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Hand processing depends on the implicit access to a spatially and bio-mechanically organized structural description of the body

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ABSTRACT

Recent evidence using a modified Simon task suggests that hand processing involves implicit coding of the spatial position of the hand relative to the side of the body to which it is attached from the viewer's reference point. This effect, called the Sidedness effect, has been found to emerge only when at least the forearm is present (the forearm thus providing the spatial reference for representing the rest of body) and it has been interpreted within the framework of the structural representation of the body. In this study we use the same modified Simon task to investigate whether hand processing involves the implicit access to a spatially and bio-mechanically organized structural body representation. In a first experiment the hand stimuli were attached to a body inappropriately without respecting the bio-mechanical constraints and no Sidedness effect was found. In Experiment 2 where the hand stimuli were presented attached to a non-bodily shape the Sidedness effect was observed only when they were attached appropriately. Whilst previous research has involved *explicit* representational processes, our results suggest that we can *implicit* access to a 'structural description of the body' and elaborate the anatomical and bio-mechanical plausibility.

1. Introduction

Many studies have addressed the issue of body representation by using the same logic that is applied to face recognition processing (Maurer, Le Grand, & Mondloch, 2002; Reed, Stone, Bozova, & Tanaka, 2003, among others). Faces and bodies, but not objects, are recognized through a configural processing of the spatial relations among their features (see Biederman, 1987; Cave & Kosslyn, 1993; Reed, Stone, Grubb, & McGoldrick, 2006), with the various body parts embedded into an overall structure with hierarchical and spatial characteristics (Reed, McGoldrick, Shackelford, & Fidopiastis, 2004). This representation has been defined as the "structural description of the body" (Buxbaum & Coslett, 2001; Corradi-Dell'Acqua & Rumiati, 2007; Sirigu, Grafman, Bressler, & Sunderland, 1991) and describes the position of the head, arms and legs relative to the trunk, as well as the exact distances among them. Such a representation mainly consists of an off-line body representation that metrically and spatially describes a typical body (either one's own body or others' body). This representation dissociates from an online body representation, called "body schema" (Buxbaum & Coslett, 2001; Schwoebel & Coslett, 2005; Sirigu et al., 1991) which furnishes a representation of how one's own body is at each given moment, based on kinematic and proprioceptive feedbacks.

The notion of configural processing related to the structural description of the body has been extensively investigated using the body inversion effect, where recognition abilities are impaired for upside down bodies (Bosbach, Knoblich, Reed, Cole, & Prinz, 2006; Stekelenburg & de Gelder, 2004; Sumi, 1984; Urgesi, Calvo-Merino, Haggard, & Aglioti, 2007). Interestingly, the inversion effect arises only in the case of complete bodies: when the task involves matching two different body parts presented individually, the inversion effect vanishes (Reed et al., 2006). More importantly, the same null effect emerges also for scrambled bodies, where the body parts are joined together without respecting the structural constraints of a normal body. Petit and Harris (2005) have suggested that two different types of processes might be involved when processing these different types of body stimuli: a configural processing for anatomically possible body postures, where the anatomical, bio-mechanical constraints are respected, and a local processing (which relies on the representation of each single body part) for impossible body postures when such constraints are violated.

The role of anatomical, bio-mechanical constraints has also been investigated in body schema research. This has been done by means

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of the *handedness* judgement task (Parsons, 1987a, 1987b, 1994; Sekiyama, 1982), a hand recognition task that implies the use of the body schema. Participants were asked to judge whether hand stimuli, displayed at different orientations, were right or left hands. Discrepancy between the orientation (and proximity) of the stimulus hand and the participants' own hand systematically increased judgement times. This has been shown by manipulating either the orientation of the stimulus (Parsons, 1987a, 1987b, 1994; Sekiyama, 1982) or the subjects' own posture (e.g., Sirigu & Duhamel, 2001), thus confirming the presence of an *imagery* process relying on the body schema representation, through which participants' own hand and the hand stimulus become aligned in the mental space. Importantly, the so called *awkwardness effect* also emerged—response times were affected by the anatomical possibility (with regards to natural joint constraints) of moving one's hand to reach the displayed orientation. It therefore seems that participants imagined actively reproducing the hand stimulus orientation with their own hand, and that this mental movement respected the physiological limits that constrain real movements (Decety & Michel, 1989; Viviani & McCollum, 1983).

Studies investigating the structural description of the body, have typically used *explicit* means (e.g. Petit & Harris, 2005; Reed et al., 2004, 2003, 2006). How we *implicitly* access such representations, and what is processed at an unconscious, pre-attentive stage, is still unknown. In particular whether anatomical, bio-mechanical constrains can be implicitly and unconsciously processed has not yet investigated. A recent study by Ottoboni, Tessari, Cubelli, and Umiltà (2005) reported on evidence suggesting that the structural description of the body can be accessed at an earlier implicit stage. Using a Simon-like paradigm (Simon, 1969), photographs of upright hands were shown centre-screen from a palm or back view. Each hand had a coloured circle in its centre. The task required participants to discriminate the colour and to respond by pressing one of two lateralized keys. When hand stimuli were presented from the back view, a consistent effect of spatial compatibility arose between the hand of response and the hand stimulus. When the hand stimuli were presented from the palm view, the effect reversed with fastest reaction times occurring in the case of the non-corresponding pairings between response hand and stimulus hand. The authors concluded that the hands are not automatically coded according to their handedness (i.e., left or right hand), but according to their *sidedness*. Sidedness refers to the spatial code generated by the side of the hand relative to a body of reference the hand is connected to. This spatial code is generated from the observer's point of view, as he or she looks at the hand stimulus. It is assumed that when hands (with their forearms) are shown without an attached body, the hand stimulus triggers the automatic generation of a body representation completing it. For instance, when a hand–forearm faces towards the observer (e.g. a palm view of a 'halt' gesture), it is mentally completed with a body whose front is in view. When a hand–forearm faces away from the observer (e.g. a backhand view of a 'halt' gesture), it is mentally completed with a body whose back is in view (Ottoboni et al., 2005). Indeed, Ottoboni et al. (2005) observed that the Sidedness effect disappeared when hand stimuli were shown without their forearms. It follows that the presence of the forearm is crucial for the Sidedness effect to emerge (presumably because it is necessary to induce the completion of the body representation). This finding is in line with what found by Reed et al. (2004) who reported that the whole upper limb, and not the hand alone, is represented as a unit within a spatially and structurally configured representation of the body.

The Sidedness effect reflects the spatial compatibility between the implicitly processed stimulus property (the left or right *sidedness* of the seen hand) and the left or right spatial code of response generated by this response configuration. Ottoboni et al. (2005, Exp. 4) observed this effect also when using the photograph of a hand attached in a body-appropriate manner to an undersized body. This result can be accounted for by assuming that the hand–body stimulus array matches (in terms of its spatial–structural configuration) the generated representation of the body. With this match achieved, the automatic coding of the spatial position of the hand relative to the side of the attached body occurs.

In the current study, we decided to use the Simon-like paradigm sensitive to the Sidedness effect to investigate whether the completion of the hand and the forearm with a body depends on anatomical human constraints. We hypothesized that *altering* the anatomical linkage between the forearm and the body might prevent any body representation, thus producing a representational mismatch (i.e. the hand stimulus is not completed and no body representation can be matched to the actually attached body). The consequence of this mismatch would be to remove the conditions of spatial compatibility, since 'sidedness' is assumed to be derivable from a spatially and structurally appropriate body configuration. In Experiment 1 we presented hand stimuli that were *inappropriately* attached to an undersized body (i.e. we used the same undersized body stimulus that Ottoboni et al. (2005, Exp. 4), had previously presented using appropriate attachments) and we predicted that in contrast with what found by Ottoboni et al. (2005), no Sidedness effect should be found. In Experiment 2, the hand stimuli were both *appropriately* (Exp. 2a) and *inappropriately* (Exp. 2b) connected to a different object (i.e. the card symbol for Clubs). We argued that if the effect has originally emerged in the presence of a cue (i.e. forearm) driving the body completion process because of the correct anatomical linkages, then it might be possible to find again the Sidedness effect even in the case of the presentation of a non-human reference, like the card symbol of Club, when normal anatomical body linkages are anyway present. Indeed, such linkages might help to mentally generate a normal body structure. A representational match with an implicitly generated structural representation of the body is predicted to occur in the case of appropriately connected stimuli only (even if the stimulus is not a human body); therefore the Sidedness effect is expected in Experiment 2a but not in Experiment 2b. If it were the case, it is plausible to assume that the Sidedness effect depends on the anatomically plausible configuration of the hand–forearm and arm configuration rather on the mere presence of a stimulus (either a human body or a non-human object) on one spatial side.

2. Experiment 1

Experiment 1 explored whether the Sidedness effect is influenced by the anatomical constraints linking the hand and the actually presented body. If the anatomical linkages are more important than the mere presence of the body, the Sidedness effect should disappear when a mismatch between the body configuration generated by the hand and the forearm, and what is actually presented occur. On the contrary, if the presence of the body is more important than the anatomical relationships between the arm segments, the Sidedness effect should be found independently of the anatomical plausibility of the hand–body linkages. To test these hypotheses, we presented hand–forearm configurations that were connected *inappropriately* to an undersized image of a body. Given that the stimulus array does not match a regular spatially and structurally specified body representation (e.g., a right hand depicted in a palm view on the right side of a body facing to the observer), the Sidedness effect should not emerge (contrary to what was found in Ottoboni et al. (2005, Exp. 4) which used appropriate connections). If the Sidedness effect should persist, this would mean that the hand–forearm configuration is processed independently from its