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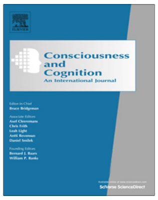

The effect of limb crossing and limb congruency on multisensory integration in peripersonal space for the upper and lower extremities

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ABSTRACT

The present study investigated how multisensory integration in peripersonal space is modulated by limb posture (i.e. whether the limbs are crossed or uncrossed) and limb congruency (i.e. whether the observed body part matches the actual position of one's limb). This was done separately for the upper limbs (Experiment 1) and the lower limbs (Experiment 2). The crossmodal congruency task was used to measure peripersonal space integration for the hands and the feet. It was found that the peripersonal space representation for the hands but not for the feet is dynamically updated based on both limb posture and limb congruency. Together these findings show how dynamic cues from vision, proprioception, and touch are integrated in peripersonal limb space and highlight fundamental differences in the way in which peripersonal space is represented for the upper and lower extremity.

1. Introduction

Many of our everyday activities and interactions rely on an implicit representation of our body. For instance, when grasping a cup in the periphery of our visual field we rely on an implicit representation of the position of our hand and when making a pass in a football game we use an internal representation of the location of our feet to hit the ball. Usually the complex processes underlying these bodily transformations are taken for granted and are not given much further thought. Only in the case of neurological deficits the importance of these complex processes and their integration with knowledge about one's body parts becomes unmistakably clear. For instance, apraxic patients and patients with autotopagnosia are characterized by an impaired ability to locate the spatial position of their body parts (e.g. Felician, Ceccaldi, Didic, Thinus-Blanc, & Poncet, 2003; Goldenberg, 1995). An autotopagnosic patient may well be able to give an accurate verbal description of the feet, but when asked to point to the location of these body parts he may be at a complete loss (Schwoebel, Coslett, & Buxbaum, 2001).

Over the last decade many studies have investigated the functional and neural mechanisms underlying the representation of our body (e.g. Berlucchi & Aglioti, 1997, 2010; de Vignemont, 2010; Dijkerman & de Haan, 2007). It has been found for instance, that neurons in the superior parietal lobe fire selectively when a fake body part is presented in an anatomically congruent position, but not when the body part is placed in an impossible position (Graziano, Cooke, & Taylor,

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2000). In addition, the visual receptive field size of visuo-tactile neurons has been shown to increase to the space surrounding the end of a handheld tool (Iriki, Tanaka, & Iwamura, 1996). These studies suggest that multimodal neurons in parietal areas provide an important neural mechanism supporting the flexible updating of the body representation based on current sensory input. In humans, multisensory interactions between touch and vision have been studied extensively by using the crossmodal congruency task (Maravita, Spence, Kennett, & Driver, 2002; Schicke, Bauer, & Roder, 2009; Spence, Pavani, & Driver, 2000). In this task participants are required to respond to tactile stimuli applied to their thumb or index finger while ignoring visual distractor stimuli. Typically, participants respond slower if the visual distractor appears at an incongruent location with respect to the tactile stimulus, which is known as the crossmodal congruency effect (CCE). It has been found that CCEs are larger when the visual distractors are superimposed on a rubber body part that is placed in an anatomically congruent compared to an incongruent position (Pavani, Spence, & Driver, 2000). In addition, the CCE is larger when the visual and tactile stimuli are presented in the same side of space as compared to when presented in different sides (CCE side effect; see: Spence et al., 2000), suggesting that the CCE provides a direct measure of the perceived proximity of visual and tactile events.

It is well known that our body representation can be flexibly updated via processes of multisensory integration, resulting in different mappings of peripersonal space (i.e. the space directly surrounding our body) based on current sensory input (Maravita & Iriki, 2004). For instance, through a process of synchronous visuo-tactile stimulation participants may experience feelings of ownership for rubber body parts (Botvinick & Cohen, 1998; Costantini & Haggard, 2007; Ehrsson, Holmes, & Passingham, 2005; Tsakiris & Haggard, 2005) and even for virtual bodies (Aspell, Lenggenhager, & Blanke, 2009; Lenggenhager, Tadi, Metzinger, & Blanke, 2007). With respect to tool use, it has been found that visual distractors presented at the end of a handheld tool interfere with judgments of tactile stimuli applied to the hand (Maravita & Iriki, 2004; Maravita et al., 2002). Normally, the effect is stronger for visual stimuli presented at the tip of the tool on the same side as that of tactile stimulation. However, when the tools were held in a crossed posture, visual distractors presented at the end of the tool which were now in the opposite visual hemifield interfered more strongly, indicating that tool crossing resulted in a remapping of peripersonal space (Maravita & Iriki, 2004; Maravita et al., 2002).

Several studies have shown that a touch to a crossed hand is initially mapped to the wrong side and then after a period of 200–400 ms remapped to the correct side (Azanon, Camacho, & Soto-Faraco, 2010; Kitazawa, 2002). Other studies have shown that hand crossing across the body midline can reverse spatial compatibility effects (Holmes, Sanabria, Calvert, & Spence, 2006; Riggio, Gawryszewski, & Umiltà, 1986) and can modulate the integration of visuo-tactile information in peripersonal space (Spence, Pavani, & Driver, 2004). In addition, it has been shown that *anatomical congruency* (i.e. placing rubber limbs in an anatomically possible or impossible position) can modulate multisensory integration as measured by the CCE (Pavani et al., 2000). However, no study has looked directly at the combined effects of *limb crossing* and *limb congruency* on multisensory integration. That is, crossing one's limbs across the body midline likely not only results in a remapping of *tactile information*, but also in an update of *visual information* regarding our body parts (e.g. we expect to see our right hand in our left visual field).

Thus, the aim of the present study was to determine the relative importance of two factors for the remapping of peripersonal space, namely *limb crossing* and *limb congruency*. To this end we used a paradigm in which participants were presented with anatomically congruent or incongruent visual body information, while their actual body parts were in a crossed or an uncrossed posture. To measure multisensory integration in peripersonal space, we used the crossmodal congruency task by applying vibrotactile stimuli to the participant's hands and by presenting visual distractors superimposed on rubber hands (Aspell et al., 2009; Holmes, Calvert, & Spence, 2007; Holmes et al., 2006; Salomon, van Elk, Aspell, & Blanke, 2012; Shore, Barnes, & Spence, 2006; Spence, Pavani, & Maravita, & Holmes, 2004).

We made the following predictions regarding our experimental manipulations. First, when both the real hands and the rubber hands were uncrossed we expected a stronger same side CCE (i.e. visual and tactile stimuli presented at the same side) compared to a different side CCE (i.e. visual and tactile stimuli presented at different sides). Such a finding would be indicative that the rubber hands are automatically perceived as a part of one's body proper. Second, following the notion that the crossing of body parts results in a remapping of touch (Azanon et al., 2010; Schicke & Roder, 2006; Yamamoto & Kitazawa, 2001), we expected that when the real arms were crossed tactile stimuli should interfere more strongly with visual distractors presented in the opposite hemifield (Spence, Pavani, & Driver, 2004). Third, given the finding that crossing one's hands impairs one's ability for tactile localization (Axelrod, Thompson, & Cohen, 1968; Roder, Rosler, & Spence, 2004; Shore, Spry, & Spence, 2002; Spence & Driver, 1994; Wada, Yamamoto, & Kitazawa, 2004; Yamamoto & Kitazawa, 2001), we expected that hand crossing would result in an overall decline in performance.

2. Experiment 1

2.1. Methods

2.1.1. Participants

In the first experiment 18 participants (five female participants, mean age = 21.2 years) were tested, who were all students at the École Polytechnique Fédérale de Lausanne in Switzerland.