

## Selective deficit of motor imagery as tapped by a left–right decision of visually presented hands

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### Abstract

This paper presents the case of MT, a patient suffering from apraxia with left-hemisphere damage who showed a selective deficit in mentally rotating images of hands whereas he was still able to mentally rotate other visual stimuli. The deficit was particularly evident when MT was asked to decide which hand (left or right) was represented in a picture. Parsons (1987, 1994) suggested that in order to carry out this task, participants would mentally rotate a representation of their own body part until it aligns with the stimulus and it does appear that MT's ability to mentally simulate movements is impaired. In contrast, he was able to mentally rotate other forms of bi- and three-dimensional stimuli. Our findings are also consistent with Kosslyn, Digirolamo, Thompson, and Alpert's (1998) proposal that there are at least two ways in which objects can be mentally rotated, one that recruits processes devoted to motor preparation (e.g., hands), and another that does not.

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### 1. Introduction

Motor imagery is the process of mentally rehearsing a motor act that is not accompanied by overt body movements. It has been studied using different paradigms such as: (i) the mental simulation of finger tapping (Sirigu et al., 1996), (ii) the generation of images of actions by means of questions (Ochipa et al., 1997), (iii) deciding whether two exemplars of a seen body part are the same or different, and (iv) deciding whether a body part presented at different orientations is a left or a right hand (Parsons, 1987, 1994).

A selective deficit affecting the performance on some of the tasks mentioned above has been described in literature (see Ochipa et al., 1997; Sirigu et al., 1996, patient RL). Little attention, however, has been paid to the issue of whether patients suffering from a disorder of motor imagery are still able to rotate mental representations of external objects, while cases of patients with a deficit in mentally rotating visually presented objects in the context of spatial agnosia have been described (Bri-

colo, Shallice, Priftis, & Meneghello, 2000; Morton & Morris, 1995; Ratcliff, 1979). Processing mechanisms for rotating hand shapes (i.e., motor imagery) and objects (i.e., mental rotation) have been dealt with in brain imaging studies; for instance, Kosslyn et al. (1998) monitored the regional cerebral blood flow (rCBF) of healthy subjects during two mental rotation tasks using the PET technique. In the first experiment the subjects had to compare and decide whether two hands or two angular branching forms (Shepard–Metzler cubes) had the same (baseline) or different orientations (rotation condition). The imaging results showed that mentally rotating branching forms enhanced bilateral activation in the right parietal lobe and in Brodmann Area 19, whereas mentally rotating hands enhanced unilateral left activation in the precentral gyrus (M1), most of the parietal lobe, the primary visual cortex, the insula, and frontal Areas 6 (premotor cortex) and 9 (superior frontal cortex). Kosslyn et al. proposed that at least two independent mechanisms are engaged in the mental rotation of hands and objects: one requiring processes that prepare motor movements and one that does not.

The present study describes the case of MT, a patient with left brain damage suffering from a selective deficit

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that affected his ability to mentally rotate hand-shaped images, but left the mental rotation of other images intact.

## 2. Case history

MT is a 49-year old Italian man, with 17 years of schooling, who was admitted to the neurological ward with right hemiparesis and aphasia caused by a stroke. A CT-scan revealed an ischemic lesion in the left hemisphere affecting Brodmann Areas 44, 43, 40, and 4 as well as the basal ganglia. MT's cognitive abilities were evaluated using a number of neuropsychological tests, the scores of which are reported in Table 1. The evaluation of MT's language abilities (Luzzatti, Willmes, & De Bleser, 1996) revealed a general profile indicative of

Broca's aphasia. His performance on tests tapping verbal and spatial short-term memory was below the normal range (Splinner & Tognoni, 1987). MT appeared impaired at imitating symbolic and meaningless upper limb gestures (De Renzi, Motti, & Nichelli, 1980). He made some errors when asked to demonstrate how to use visually presented objects that he was not allowed to touch, or to pantomime the use of the same objects on verbal command (Zanini, Bearzotti, Vorano, De Luca, & Rumiati, 1999), but his verbal recognition of the pantomimes executed by the examiner was accurate. Reaching and grasping of real objects were satisfactory, as was his actual usage of the objects (De Renzi, Piezuro, & Vignolo, 1968). His visuo-spatial abilities were extensively tested but showed no signs of visual agnosia or neglect (see BORB, Riddoch & Humphreys, 1993; VOSP, Warrington & James, 1991). A test in which he

Table 1  
Neuropsychological profile of the patient MT based on standardized tests

			MT	Controls		
Intelligence	WAIS	Total	93	100 ± 15		
	Raven matrices		50/60	22.32 ± 8.15		
Language	AAT	Token	23/50 Md–Li			
		Repetition	83/150 Md			
		Writing	18/90 Se–Md			
		Naming	62/120 Md			
		Comprehension	96/120 Li			
Visual processing	BORB	FV match	25/25	21.6 ± 2.6		
		Association match	30/30	27.5 ± 2.4		
		Object decision	18/20	17.7 ± 1.9		
Memory	VOSP	Spatial short-term memory	4	5.11 ± 1.01		
	Corsi	Verbal short-term memory	2	4.75 ± 0.86		
Executive functions	WCST	Categories	3	5 ± 1.6		
		Total errors	9			
		Perseveration errors	22%	<33%		
		Sorting color/shape	2			
		Real use	Single and multiple objects	14/14	Cut-off = 14	
Praxis	Weigl	Real use	28/28	23.2 ± 1.78		
		Real use	45/72	Cut-off = 53		
	Imitation of limb movements	Visual	17/28	20.2 ± 2.93		
		Tactile	19/28	20 ± 2.67		
	Pantomiming	Verbal command	23/28	19.93 ± 3.3		
		Action recognition	15/15	15/15		
		Copying	14	12.68 ± 1.37		
		Imitation	16/20	19.91 ± 0.42		
		Body schema	Pointing on verbal command	to his own body-parts	17/18	18
				to body parts on a drawing of a human figure	18/18	18
to the drawing of a single body part, out of 4	17/18			18		
on their own body to the part represented in a drawing	18/18			18		
on the whole body drawing to the part the examiner has touched on the subject body	18/18			18		
on multiple choice to the drawing correspondent to the part touched	18/18			18		
Deciding whether E., who points to a drawing of a human body, indicates the correct part	10/10			10		
Luria test	Right–left decision of hand shapes	Hands in repose	15\21	18 ± 0.83; range = 18–20		
		Free hands	14\21	21		

had to decide whether a line drawing represented a left or a right hand (Luria, 1967) revealed a critical deficit though his body schema representation was spared, as assessed using the test devised by Semenza and Goodglass (1985).

### 3. Experimental study

A series of psychophysical studies (Parsons, 1987, 1994) have clearly demonstrated that in order to decide whether a visually presented body part belongs to the left- or right-hand side, observers imagine moving their own body part, and not the stimulus, into the orientation of the stimulus for comparison. The main piece of evidence supporting this view is the time factor; the time required to make right–left decisions is identical or proportional to the time required for actual movements (Parsons, 1994). Secondly, the trajectory imagined for the viewer's hand is strongly influenced by the biomechanical constraints specific to the movement of the hand. In addition some subjects reported kinesthetic impressions or sensations accompanying imagined spatial transformations of the body part; these kinesthetic feelings were described as specific to the body part involved, especially for orientations that are uncomfortable or awkward to adopt physically. Accordingly, MT's pathological performance on the handedness task in the neuropsychological assessment (Luria, 1967) suggests

that the patient's motor imagery may be defective. MT's ability to rotate body parts as well as external objects was explored in the following experiments.

### 4. Experiment 1: Right–left decision of body parts

The objective of this experiment was to ascertain if the motor imagery deficit revealed by Luria's test was confined to one class of body parts (i.e., hands) or if it affected others?

#### 4.1. Method

One hundred thirty line drawings of body parts (40 hands, 26 feet, 2 eyes, 26 arms, 32 legs, and 2 ears) were presented on white cards. Except for the eyes and the ears, all other body parts were presented from different view-points.

#### 4.2. Results

Overall, MT's performance on a task of right–left discrimination of body parts (see Table 2) was less accurate (76% of correct responses) than normal controls ( $N = 20$ ) (range 125–129; mean =  $127 \pm 1.25$ ). His performance on the cards representing hands was the most affected (his performance on hand shapes versus the performance on the other body parts,  $\chi^2(1) = 11.14$ ,

Table 2  
Experiments: correct responses given by MT and by controls

<i>Experiment 1</i>			
Right–left decision of body parts	Arms	21/26	Partial mean = 26
	Hands	23/40	Partial mean = 37
	Legs	26/32	Partial mean = 32
	Feet	24/26	Partial mean = 26
	Eyes	2/2	Partial mean = 2
	Nostril	1/2	Partial mean = 2
	Ears	2/2	Partial mean = 2
	Total	99/130	Mean = $127 \pm 1.25$
<i>Experiment 2</i>			
Right–left decision of hands	Total	38/60	Mean = $58 \pm 1.07$
	Test	19/40	Mean = $38 \pm 0.87$
	Baseline	19/20	Mean = 20
<i>Experiment 3</i>			
Right–left discrimination	Objects	30/30	Mean = 30
	Arrows	30/30	Mean = 30
	Animals	30/30	Mean = 30
<i>Experiment 4</i>			
Mental rotation of external stimuli	<i>Expt. 4a</i>		
	Flags I	22/24/126 (91 %)	From 21/27 (78%) to
	Flags II	50/60/126 (83.33%)	52/55 (94%)
	<i>Expt. 4b</i>		
	Foreshortened view matching	25/25	$21.5 \pm 2.6$
<i>Expt. 4c</i>			
Cubes	35/40	Mean = $32.33 \pm 3.01$ ; range = 30–38	

$p < .001$ ). His performance on judging hands was worse than that for judging arms ( $\chi^2(1) = 3.84, p < .05$ ) or legs ( $\chi^2(1) = 11.1, p < .001$ ).

## 5. Experiment 2: Right–left decision of hand configurations

In Luria's test the stimuli consisted of hand configurations such as the sign of victory, changing in orientation. In addition to rotating his own hand into congruence with the target stimulus, the patient also had to shape his hand into that specific configuration. In the next experiment MT's ability to implicitly rotate and shape his own hand in order to align it to the orientation and posture of the visual hand was investigated.

### 5.1. Method

MT was required to judge, without moving his hands, whether a given photograph depicted a left or a right hand. In the baseline condition, 20 hands (10 right and 10 left) were presented upright in a canonical position, half showing the palm and half showing the back of the hand. In the test condition, 40 hand configurations (20 right and 20 left) were used, each one showing a different depth orientation and adopting a different posture (e.g., sign of victory).

### 5.2. Results

Results are reported in Table 2. Overall, in deciding whether a rotated hand was a left or right hand, MT's performance (38/60, 63% of correct responses) fell outside the range of control subjects ( $N = 20$ ) (range = 56–60; mean =  $58 \pm 1.07$ ). MT's performance was worse in the hand configuration condition than in the baseline ( $\chi^2(1) = 12.95, p < .001$ ).

## 6. Experiment 3: Right–left decision of external objects

MT's poor performance in Experiments 1 and 2 could be caused by a generalized left–right discrimination difficulty and not by a selective deficit affecting the mental rotation of hand representations. In the following experiment, MT was required to say whether a picture was oriented to the right or to the left. This task does not involve any mental rotation.

### 6.1. Method

Ninety stimuli (30 arrows, 30 animals, and 30 objects), facing to the right or to the left, each on an individual card, were presented in sequence. MT was asked to decide in which direction the arrow was

pointing, if the animal was moving to the left or to the right, and which hand (left/right) could grasp the object.

### 6.2. Results

MT was able to decide the direction to which the arrows were pointing, whether the animals were walking towards the left or the right, and which hand (left or right) could grasp an object oriented to the left or to the right (see Table 2), thus his deficit in deciding whether a rotated hand was left or right cannot be due to a left–right disorientation.

## 7. Experiments 4a, 4b, and 4c: Mental rotation of external stimuli

In the next three experiments we assessed MT's ability to mentally rotate visual representations of objects. Based on Kosslyn et al.'s (1998) proposal that independent mechanisms—and segregated areas associated with them—may exist for mentally rotating hand shapes and external objects, it was expected that MT would perform normally in tasks involving the ability to mentally rotate objects.

### 7.1. Method

In Experiment 4a MT was asked to compare a set of six flags to a target: the stimuli may be mirror images of the target flag, or they may be identical to the target flag but with a different orientation (see Thurstone & Jeffrey, 1983). The task was to decide whether each flag in the row showed the same (S) or the opposite (O) pattern as the target flag, which is shown first. MT had 5 min to complete as many trials as possible (max. 21 trials). This test was administered twice.

Experiment 4b consisted of matching a line drawing of an object depicted in a canonical view with the one out of two drawings depicting the same object seen from an unusual perspective (see the Foreshortened view matching test from BORB, Riddoch & Humphreys, 1993).

In Experiment 4c the patient's ability to mentally rotate three-dimensional branching forms was assessed (see Shepard & Metzler, 1971). In each trial ( $N = 40$ ), MT had to decide whether two such objects were identical, but presented in different orientations and perspective (50% of the trials), or represented different shapes (50% of the trials).

### 7.2. Results

The results of the three experiments are reported in Table 2. In Experiment 4a MT scored 24 out of 126 in the first session, making 22 correct judgments (91%).

He was faster on the second session, completing 60 trials out of a total of 126, 50 of which were correct. His performance, compared with that of the 20 control subjects fell within the normal range (range 21–52; mean  $36.6 \pm 9.43$ ) in both sessions.

In Experiment 4b MT performed at ceiling (25/25).

In Experiment 4c he scored 35/40. His performance fell within the normal range (mean =  $32.33 \pm 3.01$ ; range = 30–38) as compared with that of 10 control subjects matched for age and education.

The results from Experiments 4a, 4b, and 4c demonstrate that MT's ability to mentally rotate external bi- or three-dimensional objects other than hands, and to recognize them when presented in unusual views is relatively preserved.

## 8. Discussion

The study addresses the case of MT, an apraxic patient who was significantly more impaired in deciding whether a hand was left or right than when the handedness decision involved other body parts (see Experiment 1). His deficit was particularly pronounced with regard to representations of finger configurations. MT was in fact able to recognize a left from a right hand in the baseline when the stimuli consisted of canonical views of the hand (i.e., either from the back or from the palm); he failed on this task when the decision involved finger posture. Thus MT's deficit seemed to affect in particular the ability to mentally rotate and shape his hand until it matched the stimulus (see Experiment 2). The tests performed show that MT's poor performance when deciding whether a rotated hand was a left or right hand was not due to a general difficulty in discriminating left from right (see Experiment 3), nor to a deficient body schema representation (see Neuropsychological Assessment). Furthermore he showed clear-cut dissociation between motor imagery (i.e., involving hands) and mental rotation of representations of stimuli other than hands. This claim is based on the finding that while MT was selectively impaired in imagining and transforming images of his own hands, he was still able to mentally rotate external objects (see Experiments 4a, 4b, and 4c).

The pattern of performance exhibited by MT and that observed in right hemisphere damaged patients (see Bricolo et al., 2000; Ratcliff, 1979) is consistent with Kosslyn et al.'s (1998) proposal that there are at least two ways of mentally rotating objects, one of which implicitly requires motor processes.

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