Consciousness and Cognition 24 (2014) 98–112

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

The physiology of motor delusions in anosognosia for hemiplegia: Implications for current models of motor awareness

Martina Gandola [a,*], Gabriella Bottini [a,b], Laura Zapparoli [c], Paola Invernizzi [c], Margherita Verardi [c], Roberto Sterzi [d], Ignazio Santilli [d], Maurizio Sberna [e], Eraldo Paulesu [c,f]

[a] Department of Brain and Behavioral Sciences, University of Pavia, Pavia, Italy
[b] Cognitive Neuropsychology Centre, Niguarda Ca' Granda Hospital, Milano, Italy
[c] Department of Psychology, University of Milano-Bicocca, Milano, Italy
[d] Neurology Department, Niguarda Ca' Granda Hospital, Milano, Italy
[e] Neuroradiology Department, Niguarda Ca' Granda Hospital, Milano, Italy
[f] IRCCS Galeazzi, Milano, Italy

ARTICLE INFO

Article history:
Received 21 May 2013

Keywords:
Anosognosia for hemiplegia
Motor awareness
Motor intention
Functional Magnetic Resonance Imaging

ABSTRACT

Right brain damaged patients sometimes deny that their left arm is paralysed or even claim to have just moved it. This condition is known as anosognosia for hemiplegia (AHP). Here, we used fMRI to study patients with and without AHP during the execution of a motor task. We found that the delusional belief of having moved was preceded by brain activation of the cortical regions that are implicated in motor control in the left intact hemisphere and in the spared motor regions of the right hemisphere; patients without anosognosia did not present with the same degree of activation. We conclude that the false belief of movement is associated with a combination of strategically placed brain lesions and the preceding residual neural activity of the fronto-parietal motor network. These findings provide evidence that the activity of motor cortices contributes to our beliefs about the state of our motor system.

1. Introduction

We are normally aware that the body that we inhabit is our own; we are aware of the state of our motor system and the sense of being (rather than not being) the cause of an act (Jeannerod, 2006); these are all crucial aspects of the sense of being 'us'. Neurological and psychiatric disorders can provoke pathological experiences or beliefs[1] concerning these apparently obvious feelings (see review in Prigatano, 2010). The study of these conditions has provided important information for theories

Abbreviations: AHP, Anosognosia for Hemiplegia; BOLD, Blood Oxygen Level Dependent; fMRI, Functional Magnetic Resonance Imaging; FWE, Family-Wise Error; FDR, False Discovery Rate; MRI, Magnetic Resonance Imaging; SD, Standard Deviation; SMA, Supplementary Motor Area.

* Corresponding author. Address: Department of Brain and Behavioral Sciences, University of Pavia, Piazza Botta 6, 27100 Pavia, Italy. Fax: +39 0382986272.

E-mail addresses: martina.gandola@unipv.it (M. Gandola), gabriella.bottini@unipv.it (G. Bottini), l.zapparoli@campus.unimib.it (L. Zapparoli), p.invernizzi3@campus.unimib.it (P. Invernizzi), margheritaverardi@hotmail.com (M. Verardi), roberto.sterzi3@gmail.com (R. Sterzi), ignazio.santilli@ospedaleniguarda.it (I. Santilli), maurizio.sberna@ospedaleniguarda.it (M. Sberna), eraldo.paulesu@unimib.it (E. Paulesu).

[1] The subtle difference between the concepts of *experiences* and *beliefs* in the context of motor acts is not systematically addressed in the literature of anosognosia for hemiplegia. For simplicity, in this paper, we will assume that the behaviour of the patients, which is manifested by the reports of their beliefs (I have moved the left hand rather than I have not moved the left hand), is inspired by experiences.

1053-8100/$ - see front matter © 2014 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.concog.2014.01.001

of motor control and consciousness (Bisiach, 1988; Bottini et al., 2010; Frith, Blakemore, & Wolpert, 2000; Jeannerod, 1997). One relevant case is that of right brain-damaged patients with left hemiplegia who deny their motor deficit, even when repeatedly questioned by the examiner; this denial is a condition called anosognosia for hemiplegia (AHP) and was first described by Babinski (1914). Several interpretations of AHP have been offered (see review in Bisiach, 1995; Vallar & Ronchi, 2006). These range from the psychodynamic hypotheses of the denial of illness (Weinstein & Kahn, 1955) to a more anatomically informed hypothesis, which postulates a disconnection between the right-sided motor regions and the left-sided language brain regions that are in charge of verbally reporting the patient's feelings (Gazzaniga, 1989; Geschwind, 1965). More recently, when summarising a large body of evidence (Adair et al., 1997; Gold, Adair, Jacobs, & Heilman, 1994), Heilman (1991) and Heilman, Barrett, and Adair (1998) framed anosognosia in a "feed-forward" theory of motor control, that explains the deficit as a specific failure to formulate an intention to move. According to this model, motor plans/intentions are constantly compared with the somatosensory consequences of actions. In normal conditions, the motor intentional system activates simultaneously the motor system and a representation of how the body position will change after the execution of the movement (body representation or comparator; for a detailed description of the model see Fig. 1 in Heilman et al., 1998, p. 1907). When patients with hemiplegia, who are aware of their motor impairment, intend to perform a movement, the monitor-comparator system detects the

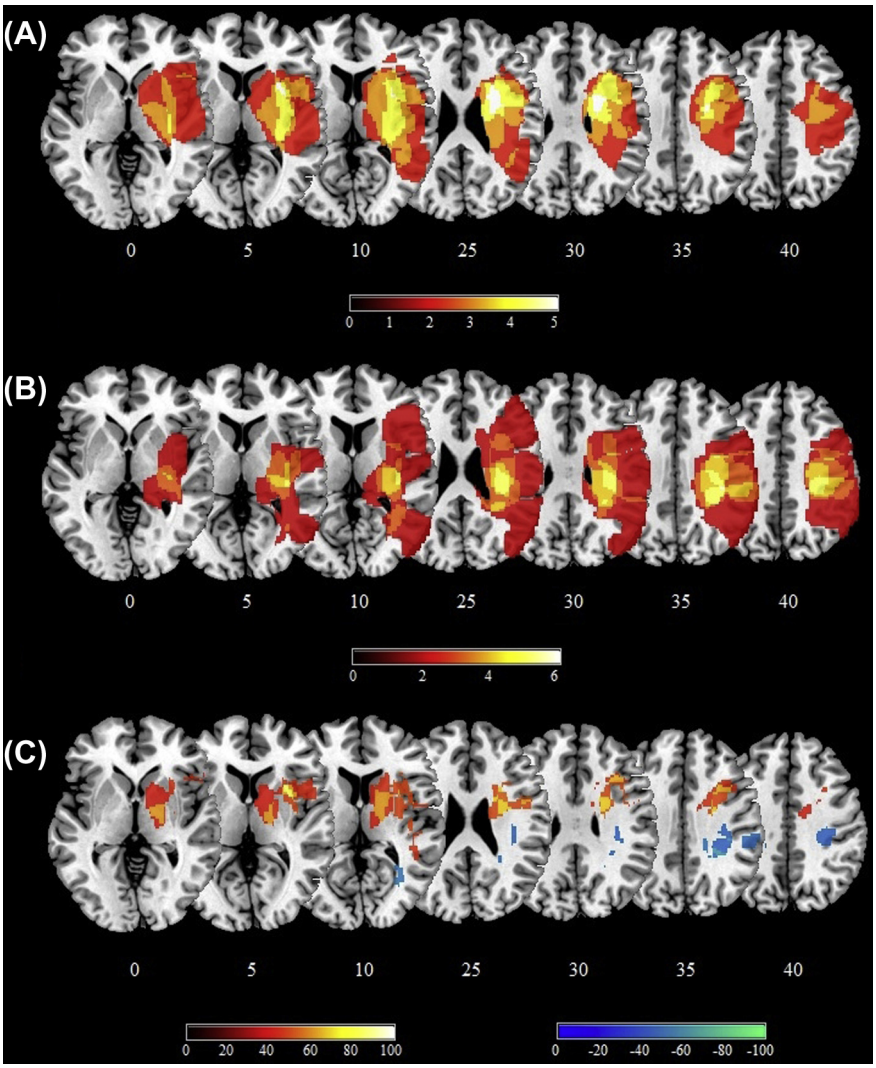

Fig. 1. Lesion plot of the AHP patients compared with non-AHP patients. (A) Overlays of the lesion plot of the five patients with AHP. The number of overlapping lesions is illustrated using different colours ranging from red (lesion in two patients) to white (lesion in five patients). (B) Overlays of the lesion plot of the six patients without AHP. The number of overlapping lesions is illustrated using different colours ranging for red (lesion in two patients) to white (lesion in six patients). (C) Subtraction analysis: the patients showing AHP ($n = 5$) minus the patients without AHP ($n = 6$). Regions frequently damaged in patients with AHP but spared in non-AHP patients are illustrated with warm colours, from dark red to white. Only the regions that were damaged at least the 40% more in the AHP group than in the non-AHP group are reported. The cold colours, from dark to light blue illustrate regions more frequently damaged in non-AHP patients than in AHP patients. Only the regions that were damaged at least the 40% more in the non-AHP group than in the AHP group patients are reported. The MNI *z* coordinates of each transverse section are given.