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Ownership illusions in patients with body delusions: Different neural profiles of visual capture and disownership

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ABSTRACT

The various neurocognitive processes contributing to the sense of body ownership have been investigated extensively in healthy participants, but studies in neurological patients can shed unique light into such phenomena. Here, we aimed to investigate whether visual capture by a fake hand (without any synchronous or asynchronous tactile stimulation) affects body ownership in a group of hemiplegic patients with or without disturbed sensation of limb ownership (DSO) following damage to the right hemisphere. We recruited 31 consecutive patients, including seven patients with DSO. The majority of our patients (64.5% overall and up to 86% of the patients with DSO) experienced strong feelings of ownership over a rubber hand within 15 sec following mere visual exposure, which correlated with the degree of proprioceptive deficits across groups and in the DSO group. Using voxel-based lesion-symptom mapping analysis, we were able to identify lesions associated with this pathological visual capture effect in a selective fronto-parietal network, including significant voxels ($p < .05$) in the frontal operculum and the inferior frontal gyrus. By contrast, lesions associated with DSO involved more posterior lesions, including the right temporoparietal junction and a large area of the supramarginal gyrus, and to a lesser degree the middle frontal gyrus. Thus, this study suggests that our sense of ownership includes dissociable mechanisms of multisensory integration.

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1. Introduction

The term confabulation typically refers to the production of false memories in the context of neurological pathology. However, it has also been used more broadly to describe the production of unintentionally false statements about one's self or the world, beyond the domain of memory (DeLuca, 2000; Feinberg & Roane, 1997; Hirstein, 2005). In this broader sense, a clear conceptual distinction between confabulation, delusion and anosognosia (unawareness of illness) becomes harder. While maintaining these separate terms therefore has conceptual advantages (Kopelman, 1999), considering confabulation in parallel to other similar symptoms allows for cross-fertilisation between studies on such phenomena (see Fotopoulou, 2010; Hirstein, 2005; Langdon & Turner, 2010).

In the present article, we focus on certain 'somatic delusions', as they typically occur following right hemisphere stroke. First, patients may show 'disturbed sensation of limb ownership' (DSO; Baier & Karnath, 2008), including 'asomatognosia', when ownership, or even the existence of a limb is denied. Some patients further present with a positive (in the Jacksonian sense; 1932) variant termed somatoparaphrenia, whereby disownership is accompanied by delusional beliefs, such as personification of the affected limb and/or attributing it to someone else (Gerstmann, 1942; see also Feinberg & Venneri, 2014; Vallar & Ronchi, 2009, for reviews). Furthermore, DSO can co-occur with an apparent inability to acknowledge or recognise one's contralesional paralysis, so-called anosognosia for hemiplegia (AHP; Babinski, 1914; see Fotopoulou, 2014, 2015 for reviews). Whether anosognosia and body ownership disturbances are caused by common underlying neural and psychological deficits or whether they represent independent disorders, remains debated (e.g., compare Baier & Karnath, 2008 and Gandola et al., 2012).

Importantly, these disorders offer a unique window of insight into the neurophysiological mechanisms by which the body is consciously experienced (body awareness). These mechanisms have received significant scientific interest in recent decades, including the development of several psychophysical and virtual reality paradigms that can generate subjective, somatic illusions in healthy volunteers (see Kilteni, Maselli, Kording, & Slater, 2015 for a review). For instance, pioneering work on illusory ownership of a fake hand, i.e., the rubber-hand illusion (RHI; Botvinik & Cohen, 1998), has emphasised the contribution of multisensory integration, i.e., the integration of sensory signals from different modalities, to the sense of body ownership (Holmes & Spence, 2005; Stein & Standford, 2008).

Vision has been one of the most studied modalities in this paradigm (Kilteni et al., 2015), however, these effects tend to be considered in the context of visuo-tactile integration. Only a few RHI studies have measured subjective feelings of hand ownership following mere visual exposure to a fake hand, i.e., independently of tactile manipulations. Some of these studies reported no effects (e.g., Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008; see also Rohde, Di Luca, & Ernst, 2011 for anecdotal evidence), while others found that 'mere vision' conditions can change feelings of ownership for the fake hand (Pavani, Spence, & Driver, 2000; Farnè, Pavani, Meneghello, & Ladavas, 2000; Guimmarra, Georgiou-Karistianis, Nicholls, Gibson, & Bradshaw, 2010; Tieri, Tidoni, Pavone, & Aglioti, 2015a, 2015b). It should be stressed that the conclusions of these studies are based on mere 'visual' conditions, rather than on negative findings from the comparison of synchronous versus asynchronous tactile stimulation; a comparison whose interpretation seems more complex than initially thought (e.g., Rohde et al., 2011). Moreover, while it is well-established that under certain circumstances, conflicting visual feedback from fake, or virtual, or visually misplaced hands via mirrors and wedge prisms (see Holmes & Spence, 2006 for review), can override proprioception (the so-called visual capture of proprioception), recent studies have established that position sense recalibrations can be dissociated from the sense of body ownership during the RHI (Abdulkarim & Ehrsson, 2016; Rohde et al., 2011; see also Makin, Holmes, & Ehrsson, 2008 for an early review). Thus, the relation between visual capture of proprioception and subjective ownership feelings remains unclear during 'mere vision' conditions. We will heuristically call this possibility, 'visual capture of ownership' (hereafter reffered to as VOC; 'visual ownership capture' for brevity).

To this end, the present study will focus on VOC by a fake hand (independently of any synchronous or asynchronous tactile stimulation). To the best of our knowledge, the neural mechanisms of VOC remain unexplored in healthy participants, as existing functional neuroimaging studies have not included 'mere vision' conditions (see Makin et al., 2008; Tsakiris, 2010 for reviews). Moreover, such functional neuroimaging studies can only establish correlations, while studies in brain damaged patients can be informative regarding the causal role of some brain areas and their connections. Unfortunately, the relation between experimentally-induced conditions of VOC and neuropsychological DSO has not been systematically explored. Moreover, comparisons between the few existing studies are hindered by the vast differences in the conceptualisation and measurement of the observed phenomena.

Indeed, in a series of studies, Berti and her colleagues, have proposed that some right hemisphere patients show what they describe as 'a monothematic delusion of body ownership', which relies on observing another person's hand in one's contralesional (affected) side and in egocentric, body-congruent perspective (Garbarini et al., 2013, 2014). However, the phenomenon may be more general and complex than these studies suggest. In a previous study involving eight hemiplegic patients with right hemisphere lesions, including one patients with DSO (Fotopoulou et al., 2008), all patients immediately accepted as their own a stationary rubber hand placed congruently with their own left hand. Thus, VOC may be a pervasive phenomenon following right hemisphere damage and it may also be dissociable from DSO (see also Zeller, Gross, Bartsch, Johansen-Berg, & Classen, 2011; Jenkinson, Haggard, Ferreira, & Fotopoulou, 2013; Bolognini, Ronchi, Casati, Fortis, & Vallar, 2014 for further dissociations between DSO and the classic RHI). Indeed, this possibility is supported by the only case study in the literature that applied

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