



Body ownership and attention in the mirror: Insights from somatoparaphrenia and the rubber hand illusion



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ABSTRACT

The brain receives and synthesises information about the body from different modalities, coordinates and perspectives, and affords us with a coherent and stable sense of body ownership. We studied this sense in a somatoparaphrenic patient and three control patients, all with unilateral right-hemisphere lesions. We experimentally manipulated the visual perspective (direct- versus mirror-view) and spatial attention (drawn to peripersonal space versus extrapersonal space) in an experiment involving recognising one's own hand. The somatoparaphrenic patient denied limb ownership in all direct view trials, but viewing the hand via a mirror significantly increased ownership. The extent of this increase depended on spatial attention; when attention was drawn to the extrapersonal space (near-the-mirror) the patient showed a near perfect recognition of her arm in the mirror, while when attention was drawn to peripersonal space (near-the-body) the patient recognised her arm in only half the mirror trials. In a supplementary experiment, we used the Rubber Hand Illusion to manipulate the same factors in healthy controls. Ownership of the rubber hand occurred in both direct and mirror view, but shifting attention between peripersonal and extrapersonal space had no effect on rubber-hand ownership. We conclude that the isolation of visual perspectives on the body and the division of attention between two different locations is not sufficient to affect body ownership in healthy individuals and right hemisphere controls. However, in somatoparaphrenia, where first-person body ownership and stimulus-driven attention are impaired by lesions to a right-hemisphere ventral attentional-network, the body can nevertheless be recognised as one's own if perceived in a third-person visual perspective and particularly if top-down, spatial attention is directed away from peripersonal space.

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1. Introduction

The sense of body ownership has been defined as the feeling that one's body belongs to oneself (Gallagher, 2000). A long tradition of experimental studies has attempted to study this facet of bodily self-consciousness by focusing on the self-attribution of body parts. Typically, in such studies participants are asked to make conceptual judgements about the ownership of body parts presented in extrapersonal space, as for example in video screens or photographs (e.g. Frassinetti, Maini, Romualdi, Galante, & Avanzi, 2008; Saxe, Jamal, & Powell, 2006). A different tradition of studies has sought to investigate feelings of body ownership as a more intuitive and less doxastic awareness of the body as one's

own (see de Vignemont, 2011; Tsakiris, 2010 for discussion). Such studies have taken advantage of the malleability of bodily representations. For example, in the Rubber Hand Illusion (RHI; Botvinick & Cohen, 1998), a rubber-hand viewed in peripersonal space (i.e. space near to the body) is experienced as part of one's body if the subject's own hand is synchronously touched out of view.

Despite the progress in understanding the sense of body ownership through such experimentally induced illusions, it remains difficult to tease apart the phenomenally elusive components of body ownership. It seems even harder to create convincing and lasting conditions of subjective body disownership (de Vignemont, 2011; Longo, Schuur, Kammers, Tsakiris, & Haggard 2008; Newport & Gilpin, 2011). By contrast, neurological patients with symptoms such as asomatognosia (lack of recognition regarding the existence or ownership of one's limbs; Vallar & Ronchi, 2009) show a clear and long-lasting, subjective experience of body disownership; denying ownership of their affected body

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parts for days, weeks or months. Sometimes this denial is accompanied by delusions about the affected arm (somatoparaphrenias; Gerstmann, 1942). The particular application of terms like asomatognosia and somatoparaphrenia remain unclear. Typically, somatoparaphrenia is regarded as a positive or productive variant of asomatognosia (in the Jacksonian sense; Jackson, 1932), and it may take several clinical forms (see Vallar & Ronchi, 2009). In the version of the syndrome that we will be focusing on here, patients recognise the existence of a limb attached to their body, but judge this as belonging to someone else. For example, the affected limb may be attributed to another person, such as a friend, relative or doctor.

Somatoparaphrenia occurs more frequently in patients with right-hemisphere lesions and is of variable duration, lasting from days to years (Vallar & Ronchi, 2009). Only a handful of single-case studies have documented clinical interventions that can lead to temporary remission of the disorder (Bisiach, Rusconi, & Vallar, 1991; Rode et al., 1992; Verret & Lapresle, 1978) and controlled, experimental investigations are equally rare (Aglioti, Smania, Manfredi, & Berlucchi, 1996; Bottini, Bisiach, Sterzi, & Vallar, 2002; Fotopoulou et al., 2011; Moro, Zampini, & Aglioti, 2004; van Stralen, van Zandvoort, & Dijkerman, 2011). Somatoparaphrenia is frequently associated with sensorimotor loss and related higher-order impairments such as neglect, but double dissociations have been noted between somatoparaphrenia and most of these deficits (Cogliano, Crisci, Conson, Grossi, & Trojano, 2012; Vallar & Ronchi, 2009). Such deficits therefore seem to be important contributing factors of the symptom, but they may not be sufficient conditions for somatoparaphrenia to arise.

Given the temporary remission of somatoparaphrenia by vestibular stimulation (Bisiach et al., 1991), Vallar and Ronchi (2009) have argued that somatoparaphrenia involves a defective higher-order spatial representation of the body and impaired multi-sensory integration (cf. similar “dyschiria”; Bisiach & Berti, 1987; and defective internal body representation explanations; Daprati, Sirigu, Pradat-Diehl, Franck & Jeannerod, 2000). In a previous experimental study (Fotopoulou et al., 2011), we were able to show that viewing one's affected arm through a conventional mirror, placed in the frontal plane, systematically reinstated ownership for the arm in two patients with somatoparaphrenia. As soon as the mirror was removed, and patients had only direct view of their arm, they again denied its ownership. Thus, patients alternated between claiming and denying ownership of their arm every few seconds. These findings suggested a dissociation between the processes that support self-recognition of the body in direct and mirror view.

Looking at our body in a mirror creates visual feedback of ourselves from a third-person perspective (or “from the outside”; see Vogeley & Fink, 2003). This mirror view of the body is subject to several unusual properties (Gregory, 1997), one being that the mirror image is left-right reversed, such that the left side of the body is located on the left side of the mirror space. In addition, the image of the body is observed in a location that is distant to the physical location of the body; nevertheless, viewing one's body in the mirror activates representations of peripersonal space (Maravita, Spence, Clarke, Husain, & Driver, 2000). More generally, the third-person perspective afforded by a mirror involves both a translocation of the egocentric (i.e. body-centered/viewer dependent) viewpoint, and engagement of allocentric (i.e. object-centered/view independent) operations (Vogeley & Fink, 2003).

These properties may be particularly relevant to somatoparaphrenia, given that the first-person perspective appears to play a special role in the sense of body ownership, with sensory, motor and other bodily signals being integrated in egocentric coordinates (Petkova, Khoshnevis, & Ehrsson, 2011; but see Lenggenhager, Tadi, Metzinger, & Blanke, 2007). In addition, it has been shown that peripersonal space and extrapersonal space (i.e. space beyond

manual reach; Berti & Frassinetti, 2000) are coded independently in patients with unilateral neglect (Cowey, Small, & Ellis, 1994; Halligan & Marshall, 1991; Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998). Moreover, recent studies show that both extrapersonal space processing and allocentric judgments draw upon the ventral ‘perception-related’ stream of visual processing, whereas both near-space processing and egocentric judgments draw upon the ‘action-related’ dorsal stream (Chen, Weidner, Weiss, Marshall, & Fink, 2012; Lane, Ball, Smith, Schenk, & Ellison, 2013; Neggers, Van der Lubbe, Ramsey, & Postma, 2006). Although previous studies of somatoparaphrenia have looked at the role of processing the body in left versus right space (Moro et al., 2004), the relation between visual perspective (first vs. third), attentional fractionating of space (peripersonal vs. extrapersonal), and body ownership remains unclear.

Several recent lesion mapping studies have compared the lesions sites of patients with body ownership disturbances and hemispatial neglect to those of patients with hemispatial neglect but without body ownership disturbances (Baier & Karnath, 2008; Feinberg, Venneri, Simone, Fan, & Northoff, 2010; Gandola et al., 2012; Invernizzi et al., 2013). Although such studies find differences in the lesions selectively associated with spatial neglect versus somatoparaphrenia, debates surround the issue of which of the identified cortical (e.g. insular cortex; Baier & Karnath, 2008; frontal lobe lesions; Feinberg et al., 2010), or subcortical (e.g. basal ganglia; Gandola et al., 2012; Invernizzi et al., 2013) regions are selective to somatoparaphrenia as opposed to neglect, hemiplegia or anosognosia. Importantly, given the clinico-anatomical aim of such studies, patients are typically categorised into groups according to a clinical assessment of body ownership, which is subsequently used in comparisons of lesion extent and location between groups with and without disownership. Such investigations may thus not take into account the frequently reported multidimensional and variable, within- and between-patients phenomenology of disownership. By contrast, correlating lesion patterns with statistically significant differences in performance between systematically varied experimental conditions has the advantage of potentially revealing more complex and heterogeneous patterns of neurocognitive impairments in such syndromes (see Fotopoulou, 2013 for discussion). This methodological advantage has been recently demonstrated in a related syndrome, anosognosia for hemiplegia; lesion analysis of patients classified on the basis of experimental rather than psychometric or clinical performance revealed different lesion-behaviour relations (see Fotopoulou, Pernigo, Maeda, Rudd, & Kopelman, 2010; Moro, Pernigo, Zapparoli, Cordioli, & Aglioti 2011).

The current study examined the role of: (i) visual feedback (direct vs. mirror) and, (ii) selective spatial attention (peripersonal vs. extrapersonal space) in body ownership. We aimed to confirm our previous finding of improved limb ownership following mirror self-observation (Fotopoulou et al., 2011), and extend them by studying how directing attention to different spatial locations may further enhance the effects of perspective afforded by vision alone. We manipulated spatial attention in a right-hemisphere stroke patient (GR) with neglect and somatoparaphrenia, by placing an orienting stimulus either near to the affected hand (peripersonal space), or well in front of the body, near to the mirror (extrapersonal space). Based on the idea that somatoparaphrenia involves an impaired first person representation of the body (Fotopoulou et al., 2011), we predicted that focusing attention in the extrapersonal, mirror space would enhance the visual processing of the reflected, third person perspective of the body and hence improve limb mirror recognition in somatoparaphrenia. By contrast, we predicted that focusing attention in the peripersonal, left hand space would diminish the visual processing of the reflected, third person perspective of the body and hence increase disownership of the hand in the mirror. These same factors were tested in three hemiplegic control patients with neglect but no

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