been shown to be diminished by increasing the distance between the participant's hand and the prosthetic hand (Lloyd, 2007, but see Zopf, Savage, & Williams, 2010), and abolished when the participant's hand is positioned at 0° rotation and the viewed prosthetic hand is misaligned, either by 90° (Tsakiris & Haggard, 2005; also see Pavani, Spence, & Driver, 2000, for a similar result using a cross-modal congruency task), or by as little as 10°, 20°, or 30° (Costantini & Haggard, 2007).[2]

It is important to consider alignment manipulations to understand the effects of distance because it has been suggested (Zopf et al., 2010; see also Makin et al., 2008) that Lloyd's (2007) finding for distance may be better explained by the mismatch in alignment between the participant's hidden receptive hand and the prosthetic hand. Lloyd set out to manipulate distance while also controlling for anatomical plausibility, but in doing so she may have introduced a possible confound. A prosthetic right hand was positioned to the left of the participant's hidden right hand and the distance between the hands was increased, by positioning the prosthetic hand further to the left. To maintain an anatomically plausible orientation relative to the participant's right shoulder, the viewed prosthetic right hand was also rotated progressively further leftward, so that, at greater distances, the fingers of the prosthetic hand pointed to the left rather than straight ahead. Thus, alignment was matched only when the participant's hidden hand and the prosthetic hand were close to one another (17.5 cm), but alignment was increasingly mismatched as the distance between the two hands increased (to 27.5 cm, 37.5 cm, 47.5 cm, 57.5 cm, 67.5 cm).

To address this issue, Zopf et al. (2010, Experiment 2) varied the distance (15 cm, 45 cm) between the participant's hidden hand and the prosthetic hand (positioned near the participant's body midline) but held alignment constant. In contrast to Lloyd's (2007) findings, Zopf et al. found that the visual RHI was not diminished when the participant's hand was 45 cm from the prosthetic hand. But before concluding that Lloyd's effects for distance were actually effects of a mismatch in alignment, we need to take into account the methodological differences between these two studies and, more generally, across the studies that have manipulated distance and alignment in the visual rubber hand paradigm. For example, some studies have used only synchronous stimulation (Costantini & Haggard, 2007; Lloyd, 2007), and some studies have compared synchronous with asynchronous stimulation (Tsakiris & Haggard, 2005; Zopf et al., 2010). The duration of stimulation has varied from 60 s (Lloyd, 2007) to 2 min (Costantini & Haggard, 2007) and 4 min (Tsakiris & Haggard, 2005). Another methodological difference is that in most rubber hand studies, including the study by Zopf et al., the prosthetic hand is at or near the

[2] Armel and Ramachandran (2003) also have examined the effects of a distance manipulation on the visual RHI but they did not specify the distance between the participant's hidden hand and the viewed prosthetic hand: the viewed prosthetic hand was positioned either at a realistic location relative to the participant's body or 91 cm in front of the participant's body. Other studies (Durgin, Evans, Dunphy, Klostermann, & Simmons, 2007; Ehrsson, Spence, & Passingham, 2004; Holle, McLatchie, Maurer, & Ward, 2011; Kontaris & Downing, 2011; Petkova & Ehrsson, 2009) have examined the effects of alignment manipulations on the visual RHI, but they used a more extreme (180°) rotation of the viewed prosthetic hand.