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Research report

Different motor imagery modes following brain damage

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ABSTRACT

In recent years, many researches have explored the relationship between overt and covert motor activity (i.e., *mental simulation*). Consistent evidence has been provided in favour of close similarities between the two functions, particularly based on behavioural and neuroimaging studies on healthy participants. Interestingly, literature on the pathological population remains largely controversial. Yet, a clear understanding of whether and how mental simulation is modified by overt motor disorders is far from a speculative question, especially in view of the increasing interest for the use of mental practice in motor rehabilitation. Here, we explored whether a single set of cognitive skills is applied while solving tasks that implicitly require mental simulation of an action, or whether alternative strategies might be elicited according to the imager's actual motor capabilities. For this purpose, we recruited a group of patients who suffered from a stroke affecting selectively either the right or the left hemisphere, responsible for motor impairments ranging in severity. We required them, and a group of age-matched healthy controls, to perform a task of simulated grasping, and two tasks involving handedness judgments (on hands and gloves, respectively). Dissociations were found between the performances of patients suffering from left versus right brain damage, according to the task and, interestingly, the actual state of the imager's motor capabilities. This finding suggests that motor imagery might include alternative mental strategies that are independent from the actual state of the motor system. We discuss how these mental operations are differently affected by motor impairment, and consider the implications of the present theoretical finding for neurorehabilitation.

1. Introduction

The ability to create and manipulate representations is an extraordinary human capacity. In the simulation domain, motor imagery represents a complex case. It is generally agreed that we can approach internal simulation of an action through two different modalities, namely from an ''*interior*'' view (a first-person perspective) or from an ''*external*'' view, as seeing oneself from a third-person perspective (Mahoney and Avener, 1977; Annett, 1995; Kosslyn et al., 2001). In the former case, the imager should be able to report vivid kinaesthetic sensations related to the imagined movement, which would

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not be present in the latter form of imagery, more visual in nature. To date, various paradigms have been used to assess our ability to produce kinaesthetic images of actions. In a broad way, they belong in two categories. On one side, there are tasks that *explicitly* require participants to mentally rehearse and subsequently execute, a movement, and compare their relative timing (Dominey et al., 1995; Sirigu et al., 1995, 1996; McLennan et al., 2000; Thobois et al., 2000; Maruff and Velakoulis, 2000; Malouin et al., 2004; Gonzalez et al., 2005; Sabate et al., 2007). These tasks imply that the individual voluntarily performs a mental simulation of the action, and would thus additionally recruit a certain degree of introspective abilities, including attention and intentional states. On the other side, there are tasks that require a judgment on a stimulus, such as telling handedness of a limb, or orientation of a potential grip. Here, participants are not explicitly asked to mentally simulate an action and/or to voluntarily access its representation. However, it is assumed that the correct response arises from *implicitly* activating a movement: in fact, the time required to respond is modulated in the same fashion as overt movements would be (Johnson, 2000; Li, 2000; Schwoebel et al., 2001, 2002; Roelofs et al., 2001; Johnson et al., 2002; Funk and Brugger, 2002; Tomasino et al., 2003; Nico et al., 2004; Fiorio et al., 2006; Amick et al., 2006).

It is generally agreed that both explicit and implicit imagery tasks share common features with the real motor act they involve (Jeannerod and Decety, 1995; Sirigu et al., 1995, 1996; Parsons et al., 1998), suggesting that they may also rely on comparable, although not identical, neural substrates (Decety et al., 1994; Stephan et al., 1995; Grafton et al., 1996; Roth et al., 1996; Gerardin et al., 2000). A corollary to this hypothesis is that, should overt motor functions be damaged, similar impairments would emerge in simulated actions. Interestingly, on this respect, the available studies are largely contradictory.

Support for a comparable impairment in real and simulated movement is mainly found when motor imagery is explicitly tested (Dominey et al., 1995; Sirigu et al., 1995, 1996; McLennan et al., 2000; Thobois et al., 2000; Maruff and Velakoulis, 2000; Malouin et al., 2004; Gonzalez et al., 2005; Sabate et al., 2007). For example, basal ganglia (BG) disorders slow down movement execution: accordingly, speed of simulated actions is slowed down when these patients are required to imagine moving a part of their body (Dominey et al., 1995; Li, 2000). Similarly, motor lesions inducing stiffness and reduced motility also decrease the speed of imagined movements (Sirigu et al., 1995). In addition, damage to the parietal cortex causing high-level motor disorders, severely disrupts motor imagery (Sirigu et al., 1995, 1996). Taken together, these observations suggest that mental simulation would be largely dependent on the state of the imager's motor system. Actually, a close relationship between actual state of the limbs and motor imagery also emerges if specific postural constraints are imposed to healthy individuals (Parsons, 1994; Sirigu and Duhamel, 2001; Vargas et al., 2004; de Lange et al., 2006).

Other findings indicate that pathologies affecting limb mobility do not necessarily compromise the ability to internally represent movements (Sirigu et al., 1996; Johnson, 2000; Johnson et al., 2002). Patients suffering from acute hemiplegia following cerebral vascular accidents can still solve tasks involving implicit motor imagery of the limb they can no longer use (Sirigu et al., 1996; Johnson, 2000). Similarly, chronic patients that failed to recover motor function, maintain the ability to internally represent actions of both the ipsilesional and contralesional hand (Johnson et al., 2002). In addition, physical absence of one limb clearly enhances difficulty of implicit imagery tasks, but does not prevent their solution (Funk and Brugger, 2002; Nico et al., 2004).

A possible explanation for these inconsistencies can be found in the type of task applied in the different studies: similarities between overt and covert motor impairment are more common following paradigms requiring explicit motor simulation (Dominey et al., 1995; Sirigu et al., 1995, 1996; McLennan et al., 2000; Thobois et al., 2000; Maruff and Velakoulis, 2000; Malouin et al., 2004; Gonzalez et al., 2005; Sabate et al., 2007), whereas dissociations are more frequent in implicit tasks (Johnson, 2000; Johnson et al., 2002; Funk et al., 2002; Nico et al., 2004). It can be argued that in the latter tasks participants eventually applied alternative strategies to motor imagery to reach a solution, such as deriving their responses from prototypical experiences, or visual-spatial operations, which do not require to be tuned precisely to the constraints applied to real actions. Indeed, when motor-impaired patients alternatively use forms of kinaesthetic and visual imagery, only the former reflects overt motor deficits (Li, 2000).

Alternatively, the inconsistencies may depend on which hemisphere is involved by brain damage, and consequently, by side of the hemi-body motor impairment. Several observations indicate that, when accessing motor representations, performance of the imager shows asymmetries comparable to those found in real movements (Maruff et al., 1999; Daprati and Sirigu, 2002). Hence, motor imagery might be performed, in the first place, by simulating movements of the dominant limb. Research on upper limb amputees supports this possibility: in a handedness-judgment task, people having lost their dominant compared to the non-dominant limb show significantly different performances (Nico et al., 2004). Similarly, a consistent proportion of the brain-damaged patients described in the literature that showed spared simulation abilities, present with overt motor impairment for the non-dominant limb (Li, 2000; Johnson, 2000; Johnson et al., 2002).

Along these lines, the present study was designed to directly assess the role of task, side of brain damage and degree of motor impairment on motor imagery, in order to a) disclose which cognitive skills are involved, and b) evaluate whether and how these operations are modulated by the actual state of the imager's motor system. Indeed, a clear understanding of the relationship between overt action and mental simulation is far from a speculative question. It is well known that imagery training improves motor performance in healthy volunteers (Driskell et al., 1994; Yaguez et al., 1998; Gentili et al., 2006), and mental practice can certainly be a helpful tool in treating several motor disorders (Jackson et al., 2001; Sharma et al., 2006), should its nature be better understood.

Here, we restricted our interest to the motor outcomes of stroke, paying particular attention to the role of the hemisphere affected by brain damage (as this would imply motor impairment of the dominant *vs* non-dominant limb), and to