Simulated Precision Grasping in Parkinson's Disease

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Summary

Subcortical lesions have been simultaneously implicated in both real and simulated movement deficits, suggesting that as with frontal lesions, self action representation and programmation are the same process (7). We have analyzed the simulated precision grasping in subjects with idiopathic bilateral PD compared to a healthy control group. Results showed that individuals with PD are impaired in the mental representation of a grasp orientation but are still capable of normally executing this movement. These observations reveal that programmation and execution of movements is spared and that motor representation is selectively impaired. Thus, programmation of real acts and representation of motor action are distinct processes.

Introduction

It is well known that there exists an intimate functional correspondence between movement execution and the mental simulation of that movement. Areas which are activated during execution are the same that that are activated during simulation as for example the frontal, parietal and subcortical regions. However, it has recently been shown that the picture is much more complex and that there are specific subareas which are differentially activated when subjects are asked to execute or mentally represent a particular movement. In SMA, for example, motor imagery but not execution involves pre-SMA. Also, patterns of differential activation in frontal cortex suggest that areas involved in execution are involved to a different degree in representation (12). It is well known that one of the major cortical outputs of the basal ganglia is to the SMA (9). Several imaging studies have shown preferential activation of this anterior loop during imagery whereas the posterior part of the putamen loop (sensorimotor cortex) is activated in movement execution (8). These two neural networks have been well documented in monkeys (1). These results suggest the existence of a mental mechanism capable of codifying the representation of movements independently of their actual execution and that this may be related to the motor task programming. Objective cues, such as pattern of responses or response time, can then be correlated with neural events observed during this mental activity. Whereas the term 'motor image' classically refers to explicit representation of an action (imagine yourself running or raising your hand), the same concept also includes other, implicit aspects of the same phenomenon. A theory of mental imagery of motor actions has to integrate temporal and kinesthetic properties of the image. One exemple of implicit motor imagery is provided by the opposition axis (OA), along which a force is applied during the grasp. The final finger position defines an OA through which opposite forces operate on the object (10). The orientation of this axis is constrained by the biomechanics of the arm, in such a way that certain orientations will be systematically avoided in order to prevent end-position discomfort or even failure of the grasp (13). Paulignan et al., (11) showed that the orientation axis for grasping cylindrical objects placed at different locations in the workspace was computed within an egocentric frame of reference. If the simulated movements follow the rules which apply to motor behavior, the prospective evaluation of the feasibility of grasping an object displayed at different orientations would require the subject to choose an adequate frame of reference in order to be able to complete the task. This choice should reflect the subject's feasibility judgements when making the response. Imagine that you are instructed to take a glass with marks on it where you are supposed to place your thumb and index finger. If the marks are placed in an appropriate position, the action is very easy, and the time to take the glass is short. If, on the contrary, the marks are placed in an odd position such that you have to rotate your arm in an awkward posture to grasp the glass, the action time increases. In a control experiment (3), subjects actually grasped a cylinder with different orientations and positions of the OA, measured by a 3D motion analyser. The effects of these parameters on response time followed the same trends as during simulated movements. Response times were found to be longer for the grasps judged to be more difficult due to the orientation and position of the opposition axis. The simulated grasp orientations outside the 45Ú-90Ú range were considered uneasy, and the preferred orientation of OA during executed mouvements was within this same range. The interpretation we gave to this result is that an action has to be simulated if it can be performed. We suggest that this simulation process is made at a level where the contingencies of the action, like the biomechanics of the arm, are represented. The arm is mentally "rotated" in the appropriate posture before the grasping movement is executed, or before the feasibility response is given. Also, impairments in the execution of movement generally accompany impairments in motor imagery. However, studies with PD subjects do not support such a functional dichotomy i.e., a problem with movement execution is also a motor imagery problem (2), suggesting that until now the functional and anatomical dichotomy between real and imaginary movements was not revealed in the subcortical lesion model. Here we show that individuals with PD are impaired in the mental represenation of a grasp orientation but are still capable of normally executing this movement.

Materials and Methods

Eight right-handed individuals with idiopathic bilateral PD (four women and four men; mean age = 59 ± 4.49 yr; all at Stage III on Hoehn and Yahr Scale; assessed during the on state; medication was 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 yr; with no detected neurological disorder) were instructed to judge whether a grasp was easy or difficult to perform while imagining a precision grip formed by the two fingers and, in another condition, to spontaneously execute actual grasping movements. The subjects were seated in front of a 15" monitor lying flat with the screen perpendicular to the body axis and at a distance of 45 cm under the orbitomeatal line. The experiment started with a preliminary run for clarifying the instructions: an opaque cylindrical container filled with water (5 cm high, 3 cm in diameter, 30 gm weight) was placed at the center of the monitor screen at a distance of 50 cm from the body plane (Figure 1). 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. 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 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 [see (3) (4) for a comparative precision assessment with 3D procedures]. 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. For each trial, a central 500 ms fixation point was followed by an image of the upper surface of the

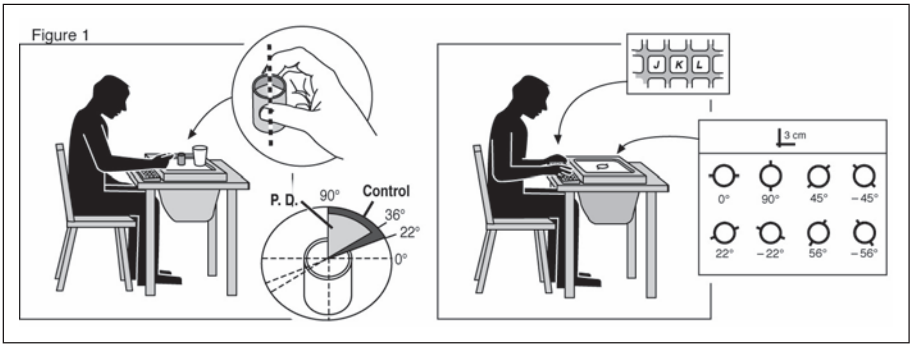

Figure 1: In the execution of real movements, the range of preferred OA was 22-90° and 36-90° for control and PD subjects, respectively. In the simulated movement condition, the subjects judged whether it would be easy, difficult or impossible to grasp and empty the cylinder with the fingers placed on the contact points, by pressing a keyboard key with their right hand.

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 made. 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. 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.

Results

The mean orientation of the OA in executed movements was 58.9Ú (±12.6) for PD subjects with preferred orientations ranging from 36Ú to 90Ú, and 59.2Ú (±15.3) for control participants with preferred orientations ranging from 22Ú to 90Ú. The preferred orientation was thus equivalent for both groups ($F(4, 56) = 0.93$, $p > 0.3$). In the simulated movement condition, the control subjects all judged grasps ouside of their preferred range of orientation as difficult, and as easy when it was within this range. Analysis of variance showed a main effect of the orientation on the feasibility level in control subjects [$F_{(2,14)}$=15.43; p<0.0003]. They considered the grasp “easy” in 78% of cases when the axis passed through the preferred angles, and in 42% when it did not. Conversely they rated the grasp “difficult” in 36% of cases when the axis did not pass through the preferred angles and in 12% when it did. The proportion of “impossible” ratings was 10% for an axis into the preferred zone but jumped to 22% in the no preferred zone. In contrast, individuals with PD judged all orientations as equally easy or difficult [$F_{(2,14)}$=0.47; p<0.6370]. They considered the grasp “easy” in 59% when the axis passed through the preferred angles and in 55% when it did not. In the same way they rated the grasp “difficult” in 33% of cases when the axis passed through the no preferred angles, in 29% when it passed through the preferred angles. The proportion of “impossible” ratings was the same (12%) in the two zones (Figure 2). 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 ms ± 425 ms for PD and 1658 ms ± 458 for control participants.

Conclusions

Individuals with PD judged all orientations as equally easy or difficult. Resolving the feasibility of grasp with an imaginary OA does not require a visual rotation of the stimulus. What is required, however, is simulating the grasp itself. It could be that the hypokinesia commonly seen in PD 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. This suggests that the geometry of the arm is not adequately represented in

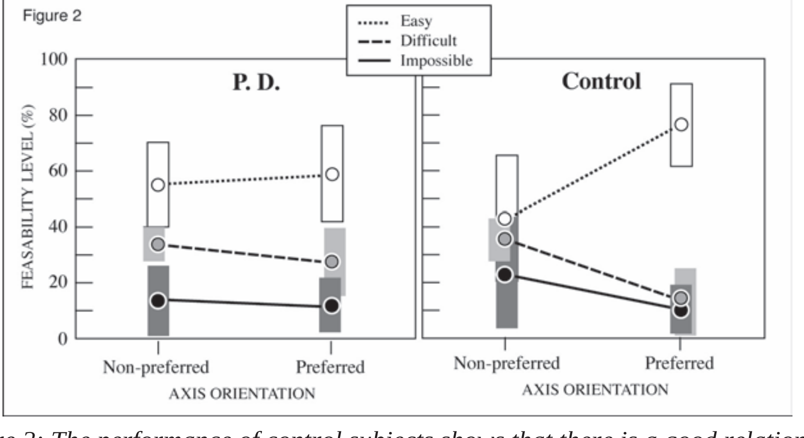

Figure 2: The performance of control subjects shows that there is a good relationship between preferred OA in real and simulated movements. In contrast, PD subjects show no such relationship; all movements in all positions are judged equally feasible.

PD. We suggest two possible interpretations: a) Programmation for motor action is a specific modality, one for real and one for simulated actions, and pre-SMA lesions affect programmation of motor representation in PD; b) Programmation for motor action is not a specific modality and is shared by both real and simulated movements — as there exists a functional co-variation between parietal cortex and SMA, L-Dopa modulated in PD (5). This modulation is accompanied by clinical changes. It remains to be determined whether the impairment in the representation of motor action precedes the movement disorder.

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