

Mental rotation of body parts and non-corporeal objects in patients with idiopathic cervical dystonia

Mirta Fiorio^{a,**}, Michele Tinazzi^{a,b}, Silvio Ionta^c, Antonio Fiaschi^a, Giuseppe Moretto^b, Mark J. Edwards^d, Kailash P. Bhatia^d, Salvatore M. Aglioti^{e,f,*}

^a Department of Neurological and Vision Sciences, Section of Rehabilitative Neurology, University of Verona, Strada le Grazie 8, 37134 Verona, Italy

^b Neurology Unit, Borgo Trento Hospital, Verona, Italy

^c Department of Clinical Sciences and Bio-imaging, University of Chieti 'G. D'Annunzio', Italy

^d Sobell Department of Motor Neuroscience and Movement Disorders and Institute of Neurology, London, UK

^e Department of Psychology, University of Rome "La Sapienza", via dei Marsi 78, 00185 Roma, Italy

^f Neuropsychology Research Centre, IRCCS "Fondazione Santa Lucia", via Ardeatina 306, 00179 Rome, Italy

Received 4 May 2006; received in revised form 7 February 2007; accepted 11 February 2007

Available online 20 February 2007

Abstract

Mental rotation of body parts is performed through inner simulation of actual movements, and is likely to rely upon cortical and subcortical systems (e.g. motor and premotor areas and basal ganglia) involved in motor planning and execution. Studies indicate that sensory and motor deficits, such as for example pain, limb amputation or focal hand dystonia, bring about a specific impairment in mental rotation of the affected body parts. Here we explored the ability of patients affected by idiopathic cervical dystonia (CD) to mentally rotate affected (neck) and unaffected (hands and feet) body districts. The experimental stimuli consisted of realistic photos of left or right hands or feet and the head of a young men with a black patch on the left or the right eye. As non-corporeal stimulus the front view of a car with a black patch on the left or the right headlight was used. The stimuli were presented at six different degrees of orientations. Twelve CD patients and 12 healthy participants were asked to verbally report whether the hands or feet were left or right, or whether the patch was on the left or the right eye or headlight. Reaction times and accuracy in performing the laterality tasks on the four stimuli were collected. Results showed that CD patients are slow in mental rotation of stimuli representing body parts, namely hand, foot and head. This abnormality was not due to a general impairment in mental rotation per se, since patients' ability to rotate a non-corporeal object (a car) was not significantly different from that of healthy participants. We posit that the deficit in mental rotation of body parts in CD patients may derive from a defective integration of body- and world-related knowledge, a process that is likely to allow a general representation of "me in the external world".

© 2007 Elsevier Ltd. All rights reserved.

Keywords: Motor imagery; Body schema; Torticollis; Basal ganglia; Egocentric space

1. Introduction

Goal-directed actions are accomplished not only by regularly monitoring the position of our body in space but also by predicting the correct sequence of movements to be executed

and the final position of our body parts. Mental rotation of corporeal objects, i.e. the ability to imagine how a body part would look if rotated away from its prototypical orientation (Thayer, Johnson, Corballis, & Hamm, 2001), is likely to contribute to the prediction process. Indeed, mental rotation of body parts seems to be carried out by simulating the actual movement of the very same body part (Parsons, 1994). The mental simulation of real perceptual-motor behaviours could be considered a sort of internal or cognitive analogue of actual movements (Duncombe, Bradshaw, Ianssek, & Phillips, 1994), useful for movement planning and prediction. The important role of the parietal cortex in this task has been highlighted by

* Corresponding author at: Department of Psychology, University of Rome "La Sapienza", via dei Marsi 78, 00185 Roma, Italy. Tel.: +39 06 49917601; fax: +39 06 49917635.

** Corresponding author. Tel.: +39 045 8027110; fax: +39 045 58088.

E-mail addresses: mirta.fiorio@medicina.univr.it (M. Fiorio), salvatoremaria.aglioti@uniroma1.it (S.M. Aglioti).

lesion studies in patients (Sirigu et al., 1995, 1996; Sirigu & Duhamel, 2001). In particular, Sirigu and Duhamel (2001) found a functional dissociation between visual and motor imagery in two patients with lesions located in different brain regions. A patient with a left parietal lobe tumour was impaired in tasks requiring mental motor imagery; on the contrary a patient with bilateral inferotemporal damage was impaired in mental visual imagery (Sirigu & Duhamel, 2001). Moreover, cortical neural networks including posterior parietal (Brodmann areas 5 and 7) and visual cortex, premotor and supplementary motor areas and primary motor cortex are activated during mental rotation of objects and body parts (Bonda, Petrides, Frey, & Evans, 1995; Ganis, Keenan, Kosslyn, & Pascual-Leone, 2000; Kosslyn, DiGirolamo, Thompson, & Alpert, 1998; Parsons et al., 1995). Further research has demonstrated that during mental rotation tasks sub-cortical structures, such as the basal ganglia, are also activated (Alivisatos & Petrides, 1997). Since basal ganglia and motor cortices are known to be involved in motor planning and execution, their activation during mental rotation suggests that actual and mentally simulated movements share largely overlapping cerebral structures.

The ability to perform mental rotation of body parts is strictly linked to the concept of “body schema”, a term that alludes to the complex of sensations, perception, memories and ideas about one’s own and others’ anatomy (Berlucchi & Aglioti, 1997). This mental construct about the body allows people to evaluate active and passive postural changes and movements, to localize tactile stimuli, to move, name, and point to specified body parts, and in general to map sensory inputs and motor outputs onto an orderly topographical model of the external anatomy of the human body. Some pathological conditions can cause changes in the mental representation of the body, thus influencing the ability to mentally rotate body parts. Recent studies have shown that brain representation of the body is modulated by peripheral alterations, such as pain (Moseley, 2004; Schwoebel, Friedman, Duda, & Coslett, 2001) and limb amputation (Nico, Daprati, Rigal, Parsons, & Sirigu, 2004). In a similar vein, we have reported in patients with focal hand dystonia with sustained muscular contractions localized to the dominant hand, an impairment of mental motor rotation of the affected body part (Fiorio, Tinazzi, & Aglioti, 2006). More specifically, patients were slower than control subjects in mentally rotating pictures of a hand (the affected body part) but not of another body segment, such as the foot. Here we sought to determine the specificity of the influence of actual motor disorders on mental rotation of body parts by testing patients affected by idiopathic cervical dystonia (CD), the most common adult-onset form of focal dystonia that is characterised by involuntary neck muscles contraction that induce abnormal head rotations and neck postures (Jankovic, Leder, Warner, & Schwartz, 1991; Nutt, Muentner, Aronson, Kurland, & Melton, 1988). We used laterality tasks, similar to that used in our study with focal hand dystonia patients (Fiorio et al., 2006), to assess the ability of patients with CD and healthy controls in mentally rotating different body parts (hands, feet, head, Experiment 1). Moreover, we further assessed the specificity of body representation by testing CD patients in a mental rotation task of non-corporeal objects (car, Experiment 2).

Table 1
Patients’ demographic and clinical information

| Patient | Gender | Age (years) | Education (years) | Torticollis ^a | Severity score ^b |
|---------|--------|-------------|-------------------|--------------------------|-----------------------------|
| 1 | F | 60 | 18 | Left | 3 |
| 2 | M | 63 | 18 | Right | 4 |
| 3 | F | 59 | 13 | Right | 9 |
| 4 | F | 59 | 5 | Right | 2.5 |
| 5 | M | 54 | 18 | Left | 7 |
| 6 | F | 44 | 14 | Left | 3 |
| 7 | M | 59 | 13 | Left | 2.5 |
| 8 | F | 68 | 5 | Left | 5 |
| 9 | F | 33 | 11 | Right | 9 |
| 10 | M | 67 | 8 | Left | 6 |
| 11 | M | 69 | 5 | Right | 5 |
| 12 | F | 71 | 8 | Left | 3 |

^a Side of rotation of the neck.

^b Burke–Fahn–Marsden movement and disability scale.

2. Methods

2.1. Subjects

We tested 12 right-handed patients affected by idiopathic cervical dystonia (7 women) and 12 right-handed healthy subjects (7 women) matched for age (mean 52.7 years, range 32–70) and education (mean 10.8 years of schooling, range 5–18). Duration of patients’ disease ranged from 4 to 11 years. Severity of motor impairment was evaluated by using the Burke–Fahn–Marsden movement and disability scale (Burke et al., 1985). Biochemical, computed tomography and magnetic resonance imaging examinations were normal, thus suggesting that dystonia was idiopathic. Four patients were untreated; the remaining eight patients had received treatment with botulinum toxin until 6 months before the study. Additional demographic and clinical information on the patient group is provided in Table 1.

All subjects gave their written informed consent after the non-therapeutic nature of the experimental tests was explained to them. Before testing, all subjects were naive about the aims of the experiments. The procedures were approved by the Local Ethics Committee of the University of Verona. All subjects were tested in the laterality judgements of body parts (hands, feet, head, Experiment 1). In addition, in order to assess the specificity of body representation, we added a further control task by testing subjects in a laterality judgement of a non-corporeal object, such as a car (Experiment 2). The order of the two experiments was counterbalanced across subjects; in view of this, the task with the non-corporeal object could be performed at the beginning as well as at the end of the whole experimental procedure.

2.2. Experiment 1

Subjects sat in front of a computer screen with their hands out of sight on their laps. The experiment was programmed using E-Prime, Beta software running on a PC. Stimuli consisted of realistic photos of a hand, a foot, and the head of a young man (Fig. 1). On each trial, subjects were asked to look at a computer screen and to maintain eyes steady on the screen throughout the entire perception-verbal report cycle. Patients’ head was kept straight by an examiner during stimuli delivery. Stimuli were large approximately 9.3 cm along the widest axis, which corresponded to about 10.65° of horizontal visual angle with participants’ viewing distance of 50 cm. Left and right hands (and feet) were mirror images of each other and could be presented in four views (back in picture plane, palm in picture plane, side from little finger and side from thumb). The head was presented only in the front side and had a black patch on either the left or the right eye. All stimuli were presented in six orientations (0°, 60°, 120°, 180°, 240° and 300°).

A total of 144 stimuli was delivered: 48 in the ‘hand block’, 48 in the ‘foot block’ and 48 in the ‘head block’. The three sessions were presented in counter-balanced order between the subjects. After each stimulus presentation, subjects

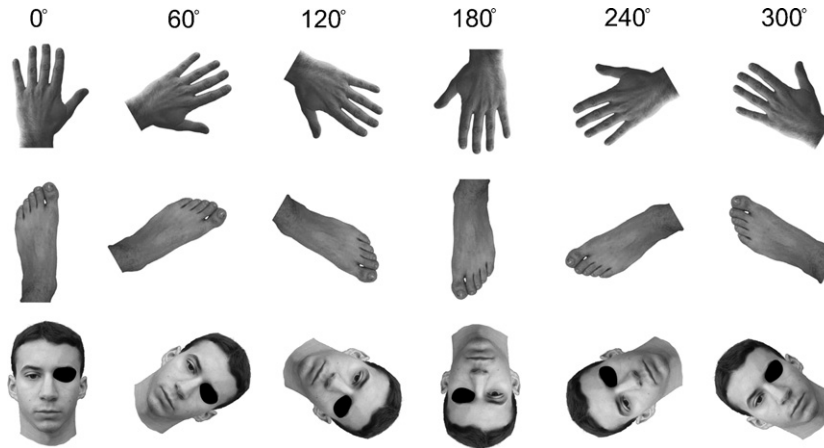


Fig. 1. Schematic representation of the experimental body-stimuli (hand, foot, head) in the six orientations (0° , 60° , 120° , 180° , 240° , 300°) used in Experiment 1. Left hand and foot stimuli were mirror images of right stimuli.

had to make a laterality judgement. More specifically, in the ‘hand/foot blocks’, the task was to verbally report whether the presented hand (or foot) was the right or the left one. In the ‘head block’ the task was to report the side of the black-patched eye. In all the blocks the choice was made by uttering the word ‘left’ or ‘right’ into a microphone positioned in front of the computer screen which recorded the subject’s reaction time. Response accuracy was keyed into the computer by the experimenter and stored for off-line analysis. Reaction time (RT) was defined as the time between the appearance of the stimulus on the computer screen and the onset of the subjects’ verbal response. Trials in which subjects did not speak loudly enough to trigger the voice box were eliminated prior to analysis (3.0%). Trials in which subjects had RTs ≥ 3 standard deviations above the mean for each cell (defined by stimulus type and side), computed for each subject independently, were also eliminated prior to analysis (2.2%). Since these out-layers values were computed independently for each control subject and each cervical dystonia patient, we reason that this procedure would not influence possible differences between the groups and allow to deal with more representative data. These trials were not associated with the most difficult rotation angles; indeed, the percentage of removed trials did not correlate with the degree of stimulus orientation (Spearman correlation, $p = 0.280$). Only RTs to trials in which the correct response was made were considered for the analysis. Pauses within a block were commensurate to the subjects’ fatigue.

2.3. Experiment 2

The recording conditions were identical to those of experiment 1. A 48 stimuli block was delivered, in which stimuli were the frontal view of a red car (10.56° of horizontal visual angle) presented in the front side on the computer screen and oriented in the same six degrees of orientation as in experiment 1. The car had a black patch on the left or the right headlight (Fig. 2).

On each trial, subjects had to report whether the black patch was on the right or the left headlight. Left and right referred to the perspective of a driver sat in the car. 2.6% of the total number of stimuli were eliminated prior to analysis because subjects did not speak loudly enough to trigger the voice box. 1.0% of trials in which RTs were ≥ 3 standard deviations above the mean were eliminated prior to analysis. These trials were not associated with the most difficult rotation angles (Spearman correlation, $p = 0.188$). In both experiments 1 and 2 the experimental stimuli remained on the screen until the subjects’ response.

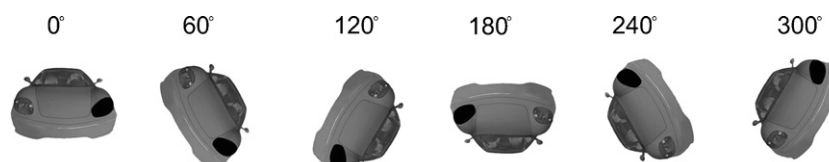


Fig. 2. Schematic representation of the non-corporeal object (car) used in Experiment 2. The car is shown in the six degrees of orientation (0° , 60° , 120° , 180° , 240° , 300°). A black patch was put on the left or the right headlight. Subjects’ task was to detect the laterality of the black patch as soon and accurately as possible.

2.4. Statistical analyses

In Experiment 1 we analysed subjects’ RTs and accuracy by means of two different analyses of variance (ANOVAs) with repeated measures. Each ANOVA had one between-subjects factor, ‘Group’ (cervical dystonia patients versus control subjects), and three within-subjects factors, ‘Stimulus type’ (hands, feet, head), ‘Stimulus side’ (right, left) and ‘Stimulus orientation’ (0° , 60° , 120° , 180° , 240° , 300°). In Experiment 2, RTs and accuracy in car laterality judgements were analysed by means of two separate ANOVAs with one between-subjects factor, ‘Group’ (cervical dystonia patients versus control subjects), and two within-subjects factors, ‘Stimulus side’ (left, right) and ‘Stimulus orientation’ (0° , 60° , 120° , 180° , 240° , 300°). In both experiments, post hoc comparisons were carried out by means of two-tailed *t*-tests. The Bonferroni correction for multiple comparisons was applied when necessary. The Spearman correlation coefficient was used for assessing in CD patients the possible relationship between dystonia severity score (Burke et al., 1985) and performance in laterality judgements of body parts (experiment 1) or non-corporeal objects (cars, experiment 2).

3. Results

To summarise, our experiments showed two main results: (1) patients’ group is clearly slower in formulating laterality judgments than control subjects for all the corporeal stimuli; (2) there is no difference between groups in the non-corporeal task. Below is a detailed description of these results.

3.1. Laterality judgements of body parts

3.1.1. Reaction time

Laterality judgement reaction times for hand, foot and head of the two experimental groups are represented in Fig. 3. RT values for both side of stimuli are reported in detail in Table 2. The analysis of variance showed that the factor Group was significant

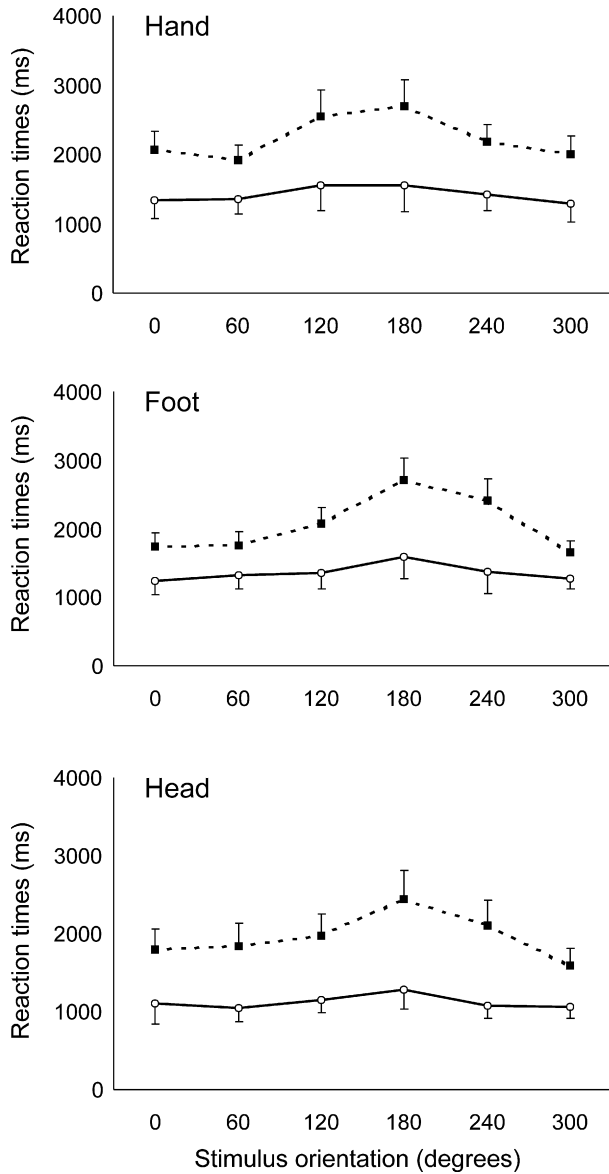


Fig. 3. Mean reaction times (bars are standard error) of CD patients (black squares) and control subjects (white circles) for the three types for the three types of body-stimuli (hands, feet, heads).

($F(1,22) = 5.81; p = 0.025$), because control subjects were faster (1300.0 ms) than patients affected by CD (2082.3 ms). The factor Stimulus side was significant ($F(1,22) = 38.72; p < 0.001$). This effect was due to faster reaction times for the right (1635.9 ms) than for the left stimuli (1746.5 ms). The factor Stimulus orientation was significant ($F(5,110) = 14.68; p < 0.001$), insofar as RTs were higher when stimuli had an orientation of 180° (2046.1 ms) than in other four orientations (0° = 1547.9 ms; 60° = 1534.4 ms; 120° = 1777.7 ms; 300° = 1480.7 ms). Moreover, RTs were significantly higher at 120° and 240° (1760.1 ms) with respect to 60° and 300°. The non-significant Stimulus type factor ($F(2,44) = 1.83; p = 0.173$) indicates that the time (averaged across groups and sides) requested for mentally rotating hands (1828.9 ms), feet (1708.2 ms) and head (1536.3 ms) was comparable.

The interaction Group × Stimulus orientation was significant ($F(5,110) = 4.27; p = 0.001$). This interaction provides information on whether differences between the two groups occur only at specific degrees of stimulus orientations. Post hoc comparisons helped to disambiguate these points and showed that: (i) CD patients were slower than control subjects at all stimulus orientations ($p < 0.041$); (ii) control subjects were faster in rotating stimuli with an orientation of 60° compared to stimuli oriented at 120° and 180° ($p < 0.007$); (iii) control subjects were also faster for stimuli at 300° compared to stimuli at 120°, 180°, 240° ($p < 0.004$) and at 0° and 240° compared to 180° ($p < 0.008$); (iv) CD patients were faster for stimuli orientation of 60° than of 120°, and 180° ($p < 0.008$); and for orientation 300° compared to 180° and 240° ($p < 0.010$).

The Stimulus side × Stimulus orientation interaction was also significant ($F(5,110) = 2.44; p = 0.039$). This interaction provides information on whether laterality judgements of right or left stimuli are differently modulated by specific degrees of stimulus orientation. Post hoc comparisons showed that: (i) laterality judgements of right-sided stimuli required longer RTs at 120° than at 0°, 60°, 300° ($p < 0.002$); and at 180° than at 0°, 60°, 240°, 300° ($p < 0.007$); (ii) laterality judgements of left-sided stimuli resulted in longer RTs at 120° than at 60° and 300° ($p < 0.007$); at 180° than at 0°, 60°, 120°, 300° ($p < 0.009$); and at 240° than 60°, 300° ($p < 0.002$).

No correlation between severity of disability and performance in the hand ($r = 0.035$), foot ($r = 0.212$) or head

Table 2
Mean RTs (ms) in the two groups for the three body-stimuli (hand, foot, head), and their laterality (left and right) and orientations (0°, 60°, 120°, 180°, 240°, 300°)

| | Right | | | | | | Left | | | | | |
|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| | 0° | 60° | 120° | 180° | 240° | 300° | 0° | 60° | 120° | 180° | 240° | 300° |
| Hand | | | | | | | | | | | | |
| Control subjects | 1293.8 | 1335.0 | 1650.6 | 1522.0 | 1284.7 | 1217.4 | 1389.7 | 1375.4 | 1467.7 | 1601.9 | 1564.0 | 1377.1 |
| CD patients | 2176.0 | 2253.9 | 2869.4 | 2344.7 | 1815.6 | 1883.6 | 1962.2 | 1565.7 | 2233.7 | 3027.4 | 2557.0 | 2125.7 |
| Foot | | | | | | | | | | | | |
| Control subjects | 1146.8 | 1313.2 | 1380.6 | 1487.7 | 1264.6 | 1231.9 | 1321.5 | 1319.6 | 1336.3 | 1706.6 | 1476.4 | 1317.0 |
| CD patients | 1592.9 | 1642.3 | 1841.6 | 2755.5 | 2118.1 | 1626.5 | 1886.0 | 1863.6 | 2311.6 | 2663.6 | 2688.7 | 1703.8 |
| Head | | | | | | | | | | | | |
| Control subjects | 1067.1 | 951.8 | 1104.8 | 1149.6 | 1097.2 | 1084.1 | 1140.6 | 1128.9 | 1200.3 | 1401.5 | 1063.2 | 1028.1 |
| CD patients | 1681.5 | 1733.6 | 1881.0 | 2555.2 | 2155.7 | 1384.0 | 1916.3 | 1929.5 | 2055.1 | 2337.4 | 2035.9 | 1789.4 |

Table 3
Mean percent accuracy in the two groups for the three body-stimuli (hand, foot, head), and their laterality (left and right) and orientations (0°, 60°, 120°, 180°, 240°, 300°)

| | Right | | | | | | Left | | | | | |
|------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | 0° | 60° | 120° | 180° | 240° | 300° | 0° | 60° | 120° | 180° | 240° | 300° |
| Hand | | | | | | | | | | | | |
| Control subjects | 79.2% | 84.4% | 84.4% | 86.5% | 89.6% | 88.5% | 84.4% | 92.7% | 86.5% | 80.2% | 84.4% | 90.6% |
| CD patients | 87.5% | 85.4% | 64.6% | 79.2% | 93.8% | 87.5% | 83.3% | 87.5% | 91.7% | 70.8% | 76.0% | 85.4% |
| Foot | | | | | | | | | | | | |
| Control subjects | 84.4% | 85.4% | 82.3% | 78.1% | 78.1% | 86.5% | 87.5% | 84.4% | 78.1% | 78.1% | 86.5% | 87.5% |
| CD patients | 75.0% | 77.1% | 76.0% | 63.5% | 72.9% | 77.1% | 66.7% | 75.0% | 70.8% | 64.6% | 77.1% | 77.1% |
| Head | | | | | | | | | | | | |
| Control subjects | 81.3% | 95.8% | 95.8% | 90.6% | 91.7% | 100% | 87.5% | 95.8% | 85.4% | 87.5% | 91.7% | 95.8% |
| CD patients | 86.5% | 83.3% | 79.2% | 70.8% | 79.2% | 79.2% | 87.5% | 89.6% | 79.2% | 70.8% | 85.4% | 83.3% |

($r=0.078$) laterality judgements was found in the patients group.

3.1.2. Accuracy

In the analysis of accuracy, the factor Group did not reach significance ($F(1,22)=3.83$; $p=0.063$), although a trend towards lower accuracy in CD patients (78.9%) than control subjects (86.9%) was found. This suggests that the significant results on RTs cannot be attributed to a speed accuracy trade-off. The factor Stimulus type was significant ($F(2,44)=5.25$; $p=0.009$) insofar as participants were less accurate in rotating feet (77.9%) than hands (84.3%) and heads (86.4%). The factor Stimulus orientation was also significant ($F(5,110)=6.42$; $p<0.001$). This effect was due to the lower accuracy for stimuli oriented at 180° (76.7%) with respect to 60° (86.4%) and 300° (86.5%). The Stimulus type \times Stimulus side \times Stimulus orientation was the only significant interaction ($F(10,220)=2.77$; $p=0.003$). Post hoc comparisons showed that this effect was due to the following: lower accuracy in mentally rotating right hand stimuli at 120° compared to 180° and 240° ($p<0.006$) and in mentally rotating left hand stimuli at 180° compared to 60°, 120°, 300° ($p<0.007$). Accuracy in head and foot laterality judgements was not different at different orientations and sides. Mean accuracy of the two groups is shown in Table 3.

No correlation between severity of disability and accuracy in hand ($r=0.130$), foot ($r=0.180$) or head ($r=0.002$) laterality judgements was found in the patients group.

3.2. Laterality judgements of a non-corporeal object

3.2.1. Reaction time

Results of Experiment 2 are represented in Fig. 4 and more detailed in Table 4. In the analysis of the reaction times, the factor Group was not significant ($F(1,22)=3.28$; $p=0.084$). Indeed, CD patients' RTs (1550.0 ms) in car laterality judgements were not statistically different from those of control subjects (1079.2 ms). Although not statistically significant, the difference of the two groups (see also Fig. 4) seems to suggest a trend towards significance. However, this might be due to the fact that, in the car condition, three patients had RTs above the

normal upper limit of 1753 ms (defined as the mean RT of the control group plus 2 standard deviations).

The factor Stimulus orientation was significant ($F(5,110)=3.32$; $p=0.008$), due to higher reaction times at 180° (1521.9 ms) than at 300° (1181.6 ms). No other effects or interaction were significant. No correlation between severity of disability and performance in the car laterality judgements was found in the patients group ($r=0.212$).

3.2.2. Accuracy

As shown in Table 5, no significant difference in accuracy between the two groups ($F(1,22)=1.85$; $p=0.187$) was found. Moreover, no correlation between severity of disability and accuracy in the car laterality judgements was found in CD patients ($r=0.254$).

3.3. Group differences in laterality judgements of body parts and non-corporeal objects

To further explore the body-specificity of the effects, we assessed whether CD patients' performance was worse than that of control subjects for bodily with respect to non-bodily stimuli. Therefore, we run one-way corrected ANOVA comparing clinical and control groups on a stimulus type-by-stimulus type basis. Results confirmed that patients were significantly slower

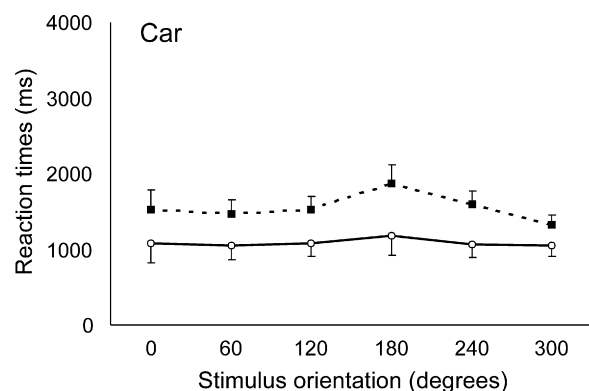


Fig. 4. Mean reaction times (bars are standard error) of CD patients (black squares) and control subjects (white circles) for the non-corporeal object (car).

Table 4

Mean RTs (ms) in the two groups for the car stimuli, and their laterality (left and right) and orientations (0°, 60°, 120°, 180°, 240°, 300°)

| Car | Right | | | | | | Left | | | | | |
|------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| | 0° | 60° | 120° | 180° | 240° | 300° | 0° | 60° | 120° | 180° | 240° | 300° |
| Control subjects | 1049.3 | 955.1 | 1004.6 | 1205.4 | 1015.2 | 1017.4 | 1101.3 | 1135.3 | 1144.9 | 1150.2 | 1100.9 | 1070.8 |
| CD patients | 1604.9 | 1520.3 | 1519.5 | 1774.8 | 1484.3 | 1405.2 | 1443.9 | 1427.0 | 1521.4 | 1957.3 | 1708.5 | 1233.1 |

Table 5

Mean percent accuracy in the two groups for the car stimuli, and their laterality (left and right) and orientations (0°, 60°, 120°, 180°, 240°, 300°)

| Car | Right | | | | | | Left | | | | | |
|------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | 0° | 60° | 120° | 180° | 240° | 300° | 0° | 60° | 120° | 180° | 240° | 300° |
| Control subjects | 97.9% | 95.8% | 95.8% | 87.5% | 93.8% | 87.5% | 95.8% | 89.6% | 91.7% | 93.8% | 89.6% | 95.8% |
| CD patients | 85.4% | 87.5% | 87.5% | 72.9% | 93.8% | 87.5% | 87.5% | 89.6% | 93.8% | 75.0% | 85.4% | 91.7% |

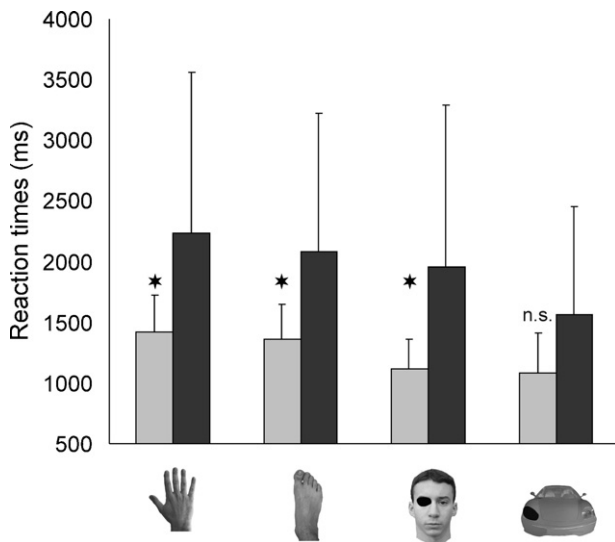


Fig. 5. Stimulus type-by stimulus type comparisons between the two groups. Dark grey columns represent CD patients' mean RTs and standard deviations, while light grey columns represent control subjects' performance. Significant difference (*) between the performance of the two groups was observed for the hand, foot and head stimuli, but not for the car stimuli (n.s.).

than control subjects in the hand ($F(1,23) = 4.25, p = 0.050$), foot ($F(1,23) = 4.48, p = 0.046$) and head ($F(1,23) = 4.59, p = 0.044$) conditions. By contrast, no significant difference in the car condition ($F(1,23) = 3.19, p = 0.088$) was found (Fig. 5). This result confirms a body-specific impairment of the patients group in performing a laterality judgement task. Comparisons in accuracy were not computed, since in the general ANOVA (see Section 3 above) we did not find any significant effect of the factor Group.

4. Discussion

The laterality judgement of body parts is a behavioural task that proved appropriate for exploring bodily spatial representation and motor planning. It has been observed that during this task subjects imagine to move a given body part from its actual posture into that of the presented stimulus (Parsons, 1987, 1994).

The present study showed that patients affected by idiopathic cervical dystonia, that is likely to be related to dysfunctions of cortico-basal ganglia circuit, are impaired in mental rotation of stimuli representing body parts, namely hand, foot and head (Experiment 1). This abnormality is unlikely due to a general impairment in mental rotation per se, since patients' ability to rotate a non-corporeal object (a car) was not significantly different from that of healthy participants (Experiment 2). Although this finding seems to support evidence for a dissociation in CD patients between corporeal and non-corporeal mental rotation, it cannot be considered an unequivocal proof of it and should be taken cautiously. Our data, indeed, do not allow us to disambiguate the trend toward significance in the non-corporeal object condition. We speculate that, in the frame of our data interpretation, prolonged RTs might be due to the use, at least in some patients, of different mental rotation strategies. On debriefing for example, some subjects reported that they imagined to be seated in the car or they felt to simulate grasping the car with the hand as though it was a toy. Interestingly this may happen under a number of circumstances, including observation of implied actions (Urgesi, Moro, Candidi, & Aglioti, 2006).

4.1. Motor impairments and mental motor rotation

The duration of mental rotation is influenced by proprioceptive information regarding limb position and by the complexity of the movements to be mentally executed (Parsons, 1994). Thus, different postures and actual biomechanical bodily constraints can influence mental motor rotation of body parts. In keeping with this notion, subjects of the present study showed longer reaction times for stimuli orientations (180°) in which actual movements would be more difficult to be performed. Body part laterality judgements are also influenced by specific body schema alterations such as those induced by chronic arm pain (Schwoebel et al., 2001), complex regional pain syndrome (Moseley, 2004), or upper limb amputation (Nico et al., 2004). In a similar vein, patients affected by focal-hand dystonia presented mental rotation deficits specific to the hand, i.e. the body part affected by the motor disturbances (Fiorio et al., 2006).

Interestingly, the slowness in mental rotation was observed also when patients rotated the unaffected hand, suggesting that the hand-specific impairment may concern the representational alteration of this body part in both hemispheres (Fiorio et al., 2006).

The present study shows deficits in head mental rotation in subjects who presented with a clear impairment in actual rotation of the very same body part. Mental rotation deficits, however, were not head-specific but body-specific, being also present for hands and feet. Since hand and feet real movements were not specifically affected by the disease in cervical dystonia, this result may seem at odds from our previous study in focal-hand dystonia, in which mental rotation deficits occurred for the hands but not for the feet (Fiorio et al., 2006). A possible explanation for the widespread mental rotation deficit in cervical dystonia, compared to focal-hand dystonia, may be related to the different patho-physiological patterns underlying the two syndromes. Indeed, unlike focal-hand dystonia, in which local sensory-motor variables may play an important role, CD patients present with a clear abnormality of the vestibular and neck proprioceptive systems (Dauer, Burke, Greene, & Fahn, 1998; Karnath, Konczak, & Dichgans, 2000; Lekhel et al., 1997). This abnormality may lead to a more general alteration of the mental representation of the entire body, resulting in mental rotation deficits regarding also body segments which are not affected by the motor symptoms.

4.2. Alterations of egocentric co-ordinate systems in patients with CD

It is in principle possible that the alterations of mental rotation in our CD patients are related to a spatial attentional bias induced by the cervical rotation and pain. Such a bias would influence patients' performance in judging the experimental stimuli (Robertson, Mattingley, Rorden, & Driver, 1998). However, we suggest that this was not the case, since a space-based attentional bias should have influenced also the mental rotation of non-corporeal objects.

Thus, a more specific representational deficit may account for our results. We posit that the deficit in mental rotation of body parts in patients with CD may derive from an alteration of the process of body- and world-knowledge integration that allows a general representation of "me in the external world". Two main kinds of information are integrated to build an accurate and up-to-date representation of our body parts in space. More specifically, signals coming from the visual and proprioceptive modalities may contribute in different ways to the computation of body position. Egocentric frames of reference derive from the continuous update of static and dynamic visual, vestibular and proprioceptive signals that tune the motor apparatus for directing actions in the extracorporeal space (Blouin et al., 1993; Paillard, 1987). This system can be built according to a number of reference frames related to the task, e.g. eye centred, head-centred, shoulder-centred, or trunk-centred. Allocentric frames of reference derive from a memory-based internal construct of the external environment which remains stable even when the body moves (Paillard, 1987). Neurophysi-

ological and neuroimaging studies provided direct evidence for a neural distinction between allocentric and egocentric spatial representations. Modulation of visual signal in two adjacent cortical fields of the monkey brain, lateral intraparietal area (LIP) and 7a, are referenced to the body and to the world, respectively (Snyder, Grieve, Brotchie, & Andersen, 1998). In humans, the fronto-striatal system plays a major role in the elaboration of the egocentric reference frame, whereas the posterior parietal region, the parahippocampal region, the hippocampus and the thalamus seem responsible for the allocentric representation of the world (Galati et al., 2000; Jordan, Schadow, Wuestenberg, Heinze, & Jancke, 2004; Kesner, Farnsworth, & DiMattia, 1989; Paillard, 1987).

Among the large variety of afferent inputs, vestibular signals, originating from the semicircular canals and otoliths, and neck proprioceptive signals play a special role in the control of body orientation, posture and motor coordination (Brandt, 1996; Cohen, 1961). Cervical proprioceptive input is processed together with vestibular afference to deduce an estimate of the head and trunk posture. In normal subjects, neck muscles vibration causes an illusory tilt of the body due to a conflict between the proprioceptive inputs induced by the vibration and other sensory modalities (Lekhel et al., 1997). The same kind of muscle vibration, in normal subjects, has been shown to cause deviation of the perceived straight-ahead (Karnath, Sievering, & Fetter, 1994) and body rotation during stepping (Bove, Courtine, & Schieppati, 2002). On the contrary, patients with cervical dystonia seem to ignore cervical proprioceptive input in the whole body postural control (Lekhel et al., 1997). In this regard, a recent study suggested that CD patients have become less sensitive to neck muscle vibration, in that patients did not show the normal body rotation due to neck vibration as observed in healthy subjects (Bove, Bricchetto, Abbruzzese, Marchese, & Schieppati, 2004).

As previously noted, receptors from neck muscles contribute to the head-position representation relative to the trunk which is necessary for the control of the head in space. Psychophysical studies show that, unlike controls, CD patients rely upon the trunk, instead than upon the head, to provide an estimation of the body mid-sagittal line (Anastasopoulos, Nasios, Mergner, & Maurer, 2003). This may suggest that, given the altered signals coming from neck and head, the trunk is a more reliable egocentric reference in CD patients (Anastasopoulos et al., 1998). A possible change within different egocentric co-ordinate system (i.e. from the head-reference system to the trunk-reference system) is unlikely to explain the results of our study. Indeed, if CD patients relied on the trunk as stable body reference, they should be able to rotate hands and feet normally which, however, was not the case. Since the ability to mentally rotate body parts is strictly related to estimation of the body spatial position, one can argue that in CD patients there is a body schema general change that also includes limbs and their movements. It seems therefore more probable that our patients' deficit was due to a less reliable body-referenced system. This may imply that CD patients rely upon allocentric frames of reference to guide their actions. Based on this notion, Muller et al. (2005) assessed CD patients in tasks tapping body-dependent and body-independent

spatial perception. Results showed that CD patients were impaired in body-centred, egocentric spatial perception, but not in body-independent, allocentric spatial perception. This pattern of results was comparable in both dark and light conditions, suggesting that visual input does not play a major role for the determination of the body-centred reference system and demonstrates the primacy of proprioceptive input from the neck region in modulating body-centred representations (Muller et al., 2005). In a similar vein, it has been shown that CD patients performed spatial memory tasks by using an allocentric strategy, while control subjects used either egocentric or allocentric strategies (Ploner, Stenz, Fassdorf, & Arnold, 2005). Thus, in CD patients allocentric spatial representations may provide a more reliable basis for spatially directed behaviour than egocentric spatial representations (Ploner et al., 2005).

Whether this egocentric-reference deficit in CD patients results from altered proprioceptive and vestibular inputs, due to local dystonia, or from altered processing of this information within the cerebral network supposedly dedicated to egocentric coding remains unknown. Future studies applying imaging techniques with the same paradigm, might help to clarify this important point.

Acknowledgments

This research was supported by grants from the Ministero Italiano Università e Ricerca (MIUR) and by Finanziamento Italiano Ricerca di Base (FIRB), Italy. We thank Mr. Marco Veronese for precious help in figures preparation.

References

- Alivisatos, B., & Petrides, M. (1997). Functional activation of the human brain during mental rotation. *Neuropsychologia*, *35*, 111–118.
- Anastasopoulos, D., Nasios, G., Psilas, K., Mergner, T., Maurer, C., & Lucking, C. H. (1998). What is straight ahead to a patient with torticollis? *Brain*, *121*, 91–101.
- Anastasopoulos, D., Nasios, G., Mergner, T., & Maurer, C. (2003). Idiopathic spasmodic torticollis is not associated with abnormal kinesthetic perception from neck proprioceptive and vestibular afferences. *Journal of Neurology*, *250*, 546–555.
- Berlucchi, G., & Aglioti, S. (1997). The body in the brain: neural bases of corporeal awareness. *Trends in Neuroscience*, *20*, 560–564.
- Blouin, J., Bard, C., Teasdale, N., Paillard, J., Fleury, M., Forget, R., et al. (1993). Reference systems for coding spatial information in normal subjects and a deafferented patient. *Experimental Brain Research*, *93*, 324–331.
- Bonda, E., Petrides, M., Frey, S., & Evans, A. (1995). Neural correlates of mental transformations of the body-in-space. *Proceedings of the National Academy of Science, USA*, *92*, 11180–11184.
- Bove, M., Brichetto, G., Abbruzzese, G., Marchese, R., & Schieppati, M. (2004). Neck proprioception and spatial orientation in cervical dystonia. *Brain*, *127*, 2764–2778.
- Bove, M., Courtine, G., & Schieppati, M. (2002). Neck muscle vibration and spatial orientation during stepping in place in humans. *Journal of Neurophysiology*, *88*, 2232–2241.
- Brandt, T. (1996). Cervical vertigo—reality or fiction? *Audiology and Neuro-otology*, *1*, 187–196.
- Burke, R. E., Fahn, S., Marsden, C. D., Bressman, S. B., Moskowitz, C., & Friedman, J. (1985). Validity and reliability of a rating scale for the primary torsion dystonias. *Neurology*, *35*, 73–77.
- Cohen, L. A. (1961). Role of eye and neck proprioceptive mechanisms in body orientation and motor coordination. *Journal of Neurophysiology*, *24*, 1–11.
- Dauer, W. T., Burke, R. E., Greene, P., & Fahn, S. (1998). Current concepts on the clinical features, aetiology and management of idiopathic cervical dystonia. *Brain*, *121*, 547–560.
- Duncombe, M. E., Bradshaw, J. L., Iansek, R., & Phillips, J. G. (1994). Parkinsonian patients without dementia or depression do not suffer from bradyphrenia as indexed by performance in mental rotation tasks with and without advance information. *Neuropsychologia*, *32*, 1383–1396.
- Fiorio, M., Tinazzi, M., & Aglioti, S. M. (2006). Selective impairment of hand mental rotation in patients with focal hand dystonia. *Brain*, *129*, 47–54.
- Galati, G., Lobel, E., Vallar, G., Berthoz, A., Pizzamiglio, L., & Le Bihan, D. (2000). The neural basis of egocentric and allocentric coding of space in humans: a functional magnetic resonance study. *Experimental Brain Research*, *133*, 156–164.
- Ganis, G., Keenan, J. P., Kosslyn, S. M., & Pascual-Leone, A. (2000). Transcranial magnetic stimulation of primary motor cortex affects mental rotation. *Cerebral Cortex*, *10*, 175–180.
- Jankovic, J., Leder, S., Warner, D., & Schwartz, K. (1991). Cervical dystonia: clinical findings and associated movement disorders. *Neurology*, *41*, 1088–1091.
- Jordan, K., Schadow, J., Wuestenberg, T., Heinze, H. J., & Jancke, L. (2004). Different cortical activations for subjects using allocentric or egocentric strategies in a virtual navigation task. *Neuroreport*, *15*, 135–140.
- Karnath, H. O., Konczak, J., & Dichgans, J. (2000). Effect of prolonged neck muscle vibration on lateral head tilt in severe spasmodic torticollis. *Journal of Neurology, Neurosurgery, and Psychiatry*, *69*, 658–660.
- Karnath, H. O., Sievering, D., & Fetter, M. (1994). The interactive contribution of neck muscle proprioception and vestibular stimulation to subjective “straight ahead” orientation in man. *Experimental Brain Research*, *101*, 140–146.
- Kesner, R. P., Farnsworth, G., & DiMattia, B. V. (1989). Double dissociation of egocentric and allocentric space following medial prefrontal and parietal cortex lesions in the rat. *Behavioural Neuroscience*, *103*, 956–961.
- Kosslyn, S. M., DiGirolamo, G. J., Thompson, W. L., & Alpert, N. M. (1998). Mental rotation of objects versus hands: neural mechanisms revealed by positron emission tomography. *Psychophysiology*, *35*, 151–161.
- Lekhel, H., Popov, K., Anastasopoulos, D., Bronstein, A., Bhatia, K., Marsden, C. D., et al. (1997). Postural responses to vibration of neck muscles in patients with idiopathic torticollis. *Brain*, *120*, 583–591.
- Moseley, G. L. (2004). Why do people with complex regional pain syndrome take longer to recognize their affected hand? *Neurology*, *62*, 2182–2186.
- Muller, S. V., Glaser, P., Troger, M., Dengler, R., Johannes, S., & Munte, T. F. (2005). Disturbed egocentric space representation in cervical dystonia. *Movement Disorders*, *20*, 58–63.
- Nico, D., Daprati, E., Rigal, F., Parsons, L., & Sirigu, A. (2004). Left and right hand recognition in upper limb amputees. *Brain*, *127*, 120–132.
- Nutt, J. G., Muenter, M. D., Aronson, A., Kurland, L. T., & Melton, L. J. (1988). Epidemiology of focal and generalized dystonia in Rochester, Minnesota. *Movement Disorders*, *3*, 188–194.
- Paillard, J. (1987). Cognitive versus sensorimotor encoding of spatial information. In P. Ellen & C. Thinus-Blanc (Eds.), *Cognitive process and spatial orientation in animal and man* (pp. 1–34). Dordrecht: Martinus Nijhoff.
- Parsons, L. M. (1987). Imagined spatial transformations of one’s hands and feet. *Cognitive Psychology*, *19*, 178–241.
- Parsons, L. M. (1994). Temporal and kinematic properties of motor behavior reflected in mentally simulated action. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 709–730.
- Parsons, L. M., Fox, P. T., Downs, J. H., Glass, T., Hirsch, T. B., Martin, C. C., et al. (1995). Use of implicit motor imagery for visual shape discrimination as revealed by PET. *Nature*, *375*, 54–58.
- Ploner, C. J., Stenz, U., Fassdorf, K., & Arnold, G. (2005). Egocentric and allocentric spatial memory in idiopathic cervical dystonia. *Neurology*, *64*, 1733–1738.
- Robertson, I. H., Mattingley, J. B., Rorden, C., & Driver, J. (1998). Phasic alerting of neglect patients overcomes their spatial deficit in visual awareness. *Nature*, *395*, 169–172.
- Schwobel, J., Friedman, R., Duda, N., & Coslett, H. B. (2001). Pain and the body schema: evidence for peripheral effects on mental representations of movement. *Brain*, *124*, 2098–2104.

- Sirigu, A., Cohen, L., Duhamel, J. R., Pillon, B., Dubois, B., Agid, Y., et al. (1995). Congruent unilateral impairments for real and imagined hand movements. *Neuroreport*, *6*, 997–1001.
- Sirigu, A., & Duhamel, J. R. (2001). Motor and visual imagery as two complementary but neurally dissociable mental processes. *Journal of Cognitive Neuroscience*, *13*, 910–919.
- Sirigu, A., Duhamel, J. R., Cohen, L., Pillon, B., Dubois, B., & Agid, Y. (1996). The mental representation of hand movements after parietal cortex damage. *Science*, *273*, 1564–1568.
- Snyder, L. H., Grieve, K. L., Brotchie, P., & Andersen, R. A. (1998). Separate body- and world-referenced representations of visual space in parietal cortex. *Nature*, *394*, 887–891.
- Thayer, Z. C., Johnson, B. W., Corballis, M. C., & Hamm, J. P. (2001). Perceptual and motor mechanisms for mental rotation of human hands. *Neuroreport*, *12*, 3433–3437.
- Urgesi, C., Moro, V., Candidi, M., & Aglioti, S. M. (2006). Mapping implied body actions in the human motor system. *Journal of Neuroscience*, *26*, 7942–7949.