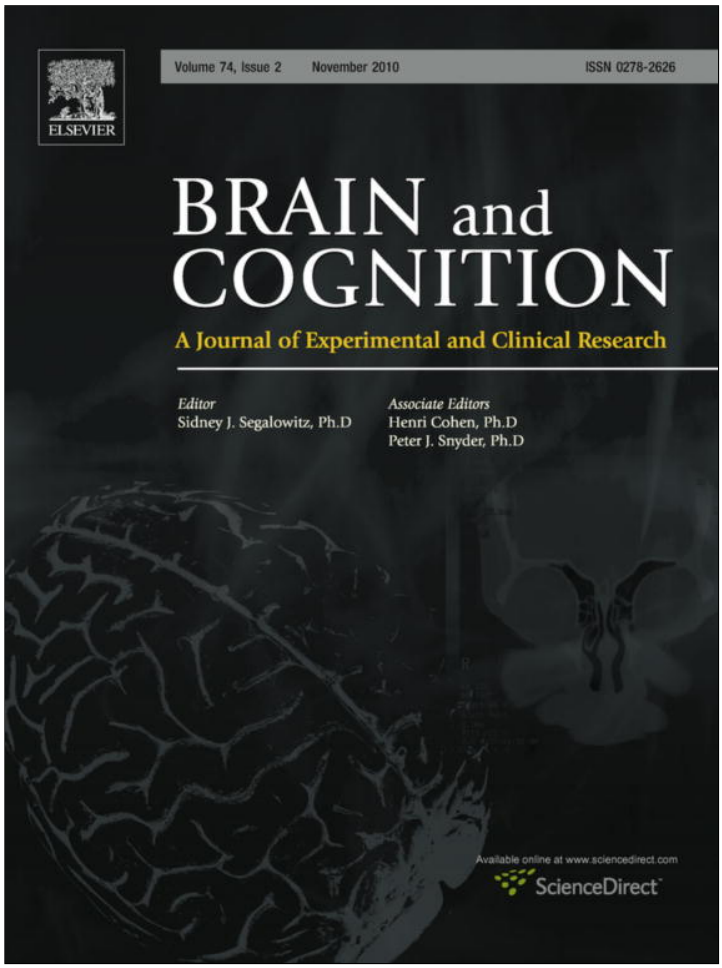

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Testing the effects of end-goal during reach-to-grasp movements in Parkinson's disease

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ABSTRACT

Previous evidence suggests that hand shaping during reaching is modulated by the presence and the nature of the end-goal following object's grasp. Here we test whether such modulation is maintained in Parkinson's disease (PD). Six participants with PD and six healthy participants took part in the study. Participants were requested to reach towards a bottle filled with water, and then: (1) grasp it without performing any subsequent action; (2) grasp it and place it accurately on a target area; (3) grasp it and pour its contents within a container. The results showed that participants shaped their hand differently depending on the presence or absence of an action following object's grasp. However, the request to perform an action after grasp determined a modulation of hand kinematics which was delayed for PD than for control participants. Further, whereas for control participants the nature of the end-goal determined a modulation of hand shaping, for PD patients such modulation was not evident. Data are discussed in terms of the role played by basal ganglia in implementing anticipatory mechanisms for the control of manipulative activities. We contend that in PD patients these mechanisms are not totally compromised, but their implementation depends on the action information that has to be anticipated.

1. Introduction

People afflicted by Parkinson's disease (PD) have significant difficulties when performing normally routine motor tasks. Amongst these tasks, prehensile movements are those which appear to be mostly impaired and therefore they have been the focus of extensive research (e.g., Alberts, Saling, Adler, & Stelmach, 2000; Castiello, Stelmach, & Lieberman, 1993; Fellows, Noth, & Schwarz, 1998; Jackson, Jackson, Harrison, Henderson, & Kennard, 1995; Muller & Abbs, 1990; Tresilian, Stelmach, & Adler, 1997). The general scenario emerging from this body of literature is the following: whereas PD patients seem to be able to scale reach-to-grasp kinematics with respect to intrinsic (e.g., size) and extrinsic (e.g., position) properties of stimuli, they seem to lack in the ability to coordinate in parallel the reaching and the grasping phases of the action (e.g., Castiello et al., 1993; Jackson et al., 1995). Therefore there seems to be an apparent contradiction between the reported lack of deficits in the planning and execution of reach-to-grasp movement and the impairment exhibited by PD patients when they perform manipulative actions during daily living activities. Such contradiction might be due to the fact that the majority of previous reach-to-grasp studies in PD patients had focused on the kinematics of two-digits grasp, i.e., the index finger and the thumb, whereas daily manipulative activities often require to coordinate the motion of all five digits.

In this respect, more recent studies report on how PD patients control multi-digits rather than two-digits reach-to-grasp movements (Schettino, Adamovich, & Poizner, 2003; Schettino et al., 2004). The results indicate that PD patients, in contrast to neurologically healthy controls, show a deficit in the coordination of the five-digit grasp during reaching. Specifically, Schettino and colleagues (2004) reported that PD patients exhibited a delay in shaping the hand posture appropriately as to grasp objects of specific shapes. This deficit was more marked when either the hand or the object to-be-grasped were made visually unavailable throughout the reach-to-grasp movement (Schettino et al., 2006). Such evidence has lead to the proposal that PD affects the ability to use predictive control mechanisms for guiding multi-digits prehensile tasks (Schettino et al., 2003, 2006).

Predictive control might be defined as the generation of a motor plan on the basis of temporal and spatial information that is not directly specified by the target. In this respect, actions which require the implementation of multiple motor steps provide an ideal opportunity to assess the functioning of predictive control mechanisms. Indeed, the skilful execution of this kind of action heavily depends on the ability to predict future states of the system and, by using such prediction, to operationalize each movement step as to achieve the overall action goal. Recent research on action sequence had shown that healthy participants reach and grasp

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an object differently depending on the intent guiding the action (e.g., Ansuini, Giosa, Turella, Altoe, & Castiello, 2008; Ansuini, Santello, Massaccesi, & Castiello, 2006; Armbruster & Spijkers, 2006). For instance, grasping a bottle with the intent to throw it rather than to pour its content within a container brings to different hand shaping kinematics during reaching (Ansuini et al., 2008). Therefore this effect of the action end-goal on kinematics is evident well before the object is actually grasped. This indicates that in neurologically healthy participants motor programming takes into account the requirements of subsequent movement steps (Ansuini et al., 2008). This aspect of 'anticipation' taps into the notion of predictive control mechanisms and therefore it is an aspect which would be interesting to assess in PD patients, who are said to have dysfunctions with the use of predictive control mechanisms (Flowers, 1976).

Hence, in the present study we investigate the motor-programming abilities of PD patients during the execution of a sequential multi-digits prehensile movement. To this end we asked participants to reach towards and grasp an object (i.e., a bottle filled with water) by using all five fingers, in three different conditions. In the first condition, participants reached for the bottle and, once grasped, no further action had to be performed (i.e., grasp condition). In the second condition, participants reached for and grasped the bottle but they had to pour its contents within a container (i.e., pour condition). In the third condition, participants were requested to reach for and grasp the bottle and to place it accurately on a base matching the diameter of the bottle's base (i.e., place condition). Such manipulations allow to assess two important aspects which so far have been poorly investigated in PD patients. First, whether they are able to take into account, during a prehensile action, the need to perform subsequent movement steps; this will be revealed by the comparison between the grasp condition and the conditions involving an action following grasping. If differences would emerge, it might be concluded that the deficit exhibited by PD patients in predictive control do not extend to reach-to-grasp movements which are part of a sequence (rather than as a single motor step). In turn, the absence of differences would suggest that the PD patients' ability to plan in advance a motor sequence is severely compromised. Second, to determine whether PD patients do execute the first part of a prehensile action sequence by anticipating the specific requirements embedded in the motor step following object grasping; this will be revealed by the comparison between the pour and the place conditions. If differences depending on the intent driving the action sequence would emerge, this might be interpreted as the demonstration that PD patients' deficit in anticipatory control and execution processes does not apply to over-learned motor context such as those considered here. In turn, an absence of differences would indicate that mechanisms underlying the predictive control, which are necessary to finely tune the execution of a composite action, are damaged in PD patients.

2. Material and methods

2.1. Participants

Six PD patients and six age-matched normal older adults served as participants (mean age: PD patients, 67.5 years; controls, 66.5 years, *t*-test for means: $t_{(10)} = .139$, $p > .05$). The PD participants were clinically evaluated by a neurologist at the time of testing and were found to have mild PD (stage 1 of the Hoehn and Yahr (1967) scale). All PD participants had clinically typical PD and their motor disabilities were responsive to anti-Parkinsonian medications. Patients' clinical features are given in Table 1. All participants were right handed and both participants' groups were screened with the Mini-Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975). No significant differences were evident when comparing MMSE scores between PD and control participants, (*t*-test for means: $t_{(10)} = -.166$, $p > .05$). All PD participants were free of significant upper limb or trunk arthritis or pain and free by any other significant neurological disease. PD patients were tested in "ON" state after having taken their first medication dose

Table 1
Characteristics of the parkinsonian patients.

Patients	Age (years)	Gender	Time since disease onset (years)	Disease stage	MMSE scores	Motor UPDRS (on medication)
GF	73	M	3	1	28	10
PG	67	M	3	1	27	12
SA	57	M	11	1	25	10
BF	84	M	8	1	25	12
DP	65	M	10	1	30	9
AA	59	F	4	1	28	8

Note: M = Male. F = Female. Stage of the disease was determined on the basis of the Hoehn & Yahr's scale. MMSE = Mini-Mental State Examination (Folstein et al., 1975). UPDRS = Unified Parkinson's disease rating scale.

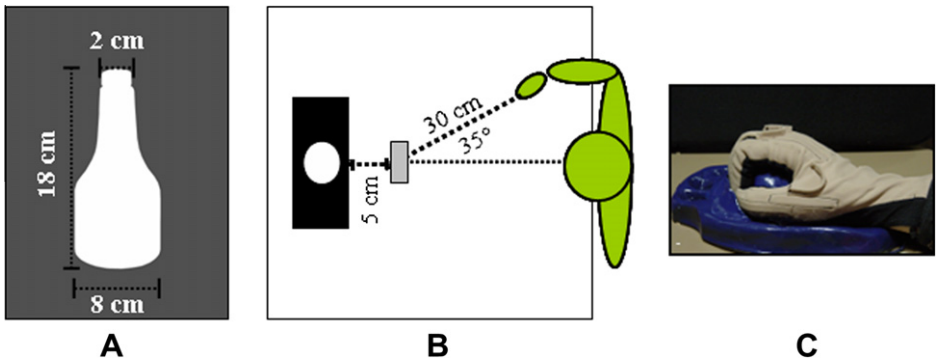

Fig. 1. Target object, experimental set-up, and hand starting position. The object used as a target (A). A schematic representation of the experimental workspace (top-view; figure is not to scale) (B). The hand starting position adopted by each participant at the beginning of each trial (C).

that day. All participants were informed about the nature of the study and signed institutionally approved consent forms. The experimental procedures were approved by the Institutional Review Board at the University of Padua and were in accordance with the declaration of Helsinki.

2.2. Stimulus

The stimulus was a plastic bottle filled with 350 ml of water (Fig. 1A) located on a 7 cm high plastic support at a 30 cm distance from the initial hand position (Fig. 1B–C). The stimulus rested on a pressure sensitive switch embedded within the plastic support.

2.3. Procedure

The participant sat on a height-adjustable chair in front of a rectangular table with the elbow and the wrist resting on the table, the forearm horizontal, the arm oriented in the parasagittal plane passing through the shoulder and the right hand on the starting position (Fig. 1B–C). The hand was pronated with the palm pressing a switch. Participant naturally reached towards and grasped the target object opposing the thumb to the four fingers of her/his right hand after hearing an auditory signal (Hz = 880; duration = 200 ms). This task could be performed under three different experimental conditions:

(1) '*Grasp condition*': participants were requested to reach towards and grasp the target object. No further action was requested.
(2) '*Pour condition*': participants were requested to reach towards, grasp the target object, lift it and pour the water within a plastic container. The bottle was re-filled after each trial as to maintain the same weight for all conditions.
(3) '*Place condition*': participants were requested to reach towards, grasp the target object, lift it, and place it precisely within a drawn circle perfectly matching the diameter of the bottle's base. The circle was drawn on a 23 cm high platform (depth = 19 cm; width = 33 cm). This platform was placed 5 cm behind the object's base (see Fig. 1B). The centroid of the location at which we located the plastic container (condition #2) and the circle (condition #3) was similar across conditions.

A block of 36 trials including 12 trials for each of the three experimental conditions was administered. Trials of different types were randomized within the block. Before the start of each trial, participants were informed about the action to be performed and a block of six practice trials (two examples for each type of experimental condition) was administered. To avoid fatigue and lack of concentration/attention, participants were given a pause every 12 trials.

2.4. Recording techniques

By resistive sensors embedded in a glove worn in the participants' right hand (CyberGlove, Virtual Technologies, Palo Alto, CA), angular values corresponding to both hand joints and fingers' distances were recorded. The sensors had a linearity of 0.62% with respect to the maximum nonlinearity over the full range of hand motion. Their resolution was 0.5° and it remains constant over the entire range of joint motion. The output of the transducers was sampled at 12-ms interval. Angular excursion was measured at metacarpal–phalangeal (*mcp*) and proximal interphalangeal (*pip*) joints of the thumb, index, middle, ring, and little fingers (T, I, M, R, and L, respectively). In order to obtain the baseline hand posture we asked the participants – before starting the experimental session – to place their right hand flat on the table and to maintain it in that position while *mcp* and *pip* joints' angles for all digits were recorded. The 'baseline' hand posture (i.e., 0°) was taken when *mcp* and *pip* joints were straight in the plane of the palm. Fingers' flexion was assigned positive values. The 'baseline' abduction angles of adjacent digits' pairs (i.e., 0°) was taken when the hand was positioned flat with pre-set abduction angles (thumb–index finger = 22°; index–middle fingers = 32°; middle–ring fingers = 45°; ring–little fingers = 50°). Fingers' aperture was assigned negative values. The onset of the reaching movement was taken at the time the switch underneath the hand was released. With the only exception of the 'grasp' condition, the offset of the reaching movement was considered at the time the switch underneath the target object was released. For the 'grasp' condition reaching offset was determined off-line. Specifically reaching offset was taken when at least ten over the fourteen recorded sensors remained stationary for at least five temporal samples. For all conditions, reach duration was calculated as the time interval between the onset and the offset of the reaching movement.

2.5. Data analysis

Since kinematic differences may be better understood when the occurrence of kinematic events is expressed in relative terms (as a percentage of the overall reach duration), we time normalize the raw data for all trials for each participant by means of a custom software (Matlab, MathWorks, Natick, MA). The time normalized data were then entered into ten repeated measures analyses of variance (ANOVA) one for each of the two joints (i.e., *mcp* and *pip*) for each digit as to determine how and to what extent the angular excursion at the analyzed joints for each digit differed across experimental conditions. For this analysis, the within-subjects factors were 'Condition' ('grasp', 'place', 'pour') and 'Time' (from 10% to 100% of the reach, at 10% intervals), and the between – subjects factor was 'Group' (PD vs. controls). Similar analyses were conducted to ascertain the effect of the experimental condition on each of the considered abduction angles (i.e., thumb–index, index–middle,

Table 2
ANOVA results for metacarpal–phalangeal (*mcp*) joints of all digits.

	Thumb	Index	Middle	Ring	Little
Condition	$F_{(2,20)} = .067$, NS	$F_{(2,20)} = 2.781$, NS	$F_{(2,20)} = 5.664$, $p < .02$	$F_{(2,20)} = 11.767$, $p < .0001$	$F_{(2,20)} = 12.167$, $p < .0001$
Time	$F_{(9,90)} = 8.844$, $p < .0001$	$F_{(9,90)} = 36.254$, $p < .0001$	$F_{(9,90)} = 21.908$, $p < .0001$	$F_{(9,90)} = 23.887$, $p < .0001$	$F_{(9,90)} = 5.530$, $p < .0001$
Group	$F_{(1,10)} = .067$, NS	$F_{(1,10)} = .276$, NS	$F_{(1,10)} = .787$, NS	$F_{(1,10)} = .001$, NS	$F_{(1,10)} = 2.595$, NS
Condition by time	$F_{(18,180)} = 1.290$, NS	$F_{(18,180)} = 13.430$, $p < .0001$	$F_{(18,180)} = 10.505$, $p < .0001$	$F_{(18,180)} = 17.188$, $p < .0001$	$F_{(18,180)} = 18.293$, $p < .0001$
Condition by group	$F_{(2,20)} = .164$, NS	$F_{(2,20)} = .219$, NS	$F_{(2,20)} = .395$, NS	$F_{(2,20)} = .568$, NS	$F_{(2,20)} = 1.067$, NS
Time by group	$F_{(9,90)} = 1.266$, NS	$F_{(9,90)} = .899$, NS	$F_{(9,90)} = .255$, NS	$F_{(9,90)} = .494$, NS	$F_{(9,90)} = .808$, NS
Condition by time by group	$F_{(18,180)} = .341$, NS	$F_{(18,180)} = 1.499$, NS	$F_{(18,180)} = .361$, NS	$F_{(18,180)} = .300$, NS	$F_{(18,180)} = .493$, NS

Note: NS = Not significant.

middle–ring, and ring–little fingers). Finally, to test for possible differences in reach duration as a function of experimental condition an ANOVA with 'Condition' ('grasp', 'place', 'pour') as within-subjects factor and 'Group' (PD vs. controls) as between-subjects factor was performed. Simple effects were used to explore the means of interest. Bonferroni's corrections (alpha level: $p < .05$) were applied.

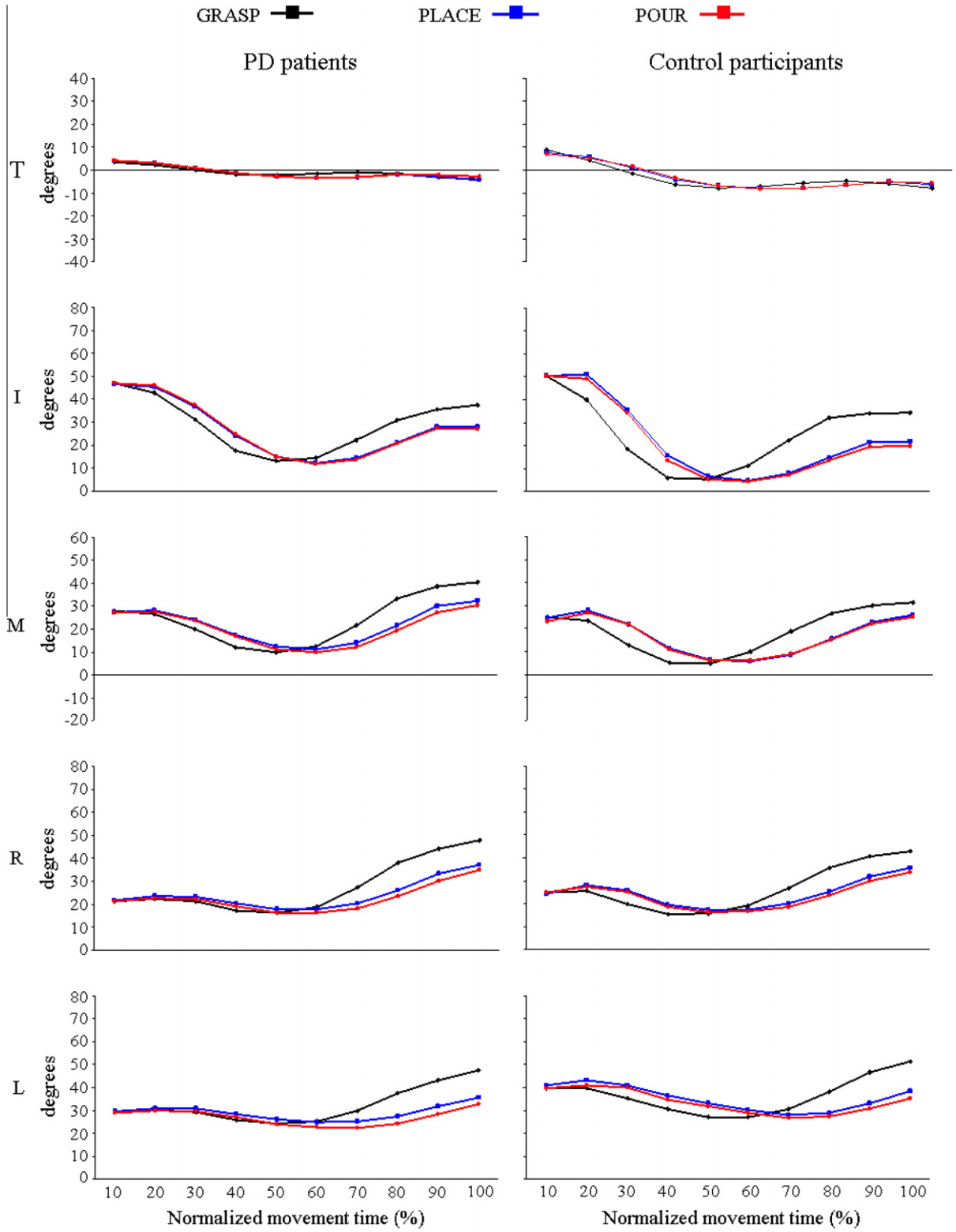

Fig. 2. Time course of fingers motion at metacarpal–phalangeal joints during reaching. Each trace depicts angular excursion at the metacarpal–phalangeal (*mcp*) joint of thumb (T), index (I), middle (M), ring (R), and little (L) finger for all experimental conditions for PD patients and control participants (left and right column, respectively). Data are averaged across trials and participants.

3. Results

3.1. Fingers' angular excursions

The ANOVA performed on fingers' angular excursions revealed that, with the only exception of the thumb, the angular excursion for *mcp* joints of all digits was significantly affected by the experimental condition. In particular, as revealed by the significant interaction 'Condition' by 'Time' found for index, middle, ring and little finger (Table 2), such an effect varied along reaching duration with *mcp* joints being more extended for the 'grasp' than for the 'place' and the 'pour' condition at the beginning of the movement

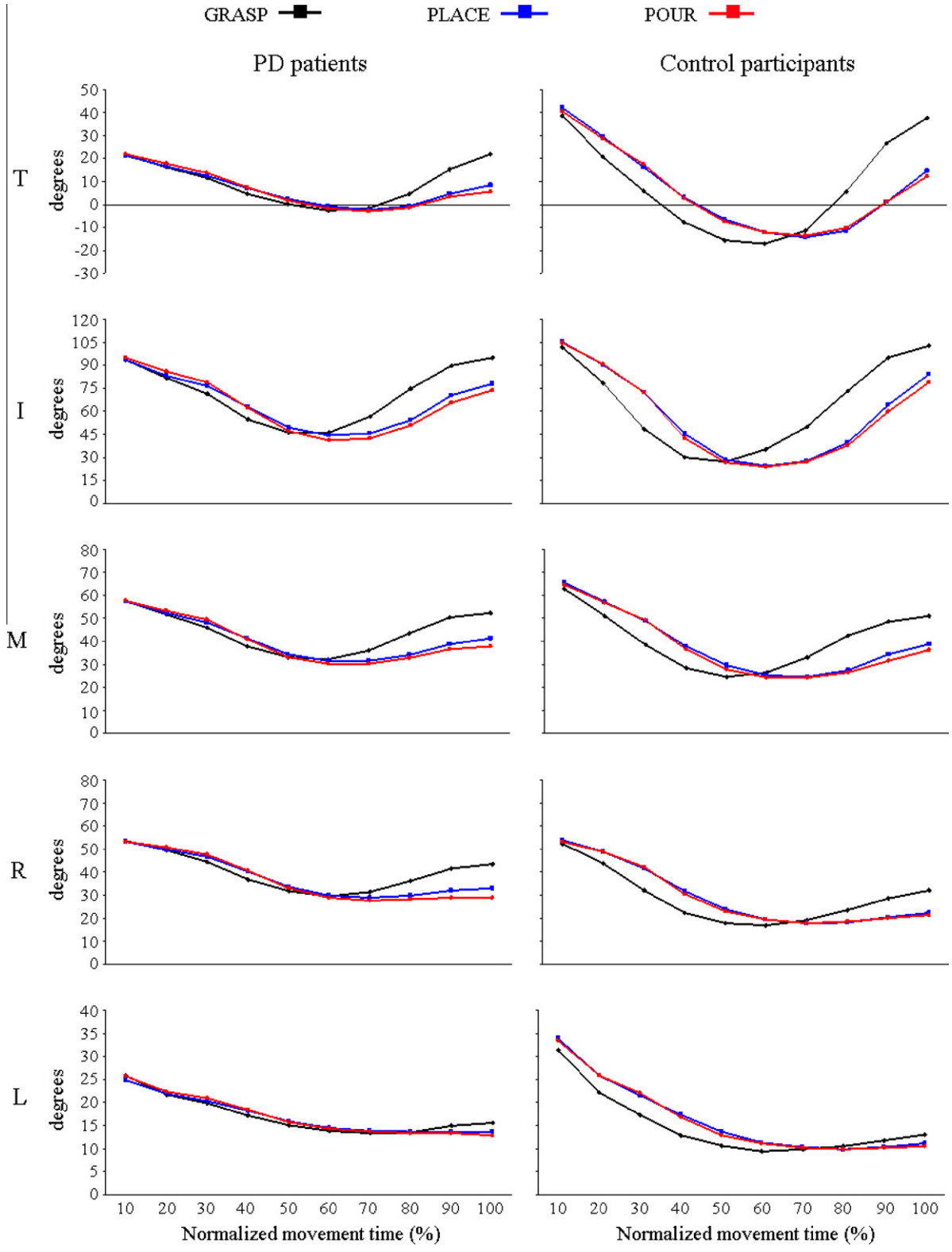

Fig. 3. Time course of fingers motion at proximal interphalangeal joints during reaching. Each trace depicts angular excursion at the proximal interphalangeal (*pip*) joint of thumb (T), index (I), middle (M), ring (R), and little (L) finger for all experimental conditions for PD patients and control participants (left and right column, respectively). Data are averaged across trials and participants.

Table 3
ANOVA results for proximal interphalangeal (*pip*) joints of all digits.

	Thumb	Index	Middle	Ring	Little
Condition	$F_{(2,20)} = 4.085$, $p < .04$	$F_{(2,20)} = 13.940$, $p < .0001$	$F_{(2,20)} = 7.827$, $p < .01$	$F_{(2,20)} = 1.572$, NS	$F_{(2,20)} = 2.846$, NS
Time	$F_{(9,90)} = 52.354$, $p < .0001$	$F_{(9,90)} = 127.705$, $p < .0001$	$F_{(9,90)} = 58{,}221$, $p < .0001$	$F_{(9,90)} = 51.291$, $p < .0001$	$F_{(9,90)} = 62.583$, $p < .0001$
Group	$F_{(1,10)} = .009$, NS	$F_{(1,10)} = 1.255$, NS	$F_{(1,10)} = .191$, NS	$F_{(1,10)} = 2.603$, NS	$F_{(1,10)} = .091$, NS
Condition by time	$F_{(18,180)} = 23.286$, $p < .0001$	$F_{(18,180)} = 25.878$, $p < .0001$	$F_{(18,180)} = 23.569$, $p < .0001$	$F_{(18,180)} = 17.106$, $p < .0001$	$F_{(18,180)} = 8.659$, $p < .0001$
Condition by group	$F_{(2,20)} = .013$, NS	$F_{(2,20)} = .078$, NS	$F_{(2,20)} = .272$, NS	$F_{(2,20)} = 4.148$, $p < .04$	$F_{(2,20)} = 3.235$, NS
Time by group	$F_{(9,90)} = 8.358$, $p < .0001$	$F_{(9,90)} = 7.609$, $p < .0001$	$F_{(9,90)} = 2.278$, $p < .03$	$F_{(9,90)} = 1.821$, NS	$F_{(9,90)} = 5.762$, $p < .0001$
Condition by time by group	$F_{(18,180)} = 4.263$, $p < .0001$	$F_{(18,180)} = 2.420$, $p < .01$	$F_{(18,180)} = 1.754$, $p < .04$	$F_{(18,180)} = .585$, NS	$F_{(18,180)} = 2.018$, $p < .02$

Note: NS = Not significant.

(i.e., from 30% up to 40% of reach duration; $p_s < .05$). However, during the second half of the reach-to-grasp movement this pattern reversed with *mcp* joints being more flexed for the 'grasp' than for the 'place' and the 'pour' condition. Of particular interest, this kinematic pattern was observed for both the controls' and the PD patients' group as indicated by the absence of significant three-ways interaction 'Condition' by 'Time' by 'Group' (Fig. 2 and Table 2).

With respect to *pip* joints, the significant interaction 'Condition' by 'Time' by 'Group' revealed that for the control group these joints were more extended during the first half of reaching movement (i.e., from 20% up to 50% of reach duration) for the 'grasp' than for the 'pour' and the 'place' conditions (see Fig. 3 and Table 3; $p_s < .05$). After 50% of reaching duration, this pattern inverted with the *pip* joints of all digits being more flexed for the 'grasp' than for the other two conditions. Compared to the healthy participants, PD patients showed a number of differences in their grasp kinematics at the level of *pip* joints. In particular, for this latter group the *pip* joints of all digits were more flexed for the 'grasp' than for the 'place' and 'pour' conditions from 70% of reach duration up to object's contact (Fig. 3 and Table 3; $p_s < .05$). However, in contrast with the pattern found for control participants, no differences were detected during the first half of the movement.

3.2. Adduction/abduction angles

Results for the ANOVAs performed on adduction/abduction angles are reported in Table 4. These analyses revealed that the angular distance between thumb and index finger was greater for the 'grasp' than for the 'pour' and the 'place' condition from the 40% up to the end of reaching movement for both the controls' and the PD patients' group (Fig. 4; $p_s < .05$). With respect to the abduction/adduction angle for the middle–ring fingers and the ring–little fingers, the significant interaction 'Condition' by 'Time' by 'Group' revealed that for PD patients these angles were smaller for the 'grasp' than for the 'place' and the 'pour' condition from 70% up to the end of the reaching movement (Fig. 4; $p_s < .05$). For the control participants, but not for the PD patients, the middle–ring and the ring–little fingers adduction/abduction angles were larger for the 'grasp' than for the 'place' and the 'pour' condition ($p_s < .05$). This pattern was evident across the entire reach duration. Further, a significant difference was also found when comparing the 'pour' and the 'place' condition for the middle–ring abduction/adduction angle from 60% up to 80% of reaching movement (Fig. 4; $p_s < .05$). For the ring–little adduction/abduction angle a similar trend was evident. Specifically both angles were smaller for the 'pour' than for the 'place' condition (Fig. 4; $p_s < .05$). No significant differences depending on experimental condition for the index–middle adduction/abduction angle were found for both groups (Table 4; $p_s > .05$).

3.3. Reach duration

The significant interaction 'Condition' by 'Group' [$F(2, 20) = 4.603$, $p < .03$] revealed that control participants exhibited a longer movement duration for the 'grasp' than for the 'pour' and the 'place' conditions (1509 ms ± S.E. = 143 vs. 1214 ms ± S.E. = 110 vs. 1199 ms ± S.E. = 117, respectively; $p_s < .05$). For PD patients reaching duration did not differ across the 'grasp', the 'pour' and the 'place' conditions (1582 ms ± S.E. = 130 vs. 1583 ms ± S.E.=123 vs. 1591 ms ± S.E.=128, respectively; $p_s > .05$).

4. Discussion

The goal of the present study was to investigate how PD patients acknowledge the need to perform an action following object grasping for the achievement of a specific goal. The results indicate that both PD and control participants shaped their hand differently during reaching when the attainment of the goal entailed a two-steps motor sequence than a single motor step, i.e. reach-to-grasp. However, whereas for control participants such difference was detected on the pattern of fingers' extension shortly after the movement started, for PD patients such differential pattern emerged at the end of the movement. Noticeably, in contrast to control participants, PD patients did not show a modulation of hand kinematics depending on the action goal (i.e., pour vs. place).

Table 4
ANOVA results for fingers' distances between digits.

	Thumb–index	Index–middle	Middle–ring	Ring–little
Condition	$F_{(2,20)} = 35.397$, $p < .0001$	$F_{(2,20)} = .572$, NS	$F_{(2,20)} = .887$, NS	$F_{(2,20)} = .160$, NS
Time	$F_{(9,90)} = 38.028$, $p < .0001$	$F_{(9,90)} = 7.033$, $p < .0001$	$F_{(9,90)} = 22.467$, $p < .0001$	$F_{(9,90)} = 5.695$, $p < .0001$
Group	$F_{(1,10)} = 1.405$, NS	$F_{(1,10)} = 4.057$, NS	$F_{(1,10)} = 4.830$, NS	$F_{(1,10)} = .008$, NS
Condition by time	$F_{(18,180)} = 12.195$, $p < .0001$	$F_{(18,180)} = 1.784$, $p < .04$	$F_{(18,180)} = 1.306$, $p < .0001$	$F_{(18,180)} = 1.223$, NS
Condition by group	$F_{(2,20)} = .102$, NS	$F_{(2,20)} = .274$, NS	$F_{(2,20)} = 5.085$, $p < .02$	$F_{(2,20)} = 1.173$, NS
Time by group	$F_{(9,90)} = .354$, NS	$F_{(9,90)} = 1.088$, NS	$F_{(9,90)} = 1.393$, NS	$F_{(9,90)} = .158$, NS
Condition by time by group	$F_{(18,180)} = .327$, NS	$F_{(18,180)} = .391$, NS	$F_{(18,180)} = 2.431$, $p < .01$	$F_{(18,180)} = 1.621$, $p < .05$

Note: NS = Not significant.

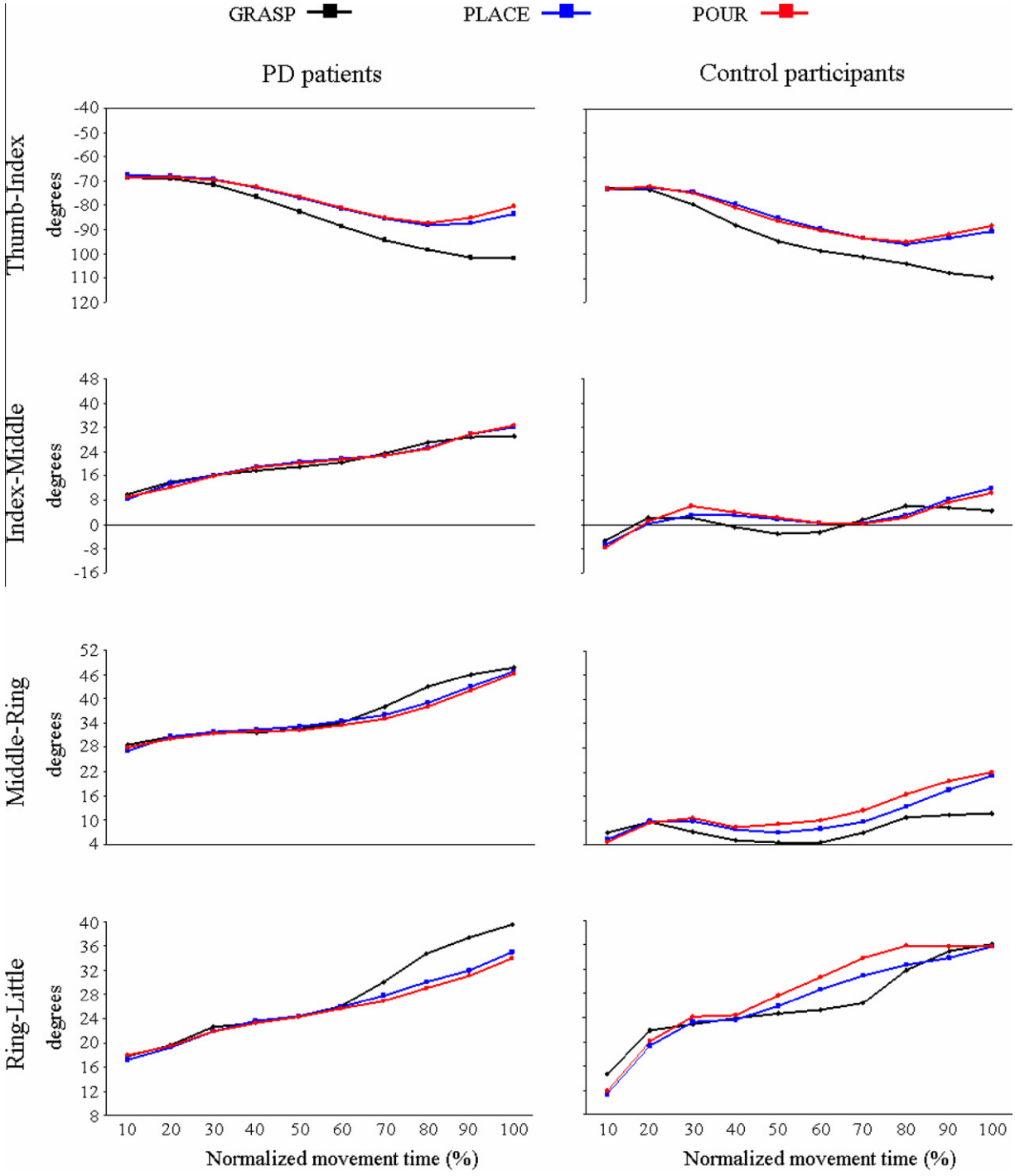

Fig. 4. Time course of fingers' distance during reaching. Each trace depicts abduction angle between thumb–index, index–middle, middle–ring, and ring–little fingers, respectively for PD patients and control participants (left and right column, respectively). Data are averaged across trials and participants.

The result that PD patients exhibited a delay in the adaptation of hand shaping concurs with previous report of delays ascribed to this population when performing reach-to-grasp movements (e.g., Castiello et al., 1993; Ingvarsson, Gordon, & Forssberg, 1997; Alberts et al., 2000; Jackson et al., 1995). For instance, it has been reported that for PD patients it is the coordination between the two components of the reach and grasp movement which shows abnormalities: the onset of the grasping component is delayed with respect to the onset of the reaching component (e.g., Castiello et al., 1993). Schettino and colleagues (2004) observed that PD patients exhibited a delay in the specification of hand shape during the reach-to-grasp movement to objects of different shapes. A result which points to a coordination deficit at the level of individual fingers' joints. The general picture from this research is that although the overall form of the motor program of PD patients appears to be maintained, PD patients are unable to specify the appropriate timing for the deployment of the prehension components and the intrinsic organization of hand's individual joints. Here we confirm and extend this literature by revealing a delay in the specification of hand shaping not only with respect to the structural features of the to-be-grasped object as previously demonstrated (Schettino et al., 2004), but with respect to the

functional need to perform a double movement. As previously suggested the delay in hand preshaping exhibited by PD patients might be ascribed to a marked deficit in the processing of grip selection (Schettino et al., 2004). Specifically this deficit has been attributed to the intimate connections between basal ganglia and the ventral premotor cortex (Clower, Dum, & Strick, 2005), an area heavily involved in the selection of specific grip types (Rizzolatti et al., 1988).

A caveat of this result is that the delay in hand shaping was evident solely at the level of the more distal interphalangeal joints (i.e., *pip joints*). Therefore, rather than a total inability to modulate in time hand configuration with respect to the presence of a subsequent action, such impairment appears to be confined to the joints which are more concerned with final grasping adjustments. A possible explanation for this specific finding might rely on the high level of variability experienced by PD patients for the establishment of contact points (Bertram, Lemay, & Stelmach, 2005). A phenomenon which might translate in the dysfunctional capability showed by PD patients to implement predictive, anticipatory control of manipulative forces (Bertram et al., 2005; Gordon, Ingvarsson, & Forssberg, 1997; Ingvarsson et al., 1997). Support for this contention becomes more transparent when comparing the results concerned with the nature of the action end-goal. Whereas for control participants a significant difference was found at the level of abduction angles when comparing the 'pour' and the 'place' condition, PD patients did not modulate hand kinematics with respect to end-goal. Specifically, for control participants middle–ring and ring–little adduction/abduction angle were smaller for the 'pour' than for the 'place' condition. For the pouring action, smaller distances among these digits might exemplify the need to balance the counterclockwise external torque dictated by the wrist rotation component embedded in the pouring action. These findings indicate that the CNS stipulates sensorimotor programs that specify both the required fingertip actions and the expected sensorimotor consequences associated with different end-goals. The development of such differential sensorimotor programs depending on end-goal supports predictive, anticipatory motor control mechanisms in manipulation which appear to be dysfunctional in PD patients. Therefore it might well be that a damage to the basal ganglia prevents the adaptation of the motor output depending on the functional requirements of the action end-goal. The results obtained for movement duration provide further strength to this proposal. For control, participants when there was no action beyond grasping, reach duration was longer than when the closing of the fingers upon the object represented the starting point for a subsequent action. A result in agreement with previous evidence suggesting that when the goal of a reach-to-grasp movement encapsulates a subsequent action, the duration of the 'first' movement is shorter than when no subsequent action is requested (e.g., Ansuini et al., 2006; Gentilucci, Negrotti, & Gangitano, 1997). For PD patients no differences in movement duration between the single and the double movement were found. This is also suggestive of an impairment in the capability to use information in advance to plan movements.

To account for these observations it might be suggested that basal ganglia could be involved in the process of forward modeling. Forward models are internal models by which the central nervous system (CNS) represents the causal relationship between actions and their consequences (i.e., motor-to-sensory transformation) (Desmurget & Grafton, 2000; Wolpert & Miall, 1996). In line with the idea of an involvement of basal ganglia in forward modeling, recent convergent observations demonstrate that basal ganglia dysfunctions affect the process of motor prediction and error detection in various domains related to action (Lawrence, 2000; Molina-Vilaplana, Contreras-Vidal, Herrero-Ezquerro, & Lopez-Coronado, 2009).

Findings from a recent computational neuroscience model (Molina-Vilaplana et al., 2009) may allow to enter deeper into the mechanisms which might determine a possible dysfunction in the process of forward modeling in PD patients. On the basis of very few assumptions Molina-Vilaplana and colleagues (2009) have been able to reproduce the fact that PD impairs the ability to correctly time the intrinsic organization of prehension major components (i.e., reaching and grasping) as well as the modulation of the whole hand shaping for specific tasks. The proposal is that this might be due to the combined action of the feedforward cortical motor program execution modulated by pallido-thalamic gating signals from basal ganglia modules and the temporal coordinative role of proprioceptive reafferent information related with the reaching phase of the movement. In this perspective, basal ganglia neural networks exert a sophisticated gating function over these channels, related to the nature of the prehensile task. What is suggested here is the possibility that dysfunctional basal ganglia affect the ability to manage the organization of different forward internal models related to prehension major components. To translate this theoretical framework within the context of our experiment it might well be that the role of basal ganglia in operating internal models extend to those which characterize the sensorimotor transformation underlying the two steps of the action considered here (i.e. reach-to-grasp and the task following it).

In conclusion the present findings extend to action goal representations the motor deficits exhibited by PD patients. When performing an action in daily life, these actions are usually driven by a desired outcome or goal. Using such anticipatory type of control allows to behave flexibly and skillfully. Therefore it might well be that the impairment experienced by PD patients during daily manipulative actions (e.g., grasping a glass) might stem from the difficulty to flexibly adequate motor patterning to the future requirements dictated by the action goal (e.g., grasping a glass for drinking). When we consider the rehabilitation of PD patients, these results may help therapists in devising improved training programs that are tailored on PD patients' difficulty to represent future states and act accordingly.

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