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Research report

Temporal coupling due to illusory movements in bimanual actions: Evidence from anosognosia for hemiplegia

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ABSTRACT

In anosognosia for hemiplegia, patients may claim having performed willed actions with the paralyzed limb despite unambiguous evidence to the contrary. Does this false belief of having moved reflect the functioning of the same mechanisms that govern normal motor performance? Here, we examined whether anosognosics show the same temporal constraints known to exist during bimanual movements in healthy subjects. In these paradigms, when participants simultaneously reach for two targets of different difficulties, the motor programs of one hand affect the execution of the other. In detail, the movement time of the hand going to an easy target (i.e., near and large), while the other is going to a difficult target (i.e., far and small), is slowed with respect to unimanual movements (temporal coupling effect). One right-brain-damaged patient with left hemiplegia and anosognosia, six right-brain-damaged patients with left hemiplegia without anosognosia, and twenty healthy subjects were administered such a bimanual task. We recorded the movement times for easy and difficult targets, both in unimanual (one target) and bimanual (two targets) conditions. We found that, as healthy subjects, the anosognosic patient showed coupling effect. In bimanual asymmetric conditions (when one hand went to the easy target and the other went to the difficult target), the movement time of the non-paralyzed hand going to the easy target was slowed by the 'pretended' movement of the paralyzed hand going to the difficult target. This effect was not present in patients without anosognosia. We concluded that in anosognosic patients, the illusory movements of the paralyzed hand impose to the non-paralyzed hand the same motor constraints that emerge during the actual movements. Our data also support the view that coupling relies on central operations (i.e., activation of intention/programming system), rather than on online information from the periphery.

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1. Introduction

Being aware of intending, controlling, and owning voluntary actions is at the root of humans' notion of self-awareness. Studying the abnormalities of the integration among the different aspects of motor behavior due to brain damages has a crucial role in addressing questions regarding the structure and functional signature of motor consciousness (Berti and Pia, 2006). Indeed, patients' counterintuitive behavior can unmask the inadequacies of theories on human brain functioning hidden from the view in the intact brain (see Churchland, 1986, for a discussion on this point). To this respect, one of the most informative neurological disorders is anosognosia for hemiplegia (hereinafter AHP), a condition in which movement cognition is dramatically distorted (see Bottini et al., 2010; Orfei et al., 2007; Pia et al., 2004 for reviews). AHP patients, affected by a complete paresis of the side of the body opposite to the brain damage (often the left side but see also Cocchini et al., 2009) deny that there is anything wrong with their contralesional limbs. The disturbance may range from emotional indifference (i.e., patients simply minimize the severity of the paralysis) to explicit denial. In this latter case, patients claim of being able to perform any kind of action with the paralyzed limb. If asked to perform a purposeful movement with the motionless limb, they may be convinced of having accomplished the action despite unambiguous evidence to the contrary coming from different sensory channels. However, it is noteworthy that explicit and implicit awareness for motor deficits can be dissociated. In other words, patients may explicitly deny a deficit despite having some insight into it, as they correctly approach bimanual tasks according to their motor impairment (Cocchini et al., 2010). Delusional beliefs concerning the affected side of the body, such as somatoparaphrenia (i.e., the ownership of the limb is ascribed to another person as, for instance, the doctor or a relative), misoplegia (e.g., hatred toward the affected limbs), or limb personifications (e.g., the plegic limb is considered as an entity with an own identity) are usually considered as additional, thought independent, abnormal manifestations (see Bottini et al., 2010 for a discussion on this point).

The interpretation of AHP is not straightforward. Theories that explain AHP either as a psychological defense against the illness (e.g., Weinstein and Kahn, 1955), a secondary consequence of sensory feedback deficits (e.g., Cutting, 1978), or a combination of sensory deficits and higher-order cognitive impairments (e.g., Levine et al., 1991) are not thought to be exhaustive explanations. Indeed, double dissociations have been shown between AHP and each of the aforementioned impairments (Adair et al., 1995; Berti et al., 2005; Bisiach et al., 1986; Coslett, 2005; Heilman et al., 1998; Marcel, 2004; Starkstein et al., 1992). Recently, it has been proposed that AHP might be explained as a domain specific disorder of motor control (Berti and Pia, 2006; Berti et al., 2007; Gold et al., 1994; Jenkinson and Fotopoulou, 2010; Spinazzola et al., 2008). In line with several findings on intact brain showing that the conscious awareness of action and movement control shares several cortical areas (e.g., Desmurget and Sirigu, 2009), it has been demonstrated that AHP follows a brain damage located within the same cortical network that is responsible for motor monitoring in the lateral premotor and insular cortex (Berti et al., 2005; Fotopoulou et al., 2010; Garbarini et al., 2012; Karnath et al., 2005; Moro et al., 2011; Vocat et al., 2010). Consequently, the well-established framework of a forward model of normal motor control (Blakemore and Frith, 2003; Wolpert et al., 1995) has been employed to predict the pattern of intact and impaired neurocognitive mechanisms pinpointing the distorted motor awareness of AHP patients. The model posits that when a subject has the intention to move and the appropriate motor commands are selected and sent to the appropriate motor areas, a prediction (forward model) of the sensory consequences of the movement itself is formed on the efference copy of the programmed motor act. This would be subsequently matched (by a comparator system) to the actual sensory feedback (see also Gold et al., 1994), and constitutes the signal on which motor awareness is constructed. This model has two important implications. First, motor awareness would, counter-intuitively, precede movement execution, instead of following it. This entails that whenever a sensory prediction is formed, motor awareness emerges before the availability of any sensory feedback. Second, motor awareness is evaluated against the sensory feedback by the operation of the comparator system that, among other functions, can differentiate between movement/no-movement conditions. Within this framework, it has been proposed that, in AHP patients, a damage to the comparator processes would alter the monitoring of voluntary actions, thus preventing them from distinguishing between movement and no-movement states. Moreover, the (non-veridical) feeling of movement would arise from an intact motor intentionality assisted by the normal activity of the brain structures that implement the intention-programming system (Berti and Pia, 2006; Berti et al., 2007; Garbarini et al., 2012; Spinazzola et al., 2008).

Evidence of preserved movement intentionality in AHP patients comes from the fact that they may show normal proximal muscle electrical activity in the affected side when they believe they are moving the plegic limb (Berti et al., 2007; Hildebrandt and Zieger, 1995). Interestingly, such an intentional stance dominates their subjective experience of willed actions because patients falsely detect the movement of their plegic arm when they intend to move it, versus when they do not (Fotopoulou et al., 2008). To the best of our knowledge, however, only one study has directly analyzed the existence in AHP patients of the same motor programs for the affected limbs that govern normal movement execution. Garbarini et al. (2012), capitalized on evidence showing that the spatial constraints known to exist in healthy subjects during a classical bimanual movement paradigm (i.e., when people have to draw circles with one hand while drawing lines with the other tend to produce curved lines and line-like circles) arise also in amputee patients with vivid subjective experience of moving their 'phantom' limb (Franz and Ramachandran, 1998). Indeed, Franz and Ramachandran (1998) found that when amputees with vivid sensation of phantom limb movement have to draw linear segments in a continuous fashion with the intact arm while performing either lines or circles with the phantom arm produced spatial coupling. As clearly pointed