Neuropsychologia 47 (2009) 835–842

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Visuomotor priming effects in Parkinson's disease patients depend on the match between the observed and the executed action

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ARTICLE INFO

Article history:
Received 4 July 2008
Received in revised form
24 November 2008
Accepted 12 December 2008
Available online 24 December 2008

Keywords:
Parkinson's disease
Action observation system
Basal ganglia
Visuomotor priming

ABSTRACT

Evidence exists that action observation activates the same cortical motor areas that are involved in the performance of the observed actions. An untested idea is whether subcortical structures such as the basal ganglia play a role in the coding of other people's actions. This study used kinematics to examine how Parkinson's disease patients react to the observation of an action which they were subsequently requested to perform. In each trial a model and an observer, which could be either a Parkinsonian patient or a neurologically healthy participant, were seated facing each other. The model was requested to grasp a stimulus (action condition), to perform a kicking action towards the stimulus (control-action condition), and to not perform any action (control condition). The task for the observer was always to grasp the stimulus after having watched the model performing her task. Results show that Parkinson's disease patients did show facilitation effects only when the model was a Parkinsonian patient. Whereas, neurologically healthy participants' movements were facilitated following the observation of either the Parkinsonian and the healthy model grasping the object. No facilitation effects were found for both the control and the control-action conditions. The fact that normal visuomotor priming takes place in PD patients when the observed action matches with what they can perform suggests that basal ganglia might not be necessary for it. However, damage to the basal ganglia might become relevant when such a match does not occur. In such circumstances, a damage to these structures might prevent the deployment of additional activity which might be necessary to influence cortical functions related to the representations of observed actions.

1. Introduction

There is increasing experimental evidence that motor areas are recruited not only when actions are actually executed, but also when they are mentally rehearsed or simply observed (for a review see Jeannerod, 2001). The neural substrate for such function is the action observation system, a network of areas which chiefly includes the inferior parietal lobule and the ventral premotor cortex (for a review see Buccino, Binkofski, & Riggio, 2004). Electrophysiological studies (Cochin, Barthelemy, Roux, & Martineau, 1999; Hari et al., 1998) showed that when a human subject observes hand actions there is an activation of the motor cortex similar, although weaker, to that occurring during active movements. In agreement with these findings, transcranial magnetic stimulation (TMS) experiments showed that motor-evoked potentials recorded from hand muscles increase during the observation of hand movements (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Strafella & Paus, 2000). Similarly, action observation brain imaging studies have showed that during observation of hand/arm actions there is an activation of the ventral premotor cortex together with inferior parietal activity (Buccino et al., 2001; Decety & Grezes, 1999; Grafton, Arbib, Fadiga, & Rizzolatti, 1996; Grèzes, Armony, Rowe, & Passingham, 2003;Pierno et al., 2006; Rizzolatti et al., 1996; Tai, Scherfler, Brooks, Sawamoto, & Castiello, 2004). Altogether these findings suggest that when individuals observe an action, an internal replica of that action is automatically generated and their motor, parietal and premotor cortices activated as if the participants were indeed interacting with the objects.

At the behavioural level, visuomotor priming takes the form of automatic imitation (Craighero, Fadiga, Umiltà, & Rizzolatti, 1996; Heyes, Bird, Johnson, & Haggard, 2005): in the absence of instruction to imitate, movement observation facilitates execution of the observed movement. For instance, by using kinematics it has been demonstrated a reduction in movement duration, an increase in the amplitude of peak velocity and an anticipation of the time to peak velocity when reach-to-grasp movements were performed

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doi:10.1016/j.neuropsychologia.2008.12.016

following the observation of a model performing a similar action (Castiello, 2003; Castiello, Lusher, Mari, Edwards, & Humphreys, 2002; Edwards, Humphreys, & Castiello, 2003). Conversely such facilitation effects were not evident in neurological participants with a dysfunction at the level of cortical areas which are part of the action observation system (Becchio, Pierno, Mari, Lusher, & Castiello, 2007; Pierno, Mari, Lusher, & Castiello, 2008).

An aspect which so far has received little attention is whether subcortical structures such as the basal ganglia react to the observation of arm/hand actions. To date, only a recent neuroimaging study in humans has revealed basal ganglia activations following action observation (Williams, Whiten, Waiter, Pechey, & Perrett, 2007). Further, the neural circuits that link the basal ganglia with the cerebral cortex are critically involved in the generation and control of voluntary movement. For instance, the pallidal output of the basal ganglia in primates has been found to be directed towards the ventrolateral thalamus, which selectively innervates the hand representation in the primary motor cortex (Holsapple, Preston, & Strick, 1991; Nambu, Yoshida, & Jinnai, 1988). Specifically, connections between the basal ganglia and other cortical areas chiefly involved in the execution and observation of grasping actions, such as the ventral premotor area and the anterior sector of the intraparietal sulcus within the inferior parietal lobule, have been uncovered (Clower, Dum, & Strick, 2002, 2005). Therefore, the basal ganglia may have an even broader sphere of influence than previously thought. An influence which may extend to the processes underlying action observation.

Here, to specifically test the role of basal ganglia in action observation we administer a visuomotor priming paradigm to Parkinson's disease (PD) patients. We designed a kinematic study in which neurologically healthy and PD participants observed either a PD or a neurologically healthy model grasping an object. Subsequently, either PD or neurologically healthy participants were requested to perform a grasping action towards the same object. There were two control conditions. For one, the model performed a kicking rather than a grasping action with the right foot. For another, the model was standing behind the object without performing a grasping action. We reasoned that if the basal ganglia play some role in action observation, then a damage to this neural structure as occurs in PD patients may reveal a differential pattern for the kind of facilitation effects as those previously described in healthy participants.

Our core finding was that whereas the action of neurologically healthy participants was facilitated following the observation of either the Parkinsonian and the healthy model performing the reach-to-grasp movement, PD patients did show facilitation only when the action was performed by the Parkinsonian model. For both groups no facilitation effects were detected when the two control conditions were administered.

2. Methods

2.1. Participants

Two groups of participants attended one experimental session of ~1 h duration. The first group ($N = 16$; mean age 53 years) were Parkinson's disease patients (see Table 1). The average duration of PD was 1.75 years and the mean age on onset was 51 years. All PD patients were treated with dopaminergic drugs. A board certified neurologist assessed Parkinsonian status using two different measures: Hoehn and Yahr (1967) severity scale and the Unified Parkinson's Disease Rating Scale (UPDRS; Fahn & Elton, 1987). Each PD patient was tested after having taken medication. Objective evidence that the patients were having optimum response to their levodopa was given by the administration of the UPDRS before the experimental session. None of the participants showed motor complications due to therapy that interfered with the task. The second group ($N = 16$; mean age 52 years) reported no neurological or skeletomotor dysfunctions. Two further participants, a PD patient (male, age 52 years) and a neurologically healthy participant (male, age 52 years) with the same characteristics as those included in the experimental groups acted as models. The Mini-Mental State Examination (MMSE) was used to provide an index of the current global cognitive state (Folstein, Folstein, & McHugh, 1975). Scores of the Parkinson's disease patients ranged from 29 to 30; all neurologically healthy participants showed a score of 30. A non-parametric comparison (Mann–Whitney U test) between Parkinson's disease and healthy participants did not reveal significant differences. There was no statistical difference in the mean age of Parkinson's disease and healthy participants (mean 53 and 52 years, respectively; $P > 0.05$). With visual acuity testing, Parkinson's disease patients scored, on average, 18 out of 20 and neurologically healthy participants 20 out of 20. All participants showed right-handed dominance (Edinburgh Inventory; Oldfield, 1971) and were naive as to the experimental design and the purpose of the experiment. This study was approved by the ethics committee at our institution and has been performed in accordance with the Declaration of Helsinki. All participants gave written informed consent after the procedure had been fully explained.

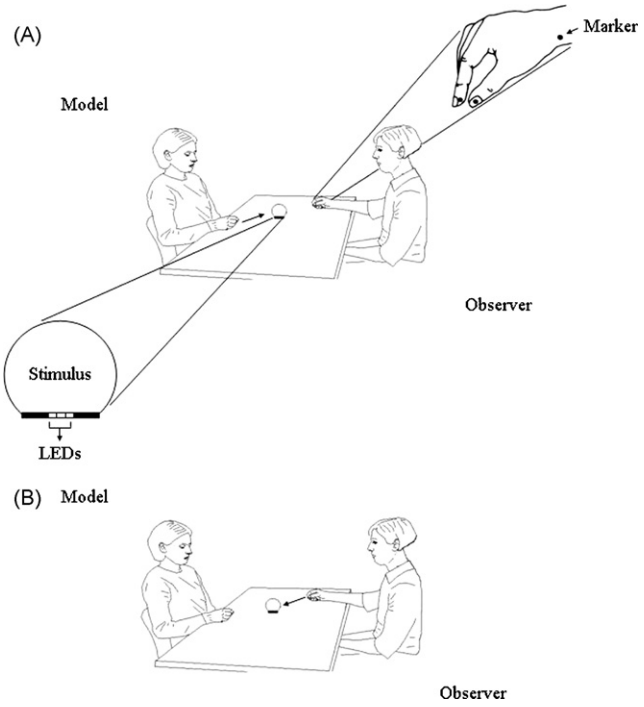

Fig. 1. Graphical representation of the experimental set-up. A schematic representation of the model reaching towards and grasping the object while being watched by the observer. The two call-outs represent the position of the markers on the participant's hand and the apparatus for the illumination of the stimulus (A). A schematic representation of the observer performing a reach-to-grasp movement after having observed the model acting upon the stimulus (B). Filled arrows indicate either the model or the observer reaching towards the stimulus (A and B, respectively).

2.2. Stimulus

The stimulus was a translucent plastic sphere (diameter: 5 cm) positioned at a distance of 30 cm from the hand starting position along the participants' mid-sagittal plane (Fig. 1A). Three LEDs were located inside the stimulus (Fig. 1A). The LEDs were connected to three metallic contacts on the exterior of the spheres. These contacts met with three other metallic plates (one to the right, one to the center, one to the left) that were fixed to the table and connected to a PC.

2.3. Experimental conditions and procedure

In each trial two participants, a model and an observer, were seated facing each other at a table (see Fig. 1). Artificial lighting within the room allowed the model and the observer to see each other and the experimental set-up clearly. The black working surface measured 90 cm × 90 cm and was smooth and homogeneous. Prior to each trial both the model and the observer put their right hand on their respective starting positions (diameter: 5 cm) positioned 20 cm in front of their mid-line. Three conditions were administered:

2.3.1. 'Action' condition

In this condition the stimulus was illuminated, indicating to either the neurologically healthy or the Parkinsonian model to reach towards and grasp the stimulus. The model was instructed to replace it in the same location. Then the stimulus was re-illuminated and the observer, either a neurologically healthy or a Parkinsonian, performed a similar action as the model. For both the model and the observer the

Table 1
Characteristics of the Parkinson's disease (PD) patients.

PD patient	Age (years)	Sex	Years since diagnosis	Stage of the disease	Most affected upper limb	Motor UPDRS (on medication)	MMSE score	Dopaminergic medication	Clinical signs						
									T	R	B	A	P	O	F
1	52	M	1	I	L	2	30	0–0–0	–	+	+	+	–	–	–
2	55	F	2	II	R	8	30	1–1–1*	–	–	+	+	–	–	–
3	51	F	1	I	R	6	29	0–0–0	–	+	R	–	–	–	–
4	52	M	1	I	L	5	30	1–0–1*	–	+	+	+	–	–	–
5	56	M	2	I	L	3	30	1–1–1*	L	+	+	+	–	–	–
6	50	M	3	II	L	10	29	1.5–1.5.–1.5*	–	+	R	+	–	–	–
7	53	F	1	I	L	4	28	0–0–0	–	+	+	–	–	–	–
8	55	M	1	I	R	8	30	0–0–0	–	–	+	–	–	–	–
9	55	F	1	II	R	5	30	1–0–1	–	–	R	L	–	–	–
10	58	F	2	II	L	9	30	1–1–1	–	–	+	+	–	–	–
11	52	F	2	II	L	12	29	0.5–0.5–0.5†	L	L	+	+	–	–	–
12	51	M	1	I	L	2	29	0–0–0	–	–	R	–	–	–	–
13	51	F	3	II	R	10	29	1–0–1	–	–	+	+	–	–	–
14	56	M	3	II	R	12	30	0.5–0.5–0.5†	–	+	R	–	–	–	–
15	50	M	2	I	L	3	30	0–0–0	L	+	+	–	–	–	–
16	53	F	2	I	L	6	30	1–0–1	–	–	+	R	–	–	–

Note: Medication: number of tablets morning–midday–evening (dopaminergic medication, *50 mg; †125 mg). Clinical signs: signs when medicated, according to examination at time of testing and self-report: T = resting and/or postural tremor, R = rigidity, B = bradykinesia, A = akinesia, P = problems with static and dynamic upright posture, O = on–off phenomenon, F = freezing; '+' = both sides affected; '–' = neither side noticeably affected; 'L' = left side mainly affected; 'R' = right side mainly affected. MMSE = Mini-Mental State Examination (Folstein et al., 1975). Stage of the disease was determined on the basis of the Hoehn & Yahr's scale.

stimulus remained illuminated throughout the duration of the trial up to the time it was lifted from the working surface. The time from the end of the model's movement and the beginning of observer's movement varied between 800 and 1000 ms. In all trials the model was present when the observer reached for the target. This condition enabled us to quantitatively measure action priming effects, specifically whether the observer's action was facilitated by the previously observed action of the model.

2.3.2. 'Control-action' condition

This condition was similar in all respect to the 'action' condition except that the model was requested to perform a different action with a different effector, i.e., kick the stimulus used for the previous condition with the right foot. The stimulus remained illuminated until the 'kick' determined an interruption between the contacts underneath the stimulus and those placed on the working surface. In order to allow the model to kick the stimulus comfortably the working surface was lowered to 60 cm from the original 80 cm and the model was requested to climb a two steps wooden stair. The length and the width of the steps (60 cm × 45 cm, respectively) allowed for a safe climbing action. Two experimenters, one to the right and one to the left of the stall were ready to help the model if needed (though for no trials the experimenters' intervention was requested). As for the 'action' condition the observer was requested to grasp the stimulus following the observation of the kicking action. The adjustable chair upon which the observer was seated was lowered down as to allow for a comfortable reach-to-grasp movement. This condition was designed to control for motor priming effects that might occur in the absence of observed and performed actions matching.

2.3.3. 'Control' condition

This condition was similar as for the 'action' condition except that the stimulus remained illuminated for 2000 ms and the model did not perform any action. This condition enabled us to quantitatively measure a no-primed baseline reach-to-grasp movement and to ascertain whether the mere presence of another person determines an 'audience' facilitation effect.

In summary, trials for either the neurologically healthy or the Parkinsonian model were of three types: (i) 'action' trials in which the model reached towards and grasped the stimulus; (ii) 'control-action' trials in which the model performed a kicking action; (iii) 'control' trials, in which the model was standing behind the object without performing any action. The observer, either a neurologically healthy or a Parkinsonian participant, always performed only one type of task, i.e., reach towards and grasp the stimulus immediately after the model's action (i.e., 'action' and 'control-action' condition) or when the stimulus was re-illuminated but no model's action occurred (i.e., 'control' condition). The model and the observer were requested to move at a leisurely pace. No instructions whatsoever in terms of imitation were given to the participants. The three conditions were administered in counterbalanced blocks. We adopted this strategy to avoid intermingling the 'action', the 'control-action' and the 'control' conditions within the same block. That is, we wanted to avoid the possibility of priming effects for the 'control' and the 'control-action' conditions would emerge due to re-enacting the 'action' trials. Participants performed 20 trials per condition with five trials for each observer/model combination.

2.4. Kinematic recordings

The ELITE motion analysis system (Bioengineering Technology & Systems [B T S]) was used to record hand movements. Reflective passive markers (0.2 cm diameter) were attached on the (a) wrist-radial aspect of the distal styloid process of the radius; (b) index finger-radial side of the nail; (c) thumb-ulnar side of the nail of the participants acting either as a model or an observer. The wrist marker was used to measure the reaching component of the action. The markers positioned on the index finger and the thumb were used to measure the grasp component of the action. When the model performed the kicking action a marker was located on the ankle of his right foot. Four infrared cameras (sampling rate 100 Hz) placed 120 cm away from each of the four corners of the table captured the movement of the markers in 3D space. Coordinates of the markers were reconstructed with an accuracy of 1/3000 over the field of view. The standard deviation of the reconstruction error was 1/3000 for the vertical (Y) axis and 1.4/30,000 for the two horizontal (X and Z) axes.

2.5. Data processing

An in-house software package was used to analyse the data and provide a three-dimensional reconstruction of the marker positions as a function of time. The data were then filtered using a finite impulse response (FIR) linear filter (transition band = 1 Hz; sharpening variable = 2; cut-off frequency = 10 Hz). Movement initiation was determined when a starting switch embedded within the working surface, upon which the hand (or the foot when the model performed the 'control-action' condition) was resting, was released. For the reach-to-grasp action, movement end was defined as the time when the fingers closed on the target and there were no further changes in the distance between the index finger and thumb. For the kicking action performed by the model movement end was determined at the time the stimulus was kicked and therefore the electronic contact between the stimulus and the working surface was lost. Movement duration was the time occurring from the beginning to the end of movement. Initiation time was taken as the time from stimulus illumination and the release of the starting switch. On the basis of previous action priming reports (Edwards et al., 2003; Pierno et al., 2008) the dependent variables specifically relevant to test our hypothesis were movement duration and the time and the amplitude of peak velocity of the wrist. These variables are particularly well-suited to test our experimental hypothesis given that they show facilitation effects in terms of movement speed. This is particularly relevant because we are dealing with a population (PD patients) in which the main deficits when performing a reach-to-grasp movement reflect on movement slowness (bradykinesia), whereas kinematic paramerization remains largely unaltered with respect to neurologically healthy participants (Castiello, Stelmach, & Lieberman, 1993; Tresilian, Stelmach, & Adler, 1997). In this respect, to consider for the well-known slowing of movements in PD patients, absolute temporal values obtained from both participant groups were expressed as a percentage of movement duration (e.g., the absolute time at which peak velocity occurred was expressed as a percentage of movement duration). Finally because PD patients have problems in the time it takes to initiate a movement (akinesia), initiation time was also analysed.

2.6. Data analysis

Preliminary analyses were conducted in order to assess movement duration, initiation time and the kinematics of the reach-to-grasp and the kicking movement for

the PD and the neurologically healthy model using *t*-tests. For the reach-to-grasp movement these analyses considered key kinematic landmarks such as the time and amplitude of peak velocity (Jeannerod, 1984). For the kicking action similar measures as for the reaching component of the reach-to-grasp movement were analysed. Such baseline assessment was based on ten reach-to-grasp and ten kicking movements towards the stimulus. Such assessment took place in a separate session from the experimental sessions. Then for each dependent variable of interest (i.e., initiation time, movement duration, the time and amplitude to peak velocity) an ANOVA with group (PD, neurologically healthy) as the between-subjects factor and type of condition ('action', 'control-action', 'control') and type of model (PD, neurologically healthy) as the within-subjects factors was conducted. In these analyses only the reach-to-grasp movements performed by the observers were considered. Post hoc comparisons were conducted using simple effects and Bonferroni's correction was applied (alpha level = 0.05).

3. Results

3.1. Models' movement

The comparison between the reach-to-grasp movement performed by the neurologically healthy and the PD model revealed the following differences. Initiation time and movement duration were longer for the PD than for the neurologically healthy model (initiation time: 683 ± 76 vs 421 ± 38 ms, $t(9) = 8.332$, $d = 0.118$, $P < 0.05$; movement duration: 1851 ± 182 vs 1045 ± 110 ms, $t(9) = 7.236$, $d = 0.114$, $P < 0.05$). Further, the amplitude of maximum peak velocity was lower for the PD than for the healthy model (488 ± 58 vs 843 ± 81 mm/s, $t(9) = 10.432$, $d = 0.121$, $P < 0.05$). The comparison between the kicking movement performed by the neurologically healthy and the PD model revealed the following differences. Initiation time and movement duration were longer for the PD than for the neurologically healthy model (initiation time: 712 ± 98 vs 472 ± 51 ms, $t(9) = 10.332$, $d = 0.118$, $P < 0.05$; movement duration: 2017 ± 265 vs 995 ± 134 ms, $t(9) = 8.541$, $d = 0.118$, $P < 0.05$). Further, the amplitude of maximum peak velocity was lower for the PD than for the healthy model (451 ± 43 vs 1021 ± 122 mm/s, $t(9) = 14.312$, $d = 0.120$, $P < 0.05$). The time at which peak velocity was reached did not differ between the two models. These findings indicate that the PD model shows both akinesia and bradykinesia which limit the speed of movement initiation and execution, respectively. For the PD model the basic pattern of reach-to-grasp performance (e.g., relative timing invariance) was preserved (at least for the dependent measures considered here) and this is basically what has been found in previous prehension tasks (e.g., Castiello et al., 1993; Tresilian et al., 1997). Nevertheless the slowness of movement provided the observers with a rather different perception of the same action. The results for the kicking action cannot be compared with previous findings given that to our knowledge no studies have compared the kicking action of PD and neurologically healthy participants.

3.2. Observers' movement

The interaction group by type of condition by type of model was significant for initiation time [$F(1,15) = 38.21$, $P < 0.0001$], movement duration [$F(1,15) = 43.21$, $P < 0.0001$], the amplitude of peak velocity [$F(1,15) = 32.64$, $P < 0.0001$] and time to peak velocity [$F(1,15) = 28.39$, $P < 0.0001$]. As shown in Fig. 2, for the neurologically healthy participants movement duration was shorter and the time at which peak velocity occurred was anticipated for the 'action' than for the 'control' and the 'control-action' conditions. This occurred when either the PD (Fig. 2A-B; white bars) or the neurologically healthy (Fig. 2A-B; black bars) acted as models. For these two dependent measures no differences between the 'control' and the 'control-action' conditions were found irrespective of the type of model (*P*s > 0.05; Fig. 2A-B). Further, when considering the 'action' condition the amplitude of peak velocity increased for movements performed following the observation of the reach-to-grasp movement performed by either the healthy or the PD model (*P*s < 0.05; Fig. 3) as compared to the action performed in the absence of action priming ('control' condition; Fig. 3). No differences were found between the 'control-action' and the 'control' condition. Finally no effect on the time to initiate the movement across experimental conditions and types of model were found (*P*s > 0.05).

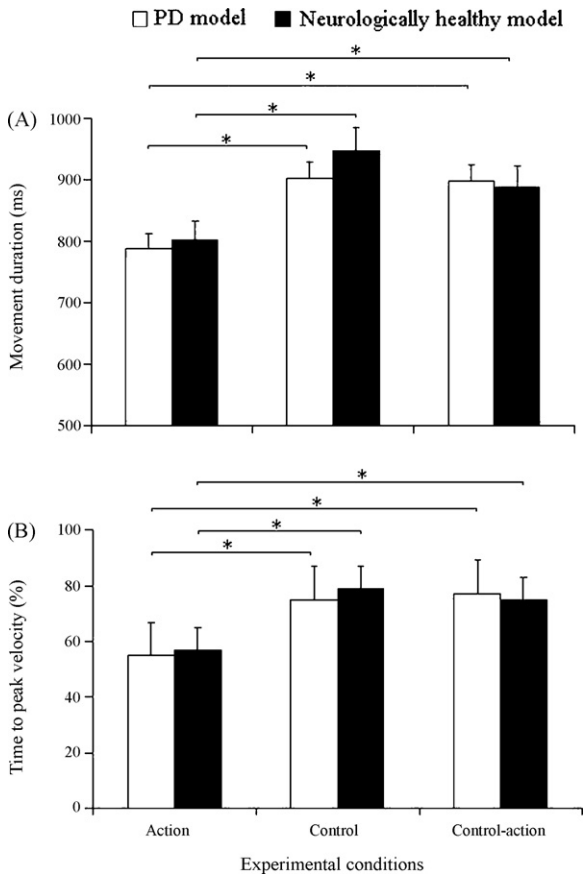

Fig. 2. Neurologically healthy participants. Graphical representation for average movement duration (A) and for the time to peak velocity (B), which was expressed as a percentage of movement duration, for the three experimental conditions. Bars represent the standard errors of the means. Asterisks indicate significant differences across conditions.

For the PD patients their action was facilitated only when they observed the PD model performing the reach-to-grasp action. In such circumstances initiation time was faster (*P*s < 0.05; Fig. 4), movement duration decreased (*P*s < 0.05; Fig. 5A) and the time of peak velocity was anticipated (*P*s < 0.05; Fig. 5B) for the 'action' than for the 'control' and the 'control-action' conditions. No differences for these measures were found when comparing them across the 'action', the 'control' and the 'control-action' conditions involving the neurologically healthy model. Further, facilitation effects during the 'action' condition were also evident on the amplitude of peak velocity. As shown in Fig. 6 the amplitude of peak velocity increased following the observation of the reach-to-grasp action performed by the PD model than following the observation of the action performed by the neurologically healthy model or when no primer was present (*P*s < 0.05). As for the neurologically healthy participants such increase was not evident for the 'control-action' condition.

Altogether these findings suggest that for healthy participants action priming occurs only when the observed action and the action they are subsequently requested to perform match. This does not occur when the observed and the executed action do not correspond. Crucially, the PD patients appeared to be unable to gain any advantage from the observation of a reach-to-grasp movement per-

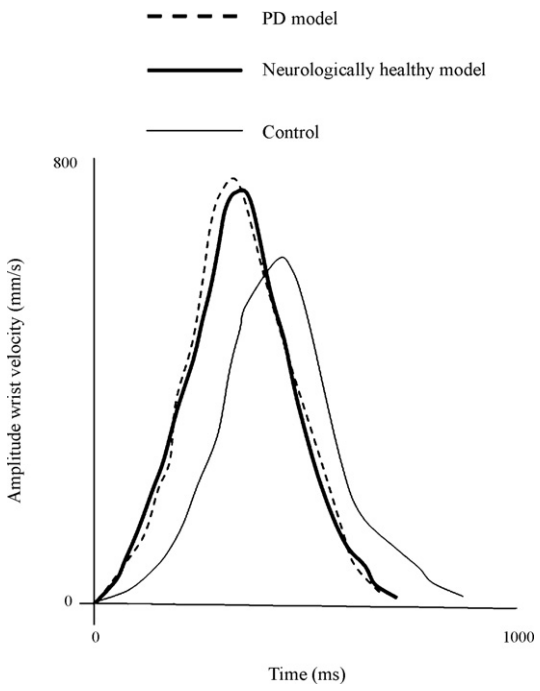

Fig. 3. Neurologically healthy participants. Mean velocity profiles (20 trials) for a representative neurologically healthy participant (n. 8) for movements performed under the 'action' condition following the observation of the action executed by either the PD or the neurologically healthy model. The velocity profile for the 'control' condition in which the reach-to-grasp movements was performed in the presence of the static neurologically healthy model is also represented.

formed by the healthy model, but their action was facilitated only by the observation of an action performed by the PD model.

4. Discussion

The present study was aimed at determining a possible involvement of the basal ganglia in action observation and, if any, how this could be linked with motor behaviour. Our results indicate that neurologically healthy participants were facilitated in their actions if they previously observed the same action performed either by a PD or a neurologically healthy model. In contrast, PD patients were not facilitated when the observed action was performed by the healthy model, but they showed facilitation effects when the model was a PD subject.

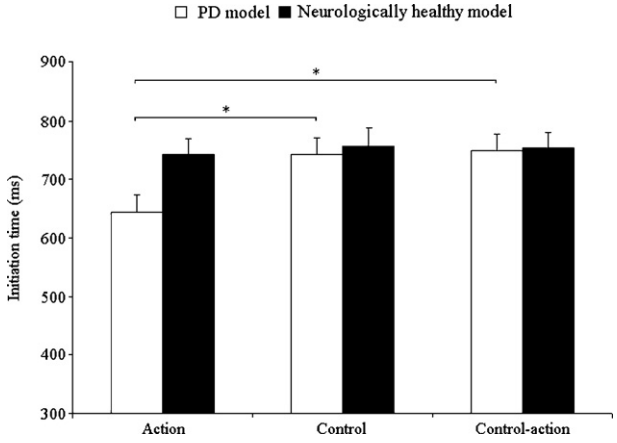

Fig. 4. Parkinsons' disease patients. Graphical representation of average initiation time with respect to the three experimental conditions. Bars represent the standard errors of the means. Asterisks indicate significant differences across conditions.

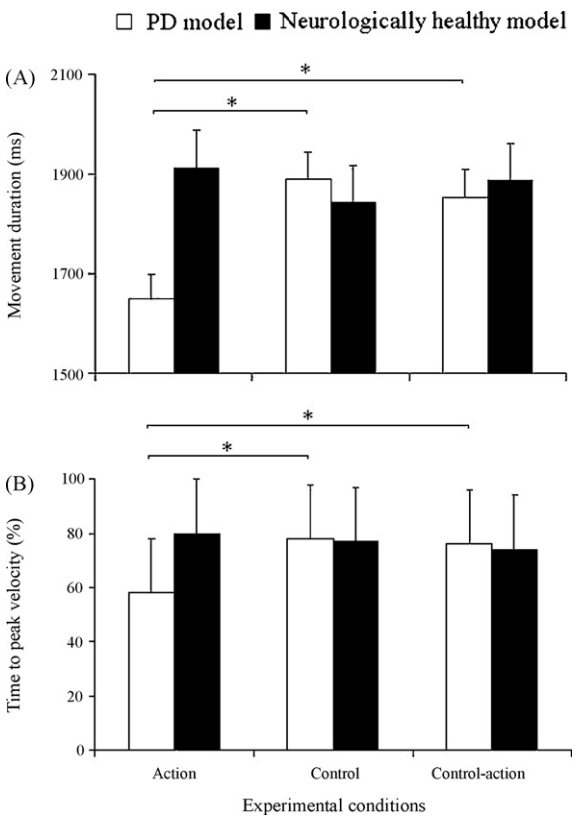

Fig. 5. Parkinson's disease patients. Graphical representation for average movement duration (A) and time to peak velocity expressed as a percentage of movement duration (B) for the three experimental conditions. Bars represent the standard errors of the means. Asterisks indicate significant differences across conditions.

We contend that PD patients could not re-enact the reach-to-grasp movement performed by the neurologically healthy model because it was an action that they could no longer perform (at least in terms of speed). In this perspective the present findings

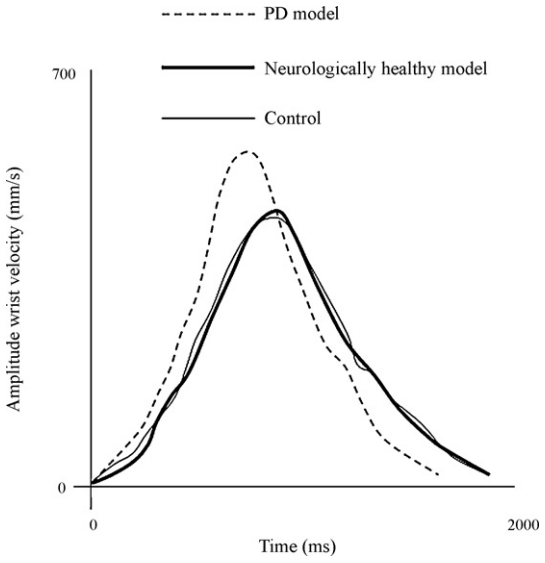

Fig. 6. Parkinson's disease patients. Mean velocity profile (20 trials) for a representative PD patient (n. 6) for movements performed under the 'action' condition following the observation of the action executed by either the PD or the neurologically healthy model. The velocity profile for the 'control' condition in which the reach-to-grasp movements was performed in the presence of the static neurologically healthy model is also represented.

may add to the characterization of the specific features of the action observation system. For instance, it is well known that action observation recruits areas involved in this system as a function of motor experience. For example, Buccino et al. (2004) showed that the action observation system is active during the observation of actions (e.g., biting) which are part of the motor repertoire of the observer, but not when the observed actions (e.g., barking) are not motorically represented in the observer's brain. Similarly, Calvo-Merino, Glaser, Grèzes, Passingham, and Haggard (2005) found that capoeira dancers showed stronger activation in the premotor and parietal areas plus in the superior temporal sulcus region, when observing capoeira movements than when observing classical ballet movements. Conversely, classical ballet dancers showed a stronger activation of the same areas during the observation of classical ballet movements than during the observation of capoeira movements. As another example from neuroimaging, it has been demonstrated that the action perception/execution system is not activated by the viewing of a robotic movements (Tai et al., 2004). Similarly, in behavioural terms, actions performed by robotic agents do not prime observers' action as the observation of a human action does (Castiello, 2003; Castiello et al., 2002; Heyes et al., 2005; Kilner, Paulignan, & Blakemore, 2003).

The present findings add to this literature suggesting that action timing as well as movement exemplars might have the capacity to modulate the action observation system. When a motor dysfunction occurs, the system adopts new ways of interacting with the environment replacing those that can no longer be performed. In the present study PD patients were asked to observe reach-to-grasp movement of which they had motor competence and experience, but that they performed at a much slower pace than before the illness occurred. Therefore, at least for the PD patients tested here, it might be advanced that they cannot take any advantage from the action performed by the neurologically healthy model because it cannot be matched in timing terms. In this respect, it has been recently reported that the cortico-motor facilitation elicited by the observation of an action performed by a healthy model is impaired in PD patients compared to age matched controls (Tremblay, Leonard, & Tremblay, 2008). Our results add to this literature by demonstrating that this might depend on the level of congruency between the observed and the executed action. In other words, it is possible that cortico-motor facilitation would emerge only if the PD patient observes an action with a timing that she can reproduce. This idea is in line with the results obtained by Dominey, Decety, Broussolle, Chazot, & Jeannerod (1995) in a study in which hemi-Parkinson's patients were requested to perform a manual finger sequencing test in three main conditions: vision, no vision and motor imagery. It was found that hemi-Parkinson's patients mentally simulate movement more slowly with the affected rather than the unaffected hand, suggesting that they could not 'image' what they could no longer perform (Dominey et al., 1995). Altogether, these findings brought to the conclusion that basal ganglia are not only involved in the aspects related to movement execution, but also for maintaining the necessary internal state for representing an observed action. In other words, covert and overt actions might share similar neural underpinnings including subcortical structures. In this respect, recent neurophysiological evidence provides further support to this idea and a way for connecting the present results to this notion. Specifically, it has been revealed that considerable component of basal ganglia output is devoted to influencing the functional operations of the posterior parietal and the ventral premotor cortices (Akkal, Dum, & Strick, 2007; Clower et al., 2005; Dum & Strick, 1999; Hoover & Strick, 1993, 1999). In particular, this has been demonstrated for the anterior intraparietal and the ventral premotor areas, two areas which are thought to be nodes in the cortical network concerned with the performance and the observation of grasping patterns (Rizzolatti & Luppino, 2001). In this view the basal ganglia may play a role in setting frontal and parietal cortices not only for the execution of actions, but also for the internal simulation of observed behaviour, providing that the internal state of the simulated action is available (Gallese, 2005; Gallese & Goldman, 1998). This might also explain why neurologically healthy subjects did not show a selective visuomotor priming depending on the type of observed action. The fact that healthy subjects are able to perform both types of the observed action might signify that they can access and, therefore, re-enact theirs motor representations.

Before these conclusions can be fully accepted, however, one may argue that what is missing here is a condition in which the healthy model performs an action at a pace that a Parkinsonian patient can perform. If it is a matter of the speed at which the movement is performed then visuomotor priming should also be evident in PD patients following the observation of a healthy model moving slower. There were, however, two main reasons behind the choice for not including such condition. First, during the pilot phase of the study asking the healthy model to perform a slow movement brought to dramatic changes in action kinematics with respect to the movement he performed at a natural speed (in both absolute and relative terms). In this respect, note that although Parkinson's disease patients exhibit a bradikinetic type of movement, key kinematic landmarks usually occur at the same percentage of time as for neurologically healthy people (Castiello et al., 1993; Tresilian et al., 1997). An effect which was found here when comparing the kinematics for the PD with the kinematics for the healthy model. A second and interconnected reason is that independently from whether the healthy model performed the movement at a 'natural' or a 'slow' pace, initiation time was maintained similar. The fast start for the 'slow' movement caused a series of stops and adjustments during the beginning of the action which were not visible in the action performed by the PD model. Therefore, in light of these two reasons the nature of the visuomotor priming (if any) arising in PD patients following the observation of a 'slow' action performed by the healthy model would have been very difficult to assign. Two factors would have been difficult to disentangle: the overall slowness and the awkward kinematics which differed from the 'natural' kinematics exhibited by both the PD and the healthy model.

4.1. Implications for rehabilitation

Recently the observation of actions has been tested as a tool for neurorehabilitation. Specifically the ability of the neural system underlying action observation to re-enact stored motor representations has been utilized as a mean for rehabilitating motor control (action observation therapy; Ertelt et al., 2007; see also Buccino, Solodkin, & Small, 2006). Stroke patients with moderate, chronic motor deficit of the upper limb underwent an action observation therapy program consisting of the observation of daily actions with concomitant physical training of the observed actions. A significant improvement of motor functions in the course of the treatment has been found. Additionally, the effects of action observation therapy on the reorganization of the motor system have also been investigated by functional magnetic resonance imaging, using an independent sensorimotor task consisting of object manipulation (Ertelt et al., 2007). The direct comparison of neural activations between experimental and control groups after training with those elicited by the same task before training yielded a significant rise in activity in the bilateral ventral premotor cortex, bilateral superior temporal gyrus, the supplementary motor area and the contralateral supramarginal gyrus.

The results from the present study add further fuel to the idea that action observation may determine improvements in motor performance and extend this notion to Parkinson's disease. Our results provide pieces of evidence that action observation has a positive impact on motor functions in Parkinson's disease. In particular, it

seems to improve two specific motor deficits of the disease, the slowness in starting and performing actions, namely akinesia and bradykinesia, respectively. Further they suggest that motor timing plays a pivotal role for the revelation of facilitation effects (at least for PD patients). This hypothesis should be tested in further experimentation specifically tailored to test rehabilitation processes in this population. For instance a crucial manipulation would be to use as models either people experiencing the same motor dysfunction as the observer or neurologically healthy participants during training and evaluate by means of both neuropsychological and neuroimaging techniques potential differences. Nevertheless what observed here clearly supports the administration of action observation therapy also to PD patients, especially because it may have the potential to provide an additional tool to conventional physiotherapy.

5. Conclusion

There are two important findings in the present study. First, whereas previously the understanding of the action observation system was mainly restricted to a cortical network of areas including the motor, parietal and premotor areas here we show that subcortical structures such as the basal ganglia might play some role in such function. This adds an additional layer of complexity to this picture by demonstrating that the basal ganglia become important when the observed and the executed action do not match. This conclusion, however, should be taken with a certain degree of caution given that Parkinson's disease has whole brain effects and particularly effects on executive functions. Further research is needed to fully understand the specific role of the basal ganglia in action observation. Second, that the present action observation paradigm might be utilized in rehabilitation programs for Parkinson's disease combining action observation with practice of the observed actions. Specifically, the positive effect of the present paradigm is achieved by exposing the PD patients to actions performed by a model showing the same motor dysfunction. These paradoxical facilitation effects may signify that although a slow action is observed, re-enacting that action (re)establishes a proper level of readiness to start and execute the action. Possibly this occurs through the circuits linking the basal ganglia with relevant motor cortical areas. This is a novel aspect which may prove to be crucial for the rehabilitation of PD patients, but also for other neurological populations who exhibit movement disorders.

Acknowledgements

Our sincere thanks to the patients who participated in the study. The work was supported by a grant from the Italian Ministry of University and Research (MUR) to UC.

References

Akkal, D., Dum, R. P., & Strick, P. L. (2007). Supplementary motor area and presupplementary motor area: Targets of basal ganglia and cerebellar output. *Journal of Neuroscience*, *27*, 10659–10673.

Becchio, C., Pierno, A., Mari, M., Lusher, D., & Castiello, U. (2007). Motor contagion from gaze: The case of autism. *Brain*, *130*, 2401–2411.

Buccino, G., Binkofski, F., Fink, G. R., Fadiga, L., Fogassi, L., Gallese, V., et al. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: An fMRI study. *European Journal of Neuroscience*, *13*, 400–404.

Buccino, G., Binkofski, F., & Riggio, L. (2004). The mirror neuron system and action recognition. *Brain and Language*, *89*, 370–376.

Buccino, G., Lui, F., Canessa, N., Patteri, I., Lagravinese, G., Benuzzi, F., et al. (2004). Neural circuits involved in the recognition of actions performed by nonconspecifics: An fMRI study. *Journal of Cognitive Neuroscience*, *16*, 114–126.

Buccino, G., Solodkin, A., & Small, S. (2006). Functions of the mirror neuron system: Implications for neurorehabilitation. *Cognitive and Behavioral Neurology*, *19*, 55–63.

Calvo-Merino, B., Glaser, D. E., Grezes, J., Passingham, R. E., & Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral Cortex*, *15*, 1243–1249.

Castiello, U. (2003). Understanding other people's actions: Intention and attention. *Journal of Experimental Psychology: Human Perception and Performance*, *29*, 416–430.

Castiello, U., Lusher, D., Mari, M., Edwards, M. G., & Humphreys, G. W. (2002). Observing a human or a robotic hand grasping an object: Differential motor priming effects. In W. Prinz & B. Hommel (Eds.), *Common mechanisms in perception and action* (pp. 321–332). Cambridge: MIT.

Castiello, U., Stelmach, G. E., & Lieberman, A. N. (1993). Temporal dissociation of the prehension pattern in Parkinson's disease. *Neuropsychologia*, *31*, 395–402.

Clower, D. M., Dum, R. P., & Strick, P. L. (2002). Substantia nigra pars reticulate provides input to area 7B of parietal cortex. *Society for Neuroscience Abstract*, *28*, 460.1.

Clower, D. M., Dum, R. P., & Strick, P. L. (2005). Basal ganglia and cerebellar inputs to 'AIP'. *Cerebral Cortex*, *15*, 913–920.

Cochin, S., Barthelemy, C., Roux, S., & Martineau, J. (1999). Observation and execution of movement: Similarities demonstrated by quantified electroencephalography. *European Journal of Neuroscience*, *11*, 1839–1842.

Craighero, L., Fadiga, L., Umiltà, C., & Rizzolatti, G. (1996). Evidence for visuomotor priming effect. *Neuroreport*, *8*, 347–349.

Decety, J., & Grezes, J. (1999). Neural mechanisms subserving perception of human actions. *Trends in Cognitive Sciences*, *3*, 172–178.

Dominey, P., Decety, J., Broussolle, E., Chazot, G., & Jeannerod, M. (1995). Motor imagery of a lateralized sequential task is asymmetrically slowed in hemi-Parkinson's patients. *Neuropsychologia*, *33*, 727–741.

Dum, R. P., & Strick, P. L. (1999). Pallidal and cerebellar inputs to the digit representations of the dorsal and ventral premotor areas (PMd and PMv). *Society for Neuroscience Abstract*, *25*, 1925.

Edwards, M. G., Humphreys, G. W., & Castiello, U. (2003). Motor facilitation following action observation: A behavioural study in prehensile action. *Brain and Cognition*, *53*, 495–502.

Ertelt, D., Small, S., Solodkin, A., Dettmers, C., McNamara, A., Binkofski, F., et al. (2007). Action observation has a positive impact on rehabilitation of motor deficits after stroke. *NeuroImage*, *36*, T164–T173.

Fadiga, L., Fogassi, L., Pavesi, G., & Rizzolatti, G. (1995). Motor facilitation during action observation: A magnetic stimulation study. *Journal of Neurophysiology*, *73*, 2608–2611.

Fahn, S., & Elton, R. L. (1987). Committee of the UPDRS Development Committee. Unified Parkinson's disease rating scale. In S. Fahn, C. D. Marsden, & M. Goldstein (Eds.), *Recent developments in Parkinson's disease II* (pp. 153–163). New York: Macmillan.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). 'Mini-mental state': A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*, 189–198.

Gallese, V. (2005). Embodied simulation: From neurons to phenomenal experience. *Phenomenology and the Cognitive Sciences*, *4*, 23–48.

Gallese, V., & Goldman, A. (1998). Mirror neurons and the simulation theory of mind reading. *Trends in Cognitive Science*, *2*, 451–493.

Grafton, S. T., Arbib, M. A., Fadiga, L., & Rizzolatti, G. (1996). Localization of grasp representations in humans by positron emission tomography. 2. Observation compared with imagination. *Experimental Brain Research*, *112*, 103–111.

Grèzes, J., Armony, J. L., Rowe, J., & Passingham, R. E. (2003). Activations related to 'mirror' and 'canonical' neurons in the human brain: An fMRI study. *Neuroimage*, *18*, 928–937.

Hari, R., Forss, N., Avikainen, S., Kirveskari, E., Salenius, S., & Rizzolatti, G. (1998). Activation of human primary motor cortex during action observation: A neuromagnetic study. *Proceedings of the National Academy of Sciences of the United States of America*, *95*, 15061–15065.

Heyes, C. M., Bird, G., Johnson, H., & Haggard, P. (2005). Robotic movement elicits automatic imitation. *Cognitive Brain Research*, *22*, 233–240.

Hoehn, M. M., & Yahr, M. D. (1967). Parkinsonism: Onset, progression and mortality. *Neurology*, *17*, 427–442.

Holsapple, J. W., Preston, J. B., & Strick, P. L. (1991). The origin of thalamic inputs to the 'hand' representation in the primary motor cortex. *Journal of Neuroscience*, *11*, 2644–2654.

Hoover, J. E., & Strick, P. L. (1993). Multiple output channels in the basal ganglia. *Science*, *259*, 819–821.

Hoover, J. E., & Strick, P. L. (1999). The organization of cerebellar and basal ganglia outputs to primary motor cortex as revealed by retrograde transneuronal transport of herpes simplex virus type 1. *Journal of Neuroscience*, *19*, 1446–1463.

Jeannerod, M. (1984). The timing of natural prehension movements. *Journal of Motor Behavior*, *16*, 235–254.

Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage*, *14*, S103–S109.

Kilner, J. M., Paulignan, Y., & Blakemore, S. J. (2003). An interference effect of observed biological movement on action. *Current Biology*, *13*, 522–525.

Nambu, A., Yoshida, S., & Jinnai, K. (1988). Projection on the motor cortex of thalamic neurons with pallidal input in the monkey. *Experimental Brain Research*, *71*, 658–662.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*, 97–113.

Pierno, A. C., Becchio, C., Wall, M. B., Smith, A. T., Turella, L., & Castiello, U. (2006). When gaze turns into grasp. *Journal of Cognitive Neuroscience*, *18*, 2130–2137.

Pierno, A. C., Mari, M., Lusher, D., & Castiello, U. (2008). Robotic movement elicits visuomotor priming in children with autism. *Neuropsychologia*, *46*, 448–454.

Rizzolatti, G., Fadiga, L., Matelli, M., Bettinardi, V., Paulesu, E., Perani, D., et al. (1996). Localization of grasp representations in humans by PET: 1. Observation versus execution. *Experimental Brain Research*, *11*, 246–252.

Rizzolatti, G., & Luppino, G. (2001). The cortical motor system. *Neuron*, *31*, 889–901.

Strafella, A. P., & Paus, T. (2000). Modulation of cortical excitability during action observation: A transcranial magnetic stimulation study. *Experimental Brain Research*, *11*, 2289–2292.

Tai, Y. F., Scherfler, C., Brooks, D. J., Sawamoto, N., & Castiello, U. (2004). The human premotor cortex is mirror only for biological actions. *Current Biology*, *14*, 117–120.

Tremblay, F., Leonard, G., & Tremblay, L. (2008). Corticomotor facilitation associated with observation and imagery of hand actions is impaired in Parkinson's disease. *Experimental Brain Research*, *185*, 249–257.

Tresilian, J. R., Stelmach, J. E., & Adler, C. H. (1997). Stability of reach-to-grasp movement patterns in Parkinson's disease. *Brain*, *120*, 2093–2111.

Williams, H. G., Whiten, A., Waiter, G. D., Pechey, S., & Perrett, D. I. (2007). Cortical and subcortical mechanisms at the core of imitation. *Social Neuroscience*, *2*, 66–78.