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Vision of the body improves inter-hemispheric integration of tactile-motor responses

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ABSTRACT

Sensory input from and motor output to the two sides of the body needs to be continuously integrated between the two cerebral hemispheres. This integration can be measured through its cost in terms of processing speed. In simple detection tasks, reaction times (RTs) are faster when stimuli are presented to the side of the body ipsilateral to the body part used to respond. This advantage – the *contralateral-ipsilateral difference* (also known as the crossed-uncrossed difference: CUD) – is thought to reflect inter-hemispheric interactions needed for sensorimotor information to be integrated between the two hemispheres. Several studies have shown that non-informative vision of the body enhances performance in tactile tasks. However, it is unknown whether the CUD can be similarly affected by vision. Here, we investigated whether the CUD is modulated by vision of the body (i.e., the stimulated hand) by presenting tactile stimuli unpredictably on the middle fingers when one hand was visible (i.e., either the right or left hand). Participants detected the stimulus and responded as fast as possible using either their left or right foot. Consistent with previous results, a clear CUD (5.8 ms) was apparent on the unseen hand. Critically, however, no such effect was found on the hand that was visible (− 2.2 ms). Thus, when touch is delivered to a seen hand, the usual cost in processing speed of responding with a contralateral effector is eliminated. This result suggests that vision of the body improves the interhemispheric integration of tactile-motor responses.

1. Introduction

Performing finely tuned movements and complex motor skills using the hands requires close coordination between the two sides of the body. However, sensory input and motor functions are lateralised to the contralateral cerebral hemisphere (Fritsch & Hitzig, 1870; Penfield & Boldrey, 1937), although recent studies have also revealed some level of ipsilateral processing (Tamè et al., 2012; Tamè, Pavani, Papadelis, Farnè, & Braun, 2015; for a review see Tamè, Braun, Holmes, Farnè, & Pavani, 2016). This raises the question of how this coordination between the sensory and motor systems happens. A century ago, Poffenberger developed a behavioural approach to quantify the sensorimotor transfer, which has proven useful in studying this process (Marzi, 1999; Poffenberger, 1912). He showed that people have faster reaction times (RTs) when visual stimuli are presented in the visual field ipsilateral to the hand used to respond, than when presented in the contralateral visual field. He proposed that this contralateral-ipsilateral difference (also known as crossed-uncrossed difference: CUD) reflects the time required for signals to transfer between the two cerebral hemispheres. The logic of the Poffenberger paradigm is that when the sensory stimulus and motor effector are on the same side of the body, sensorimotor information can be integrated and processed within the same hemisphere (uncrossed time). By contrast, if sensory input is presented contralateral to the effector used to respond, the information has to be integrated across hemispheres (crossed time). The most likely anatomical pathway to mediate this effect is considered to be the corpus callosum (CC) (Berlucchi, Aglioti, Marzi, & Tassinari, 1995; Marzi, Bisiacchi, & Nicoletti, 1991; Poffenberger, 1912).

Although most studies using this paradigm have investigated the CUD effect in the visual domain (Bashore, 1981; Chaumillon, Blouin, & Guillaume, 2014; Jeeves, 1969; Pellicano, Barna, Nicoletti, Rubichi, & Marzi, 2013), several studies have found that the same effect also holds for other sensory modalities such as audition (Böhr et al., 2007; Elias, Bulman-Fleming, & McManus, 2000) and touch (Kaluzny, Palmeri, & Wiesendanger, 1994; Moscovitch & Smith, 1979; Muram & Carmon, 1972; Schieppati, Musazzi, Nardone, & Seveso, 1984; Tamè & Longo, 2015; Tassinari & Campara, 1996). Recently we used this paradigm to show that interhemispheric integration of the tactile and motor responses varies as a function of the specific body part stimulated (Tamè & Longo, 2015). Specifically, we found that sensor-

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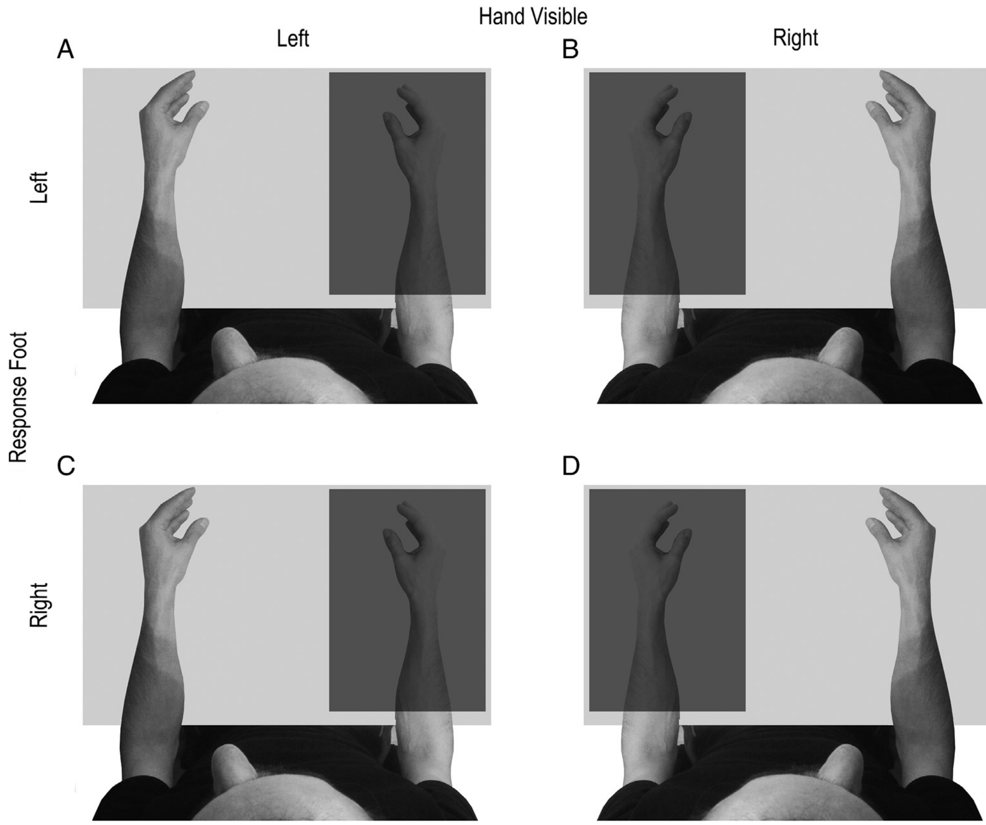

Fig. 1. Schematic depiction of the four experimental conditions. Tactile stimuli were always delivered unpredictably on the left or right middle fingers. Across conditions, participants looked toward the left hand responding with the left (A) or right (C) foot or looked toward the right hand responding with the left (B) or right (D) foot. Vision of one hand was prevented by a sheet of black cardboard.

imotor interactions change along the proximal-distal axis with faster integration when tactile stimuli were delivered on the forehead than on the fingers.

The high spatial acuity of vision strongly contributes to the spatial encoding of body parts, affecting the processing of signals coming from other sensory modalities such as touch (Cardini, Longo, & Haggard, 2011; Pavani, Spence, & Driver, 2000). In this respect, vision of the body has been shown to affect perception of multisensory stimuli by modulating unisensory performance in several ways. For instance, seeing the body, even when vision is completely non-informative about the tactile stimulus, modulates tactile distance perception (Longo & Sadibolova, 2013), reduces pain (Longo, Betti, Aglioti, & Haggard, 2009; Romano & Maravita, 2014), and also produces limb-specific modulation in skin temperature (Sadibolova & Longo, 2014). Moreover, vision of the body has been shown to enhance tactile performance (Cardini et al., 2011; Kennett, Taylor-Clarke, & Haggard, 2001; Press, Taylor-Clarke, Kennett, & Haggard, 2004; Tamè, Farnè, & Pavani, 2013; Tipper et al., 1998, 2001). For instance, tactile two-point discrimination is improved by vision of the arm (Kennett et al., 2001). Press et al. (2004) investigated whether vision of the body enhances tactile performance generally or whether this effect instead depends on specific characteristics such as the spatial nature and the difficulty of the task. Their results showed that non-informative vision of the body enhances tactile performance only when the task is difficult (e.g., tactile discrimination) and requires a spatial computation. Therefore, the effect of vision on tactile processing seems to rely on quite specific multimodal interactions (Press et al., 2004).

In this study, we investigated whether vision of the body affects the interhemispheric integration of tactile and motor information between the two sides of the body, using the Poffenberger paradigm. We tested whether tactile stimuli delivered on the middle fingers of the two hands produced comparable CUDs when one hand was visible, while the other was occluded. As described above, previous reports have shown that vision modulates performance both in terms of accuracy and RT in response to tactile stimuli under specific circumstances, namely when the task is both difficult and has a spatial component (Press et al., 2004). If vision affects the interhemispheric integration of tactile-motor responses, the magnitude of the CUD should be reduced or absent for the visible hand compared to the occluded hand. In contrast, if vision does not affect interhemispheric tactile-motor integration, the CUD should be similar for both hands (i.e., contralateral and ipsilateral with respect to the responding foot).

2. Material and methods

2.1. Participants

Twenty-nine participants (mean ± SD = 30 ± 8.6 years; 12 females) took part in the study. Participants gave their informed consent prior to participation and reported normal or corrected to normal vision and normal touch. The study was approved by the local ethics panel. All participants were right-hand, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971; M = 79, range 11–100).

2.2. Apparatus and stimuli

Tactile stimuli were delivered on the middle fingers of both hands using two stimulators (Solenoid Tactile Tapper, M & E Solve, UK). The solenoid tappers (8 mm in diameter) producing the suprathreshold tactile stimuli were driven by a 9 V square wave. The apparatus was controlled by means of a National Instruments I/O Box (NI USB-6341) connected to a computer through a USB port. Tactile stimulation was delivered for 5 ms. Tappers assigned to the two sides of the body (left or right middle finger) were randomly changed for every participant, to