A dissociation between real and simulated movements in Parkinson's disease

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Subcortical lesions have been simultaneously implicated in both real and simulated movement deficits. However, the analysis of the simulated opposition axis in precision grasping reveals that, in individuals with idiopathic bilateral Parkinson's disease motor imagery is impaired and that execution of overt movements is spared. This constitutes the first lesion observation congruent with the anatomical and functional dichotomy between real and simulated movements seen in experimental studies. These results underline the modality-specific nature of motor imagery and show that subcortical damage differentially impacts on motor activity. *NeuroReport* 15:000–000 © 2004 Lippincott Williams & Wilkins.

Key words: Motor imagery; Opposition axis; Parkinson's disease; Prehension

INTRODUCTION

A critical advance in our understanding of the relationship between motor imagery and overt movement is that there are specific, overlapping brain sites which are differentially activated when subjects are asked to execute or mentally represent a particular movement. In the supplementary motor area, for example, activation data reveal only partial overlap between the zones activated for imagery and those activated for execution [1]. In addition, patterns of differential activation in frontal cortex suggest that areas involved in execution are involved to a different degree in representation [2]. The same is true for areas in the posterior parietal cortex (PPC) where there exists a functional and activation dichotomy between motor imagery and overt movement [1]. The basal ganglia may also play a particular role in motor imagery. Imaging studies have shown preferential activation of the anterior loop during imagery whereas the posterior part of the putamen loop is activated in movement execution [3]. These two neural networks have been well documented in monkeys [4]. The effect of brain lesions are also good indicators of the role of some of these sites in controlling motor imagery. However, only in individuals with posterior parietal (PPC) damage is motor imagery impaired and execution spared [5]. In frontal [6] and subcortical [7] lesions, both overt and simulated movements are similarly impaired, suggesting that the PPC plays a critical role in generating motor imagery. However, it appears that the same basal ganglia structures are implicated in the coordination of both real and simulated movements, i.e., a problem with movement execution is also a motor imagery problem [7]. The current study showed that individuals with Parkinson's disease, who are impaired in the mental representation of a grasp orientation, are still capable of normally executing this movement, suggesting that the coordination processes for execution are separate from those for motor imagery.

MATERIALS AND METHODS

Subjects: Eight right-handed individuals with idiopathic bilateral parkinson's disease (four women and four men; mean age 59 ± 4.49 years; all patients at Stage III on Hoehn and Yahr Scale; evaluated during the on state; medication 800 mg L-dopa daily; with little or no akinesia in their dominant hand after medication) and eight right-handed healthy volunteers (three women and five men, mean age 58 ± 5.08 years; with no detected neurological disorder) participated in the experiment. They all gave their informed consent. Before the experiment, they received an explanation of the methods used. The purpose of the study was revealed once the experiment was over. The experiment was approved by the local ethics committee. Half of the subjects in each group started the experimental session with the letter rotation task and the others with the opposition axis task. The three task (letters rotation, simulated and real movements) were done during the same session.

Experimental design: The subjects were seated in front of a 15 inch monitor lying flat with the screen perpendicular to the body axis and at a distance of 45 cm under the orbitomeatal line. The opposition axis experiment started with a preliminary run for clarifying the instructions: an opaque cylindrical container filled with water (5 cm high, 3 cm diameter, 30 g weight) was placed at the center of the monitor screen at a distance of 50 cm from the body plane (Fig. 1a). Another plastic container was placed behind the first one. Subjects were asked to lift the plastic cylinder filled with water, pour the water into the other container and return the cylinder to its original position using a precision grip formed by the right thumb and index fingers [8]. The onset of the hand movement was located 10 cm right of the sagittal axis. Subjects were also asked to carefully observe the axis defined by the contact point of the fingers on the cylinder surface, along which the forces were applied during the grasp (the opposition axis). They were explicitly instructed not to use their left hand or any other fingers except the thumb and index finger of their right hand. They were also instructed not to stand up nor use a vertical grip nor perform any pronation/supination movement of the wrist to complete the grasping movement. This action was repeated at least 20 times at the beginning of the experiment before the tips of the right thumb and index finger were painted. The OA was then defined as the line connecting these two contact points on the cylinder. The OA orientation was calculated with a protractor with respect to the frontal plane in the last five executed movements. After the real grasp both objects were removed from the subject's view. During the simulated movements, the computer monitor was used to display the target stimuli (Fig. 1b). For each trial, a central 500 ms fixation point was followed by an image of the upper surface of the cylinder (a circle) which remained on the screen, at the same location where the real cylinder was placed during the preliminary run, until a response was given. Each circle was marked with two contact points (without the name of the fingers) which defined an OA at 0°, 22°, 45°, 56°, 90°, −22° (338°), −45° (315°) and −56° (304°) with respect to the frontal plane. The subjects' task consisted in judging as quickly as possible whether the previously experienced action of grasping the cylinder full of water and emptying it into the other container would be possible with the fingers placed according to the opposition axis indicated on the circle. No actual movement was allowed. The subjects had to rate the level of feasibility of the grasp (easy, difficult, impossible), by pressing keyboard keys with their right hand. Half of the subjects pressed j (easy), k (difficult), l (impossible) and the reverse order for the other half, with the three middle fingers. Each subject was given a brief training period. There were eight orientations randomly displayed 50 times each. Feasability level and response time were recorded.

In the letter rotation experiment, the letters F, L and R were displayed in canonical or mirror form at 0°, 30°, 60°, 90°, 120°, 150° and 180° with respect to the frontal plane. The subjects had to identify the canonical forms by pressing keyboard keys with their right hand. Half of the subjects used the "j" key for canonical and "k" key for mirror form. The other subjects pressed the "k" key for canonical and "j" key for mirror form with their index and major fingers, respectively. The task consisted of 42 random stimuli, each displayed twice. The stimuli remained on the screen until the subjects pressed the response key. Response time (time interval between the display of the stimulus and the key press) and response accuracy were recorded.

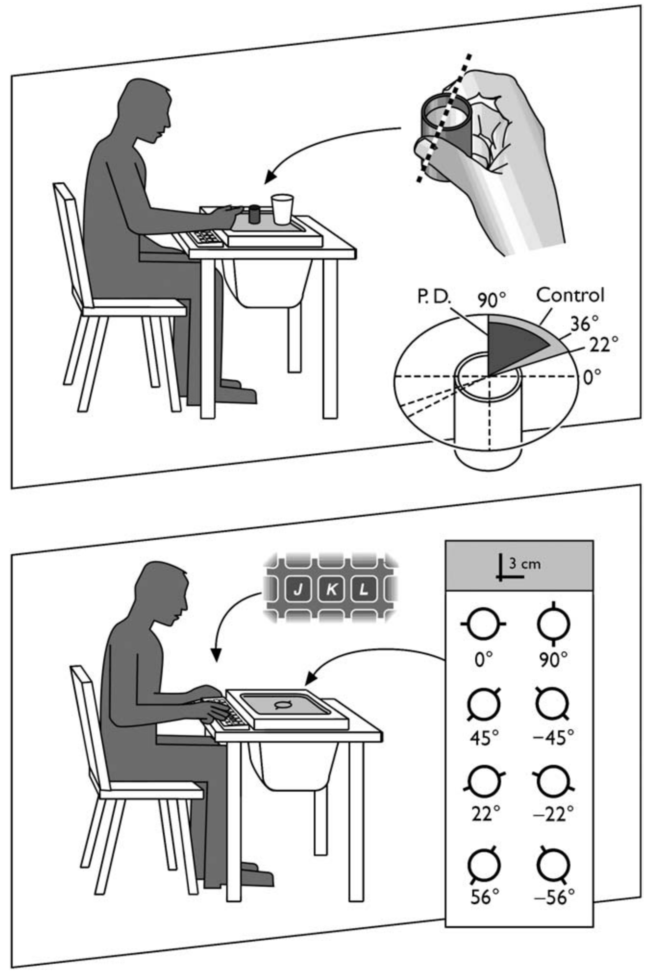

Fig. 1. (**a**) In the execution of real movements, subjects were asked to lift a cylinder filled with water, empty it in another container and return the cylinder to its original position, using a precision grip formed by the right thumb and index fingers. The OA is the line connecting the two contact points. Range of preferred OA was 22–90° and 36–90° for control and Parkinson's disease subjects, respectively. (**b**) In the simulated movement condition, the target stimuli were marked with two contact points which defined the OA with respect to the frontal plane. Subjects judged whether it would be easy, difficult or impossible to grasp and empty the cylinder with the fingers placed on the contact points, by pressing a keyboard key with their right hand.

RESULTS

Preferred orientation of opposition axis: The mean orientation of the OA in executed movements was 58.9 ± 12. 6° for Parkinson's disease subjects with preferred orientations ranging from 36° to 90°, and 59.2 ± 15.3° for healthy participants with preferred orientations ranging from 22° to 90°. (Fig. 1a). The preferred orientation was thus equivalent for both groups ($F(4,56)=0.93$, $p>0.3$).

Simulated movements: In the order to compare with the performed task results the eight different orientations presented during the simulated task have been separated into two clusters: −56°; −45°; −22°; 0° (no preferred angles) and 22°; 45°; 56°; 90° (preferred angles).

In control subjects a significant effect of the orientation on response times was observed ($F(1,7)=14.31$; $p< 0.0069$). The shortest response times were observed at the preferred angles (1475 ms) while longest response times were found at the least preferred angles (1822 ms). This long response time significantly differed from that for 22°–90°. In patients there was no significant effect of orientation on response times ($F(1,7)=2.18$; $p<0.1831$), which were 1734 ms at 22° to 90° and 1825 ms at –56° to 0°. There was a significant difference in the response times of the two subject groups ($F(1,14)=5.36$; $p<0.0362$) with controls responding more quickly than the patients at 22°–90° (preferred angles). The time taken to complete the experiment was the same for both groups of subjects ($F(1,14)=0.32$; $p>0.5$). Mean judgment decision time was 1779 ± 425 ms for Parkinson's disease and 1648 ± 458 ms for control participants.

Feasibility: ANOVA shows a significant main effect of orientation on the feasibility level in controls ($F(2,14)=15.43$; $p<0.0003$). Controls considered the grasp easy in 78% of cases when the axis was at one of the preferred angles, and in 42% when it belonged to the not preferred angles. Conversely they rated the grasp difficult in 36% of cases when the axis passed through the not preferred angles, and in 12% when it passed through the preferred angles. *Post-hoc* analysis showed a significant decrease in easy ratings and a significant increase in difficult ratings as the imaginary opposition axis moved away from the preferred angles zone. The proportion of impossible ratings was 10% for an axis into the preferred zone but it jumped to 22% at the no preferred zone.

Unlike controls, there was no significant effect of the orientation on the feasibility level in parkinsonian subjects ($F(2,14)=0.47$; $p<0.6370$). They considered the grasp easy in 59% of cases when the axis passed through the preferred angles, and in 55% of cases when it belonged to the not preferred angles. The grasp was rated difficult in 33% of cases when the axis passed through the not preferred angles, and in 29% when it passed through the preferred angles. The proportion of impossible ratings was the same (12%) in the two zones (Fig. 2).

Letter rotation: A two-way ANOVA revealed a main effect of the orientation of letters on response time ($F(6,84)=20.11$, $p<0.00001$). Response time increased with the degree of angular rotation and planned comparison contrasts also revealed a linear trend for angular rotation ($p<0.006$) in both Parkinson's disease patients (87%) and controls (95%). There was no difference between the two groups in response time ($F(6,84)=0.45$, $p>0.8$) or in the number of errors in letter identification, in either canonical or mirror-reflected letters ($F(1,14)=0.20$, $p>0.6$). These results are in agreement with those of Duncombe *et al.* [9] who obtained similar results with their Parkinson's disease participants.

DISCUSSION

In the simulated movement condition, the control subjects all judged grasps outside of their preferred range of orientation as difficult, and as easy when it was within this range. This suggests that control subjects, in the simulated grasps, take into account the same biomechanical limitations as actually performed movements. This is in agreement with our previous observations with healthy subjects [10]. In contrast, individuals with Parkinson's disease judged all orientations as equally easy or difficult (Fig. 2). Parkinson's disease subjects, in resolving the simulated grasps, did not simulate the preferred orientation. It could be that the hypokinesia commonly seen in Parkinson's disease may influence difficulty judgments. However, this was not the case as the time taken to complete the experiment was the same for both groups of subjects. Thus, the deficit in simulated movements seen in individuals with Parkinson's disease should not be a consequence of biomechanical limitations.

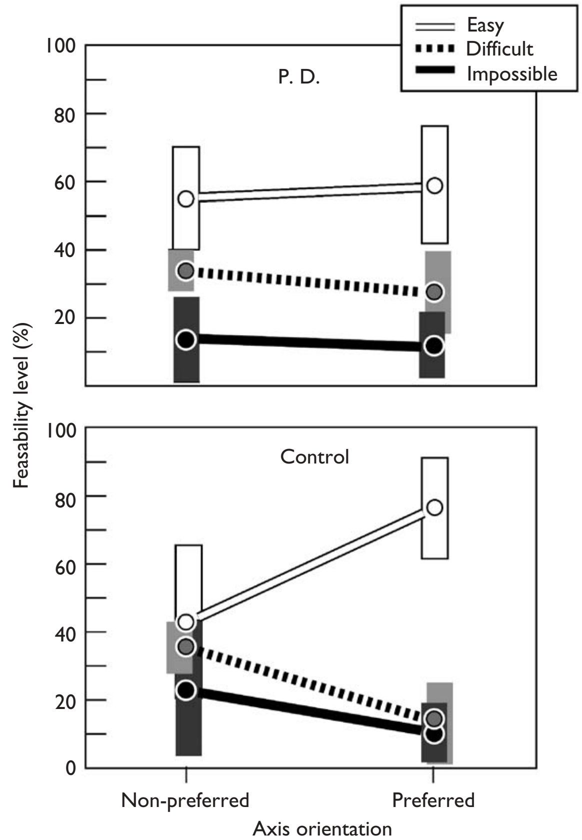

Fig. 2. The performance of control subjects in judging whether a particular grasp is easy or difficult shows that there is a good relationship between preferred OA in real and simulated movements. In contrast, Parkinson's disease subjects show no such relationship; all movements in all positions are judged equally feasible.

It had already been suggested that individuals with Parkinson's disease have a visuospatial deficit which reflects problems in mental rotation [11]. To determine the extent to which the deficit in motor imagery we observed in is modality specific, the subjects in this study participated in a classic experiment [12] and were instructed to judge the orientation of canonical and flipped letters under varying angles of rotation. It is already known that the identification of rotated letters in the frontal plan and flip path do not require the involvement of motor structures [13].

Individuals with Parkinson's disease are able to perform grasping movements without problems in the preferred orientations. They are also able to mentally rotate letters in a frontal plan and to also flip them. This is in direct contrast with their impairment in simulating grasping, either in preferred or non-preferred orientations.

Until now, studies investigating motor rotation and visual rotation have generally used abstract 3D shapes and pictures of hands. In these studies, a visual rotation of both abstract stimuli and hands is required for correct identification before a response comparison with the resting hand [14] or with the reference object [15] orientation is given. In addition, in experiments on the influence of motor rotation on visual rotation, subjects are required to effect a visual rotation of the stimulus for correct identification or judgment during execution of a movement [16]. In this perspective, teasing out the visual rotation component from the motor component in motor imagery is difficult and may lead one to conclude that the two exert a mutual influence. To determine whether a grasp is feasible or not in the present OA task, there is no requirement for such a visual rotation; what is required is simply the simulation of the grasp movement. The simulation of OA movements allows us to isolate the modality-specific nature of motor imagery.

CONCLUSION

Individuals with Parkinson's disease are impaired in the mental representation of a grasp orientation but are still capable of normally executing this movement, suggesting that the coordination processes for execution are separate from those for motor imagery. This constitutes the first lesion observation congruent with the anatomical and functional dichotomy between real and simulated movements seen in experimental studies.

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