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Social intentions in Parkinson's disease patients: A kinematic study

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Abstract

Dysfunction of the dopaminergic system leads to motor, cognitive and motivational symptoms in brain disorders such as Parkinson's disease (PD). Moreover, the dopaminergic system plays an important role in social interactions. The dopaminergic input to the basal ganglia (BG) thought to integrate social cues during the planning and execution of voluntary movements remains, however, largely unexplored. Since PD provides a model to assess this function in humans, our study aimed to investigate the effects of social intentions on actions in non-demented PD patients receiving dopamine replacement therapy (Levodopa = l-Dopa) and in neurologically healthy control participants. Patients' ability to modulate motor patterning depending on the intention motivating the action to be performed was evaluated both in 'on' (with l-Dopa) and 'off' (without l-Dopa) states. Participants were instructed to reach for and to grasp an object; they were then told to hand it to another person (social condition) or to place it on a concave frame (individual condition). A 'passive-observer' condition, which was similar to the 'individual' condition except for the presence of an onlooker who simply observed the scene, was also assessed to exclude the possibility that differences might be due to the presence of another person. Movement kinematics were recorded using a three-dimensional motion analysis system. Study results demonstrated that the controls and the PD patients in an 'on' state adopted different kinematic patterning for the 'social' and the 'individual' conditions; the PD patients in the 'off' state, instead, were unable to kinematically differentiate between the two conditions. These results suggest that l-Dopa treatment has positive effects on translating social intentions into specific motor patterns in PD patients.

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1. Introduction

While focussing their attention on social cognition, cognitive psychologists and neuroscientists developed paradigms to investigate isolated individual minds. The isolation paradigm approach has led to the paradox of studies investigating social interactions while examining individuals physically isolated in separate compartments without any face-to-face contact. These isolation experiments reflect an underlying assumption that social interaction is ultimately reducible to simply understanding individuals’ mental states while they are interacting — or at least, think they are interacting, with other agents (e.g., Jacob & Jeannerod, 2005). Recent findings demonstrating that social interaction is deeply rooted in real social contacts have challenged that view (e.g., Knoblich & Sebanz, 2008; Sebanz, Bekkering, & Knoblich, 2006).

The theory that the social context influences action planning and execution has been tested by a variety of kinematical studies that have demonstrated that intention mechanisms modulate motor activation (Becchio, Sartori, & Castiello, 2010; Castiello, 2003; Castiello, Lusher, Mari, Edwards, & Humphreys, 2002; Edwards, Humphreys, & Castiello, 2003; Georgiou, Becchio, Glover, & Castiello, 2007; Mason & MacKenzie, 2005; Meulenbroek, Bosga, Hulstijn, & Miedl, 2007). That body of research established that kinematic movement patterns within a social context are different from those observed in the same participants carrying out movements with the same requirements in terms of speed and accuracy but performed in isolation, or more specifically, without any intention to interact socially. Becchio, Sartori, Bulgheroni, and Castiello (2008a), in particular, sought to determine if reach-to-grasp kinematics are, in fact, sensitive to social goals. Participants in their experiments were assigned individual and social experimental conditions. In the former, the participants were instructed to reach for and grasp an object; they were then told to move it from one place to another. In the latter, the participants were instructed to reach for and grasp the same object but instead of simply moving it, they were expected to hand it to another person. The study’s results revealed that movement kinematics were sensitive to ‘social’ manipulation and provided compelling evidence that different motor patterns are at the service of different intentions.

In neural terms, a variety of studies on social interactions have revealed activations in the ventral striatum (VS), one of the key brain regions of the reward pathway (Báez-Mendoza & Schultz, 2013). VS activations are evidence when people are engaged in online social interactions in which there is mutual contingency between the actors (Behrens, Hunt, Woolrich, & Rushworth, 2008; Walter, Abel, Ciaramidaro, & Erk, 2005). A wide range of social interactions characterized by various levels of complexity such as a simple interpersonal gaze (Kuzmanovic et al., 2009; Pfeiffer et al., 2014; Redcay et al. 2010; Schilbach et al., 2010; Williams, Walter, Perra, Perrett, & Whiten, 2005), a ball game between virtual avatars (David et al., 2006), or more complicated actions producing cooperative behaviour such as neuroeconomic trust games (Rilling et al., 2002) have proved to activate this area. All of this suggests that social interaction generates a rewarding experience whenever mutual contingency characterizes individuals’ behaviour.

The fact that the VS may be activated during social interaction implies that the basal ganglia (BG), the main recipient of VS outputs (Draganski et al., 2008), are involved in these endeavours. The BG are implicated in sensorimotor learning and receive a strong dopaminergic signal, which has been shown to play an important role in social interactions (Leblois, 2013). Despite this evidence, however, how the BG works to integrate social cues and how a dysfunction of the dopaminergic system can affect the ability to plan and to execute actions in a social context remains largely unexplored. Considering that the dopaminergic dysfunction causes motor, cognitive, and motivational outcomes in Parkinson’s disease (PD) patients (Alexander & Crutcher, 1990), this group might offer an opportunity to investigate the role of the BG in socially-oriented motor interactions. The aims of the present study were then: (i) to investigate movement planning and execution by non-demented PD patients intending to interact socially or individually and, (ii) to evaluate the effect of dopaminergic therapy on these patients while in ‘on’ (with L-Dopa) and ‘off’ (without L-Dopa) states. PD patients in ‘off’ or ‘on’ states and neurologically healthy control participants were asked to carry out intentional actions in two different conditions: in an individual or in a social context. For the individual task, participants were instructed to reach for and grasp an object and then to move it from one place to another. For the social condition, participants were instructed to reach for and grasp the same object, but then to hand it to another person. Moving an object from one place to another and handing it to another person are both intentional actions, which involve object displacement. The critical difference lies in the value of the intentional component: while grasping an object with the goal of simply moving it implies a purely individual intention, grasping the same object with the goal of handing it to someone else implies a social one, i.e., the action was at least partially motivated by the intention to affect another person’s behaviour. A ‘passive-observer’ condition, similar to the individual condition, was also tested to exclude the possibility that differences in the social conditions might be due to the simple presence of another person in the room.

We hypothesized that, as previously demonstrated, neurologically healthy participants would show differences in the kinematic parameterization depending on whether the action was performed with the intent of acting individually or socially. In addition, if the dopamine system plays a role in social interactions, then PD patients in ‘off’ state should not, according to this hypothesis, exhibit the same motor patterns observed within-subjects when experiencing ‘on’ state or as compared to neurologically healthy participants.

2. Methods

2.1. Participants

One group of participants (N = 16, 8F; age 53.5 ± 2.34 years; age range: 51–59 years) was made up of patients diagnosed with
Table 1 – Characteristics of the Parkinson’s disease (PD) patients.

<table>
<thead>
<tr>
<th>PD patient</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Years since diagnosis</th>
<th>Stage of the disease</th>
<th>Most affected upper limb</th>
<th>UPDRS (on meds)</th>
<th>UPDRS (off meds)</th>
<th>MMSE score</th>
<th>Dopaminergic medication</th>
<th>Clinical signs</th>
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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, 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. UPDRS, United Parkinson’s Disease Rating Scale, Motor section (range from 0 to 108; higher scores indicate greater impairments).

PD (see Table 1). The average duration of PD was 1.75 (±.77; range: 1–3 years) years and the mean age at onset was 51 yrs. All the PD patients were being treated with dopaminergic drugs. A board certified neurologist assessed the patients’ parkinsonian status using two measures: the Hoehn and Yahr scale (Hoehn & Yahr, 1967) and the Unified Parkinson’s Disease Rating Scale (UPDRS; Fahn & Elton, 1987). Each PD patient was first tested before receiving his/her first morning dose of Carbidopa-Levodopa, at least 12 h after the last dose (thus in ‘off’ state), and then a second time, one to 2 h after receiving the medication. Patients’ response to medication was verified by administering the UPDRS (Fahn & Elton, 1987) during ‘off’ and ‘on’ states. None of the participants showed motor complications due to therapy that could interfere with the task at hand. Those patients and a gender- and age-matched control group (N = 16; age: 53.6 ± 2.57 years; age range: 51–59 years, PD age vs control: Mann–Whitney, U-value = 128, Z = .0188, p = .98) of neurologically healthy individuals without neurological or skeletonmotor impairments were administered the Mini-Mental State Examination (MMSE) which measures global cognition (Folstein, Folstein, & McHugh, 1975). The scores of the PD patients ranged between 28 and 30; the healthy participants all scored 30, indicating no significant differences among groups (Mann–Whitney, U-value = 96, Z = −1.187, p = .23). The average visual acuity of the PD patients was 18/20 and it was 20/20 in the healthy participants. All the participants showed right-handed dominance (Edinburgh Inventory; Oldfield, 1971) and were naive about the experimental design and the purposes of the experiment. The study was approved by the ethics committee at the local institution and was performed in accordance with the principles of the Declaration of Helsinki. All participants gave written informed consent and were fully debriefed at the end of the experiment.

2.1.1. Apparatus

A schematic representation of the apparatus is illustrated in Fig. 1. The stimulus was an egg-shaped object (long axis = 5.7 cm) positioned on a holder in the middle of a black table (Fig. 1a). A starting switch was positioned on a pad (7 × 6 cm) located 15 cm from the edge of the table, immediately in front of the participant, in line with his/her mid-sagittal plane and positioned 21 cm far from the stimulus holder. Another pad, upon which a plastic concave frame was resting, was located 28 cm to the right of the stimulus holder on the table (see Fig. 1a). Reflective passive markers (diameter: .25 cm) were attached to (a) the ulnar styloid process of the wrist, (b) the tip of the index finger, and (c) the tip of the thumb of the participant’s right hand (see Fig. 1a). The wrist marker was used to measure the reaching component of the action; the forefinger and the thumb markers were used to measure its grasp component. Another marker was attached to the top of the experimental stimulus. Movements were recorded using a SMART motion analysis system (Bioengineering Technology & Systems [B/TS]). Six infrared cameras (sampling rate 200 Hz) positioned around and slightly above the table (see Fig. 1a) were utilized to capture the location of the markers in 3D space. Coordinates of the markers were reconstructed with an accuracy of 1/3000 mm over the field of view. The standard deviation of the reconstruction error was 1/3000 mm for the vertical (Y) axis and 1.4/3000 mm for the two horizontal (X and Z) axes.

2.1.2. Procedure

The participants were tested individually in a dimly lit room. Each participant was instructed to place his/her right hand in a prone position on the starting switch. The participant’s index finger and thumb were slightly opposed on the pad.
Fig. 1 — Graphical representation of the experimental set up for the individual condition (panel ‘a’), the social condition (panel ‘b’) and the passive observer condition (panel ‘c’).
The top of the object was calculated. The participants were advised before each trial of which condition would have been tested next and, thus of which series of actions were expected of them when the signal (880 Hz/200 ms) was sounded. The three conditions and series of actions connected to the trials were:

(i) Individual Condition. Each participant was instructed to move his/her hand from the starting position, to reach for and grasp the stimulus sitting on the holder, and then to place it on a concave shaped frame matching the hand of the experimenter who was involved in the social condition (see below).

(ii) Social Condition. The starting position was the same as for the individual condition. Each participant was instructed to reach for and grasp the stimulus and to then hand the object to another person who was seated on the right side of the table (see Fig. 1b); that person was sitting at the table with his/her right hand resting on the concave frame in a supine position. The person took the object that was handed to him/her.

(iii) Passive Observer Condition. The starting position was the same as that of the individual condition. Each participant carried out the same action as that in the individual condition; the only difference was that in this case there was a passive observer seated on the participant’s right side who simply observed the scene (see Fig. 1c).

For all conditions, at the end of each trial, the participant put the stimulus back in its original position in the holder, returned to the starting position and pressed the starting switch. Following a variable interval (2–4 sec) the subsequent trial started. The order of conditions was randomized in each of the participants. The neurologically healthy participants performed 10 trials for each condition. The PD patients performed 10 trials for each condition in both the ‘on’ and ‘off’ states.

2.1.3. Data processing
The SMART analyzer software package (B/T/S) was used to analyse the data and provide a 3-D reconstruction of the marker positions as a function of time. The data were then filtered using a finite impulse response linear filter (transition band = 1 Hz, sharpening variable = 2, cut-off frequency = 10 Hz). Following this operation, the tangential speed of the wrist marker and the distance between the index finger and the thumb were computed. These data were used to determine the beginning and ending of the movement using a standard algorithm (i.e., threshold for movement onset and offset was ~ 5 cm/sec). For the reach-to-grasp phase, movement onset was defined as the earliest point in time in which wrist movement was noted. The offset was defined as the last point in time in which movement of the thumb and index finger was noted. For the place phase, the onset and offset of the movement were calculated using the same algorithm (i.e., threshold for movement onset and offset was ~ 5 cm/sec). The tangential speed of the marker positioned at the top of the object was calculated.

2.1.4. Data analysis
Statistical analysis was confined to the dependent variables held to be specifically relevant to the hypothesis being tested. In particular, these variables (see below) were chosen because, as previously demonstrated, they proved to be sensitive to variations in social contexts (Becchio et al., 2008a, 2008b; Georgiou et al., 2007; Sartori, Becchio, Bulgheroni, & Castiello, 2009). The action was performed in two steps, namely reaching for and grasping the stimulus (‘reach-to-grasp’ phase) and placing the stimulus on the concave frame or in the other person’s hand (‘place’ phase). Separate analyses were performed for each action step. The parameter linked to the grasp component was obviously considered only for the reach-to-grasp phase. Conversely, parameters concerned with the reaching component were analysed for both movement phases. The initiation time (i.e., the time at which the movement begins following the moment the signal sounded), the movement duration, the amplitude of the peak arm velocity, the deceleration time (i.e., the time from the peak velocity to the end of the movement), the time and the amplitude of the maximum distance between the markers positioned on the index finger and the thumb (i.e., the time of the maximum grip and the amplitude of the maximum grip aperture, respectively) were analysed for the ‘reach-to-grasp’ phase. The amplitude of peak velocity and the deceleration time for the ‘place’ phase were also calculated. These variables were considered suited to test our experimental hypothesis because we were dealing with a population (PD patients) showing impairment characterized by delayed movement onset (i.e., akinesia) and movement slowness (i.e., bradykinesia) during reach-to-grasp movements. Kinematic parameterization has instead been found to be largely unaltered with respect to the reach-to-grasp movement in neurologically healthy participants (Castiello, Stelmach, & Lieberman, 1993; Tresilian, Stelmach, & Adler, 1997). In view of the known movement delay in PD patients, absolute temporal values obtained from the two groups were expressed as a percentage of the movement duration (e.g., the absolute time at which the peak velocity occurred was expressed as a percentage of the movement duration). For each participant of the two groups, mean values per dependent measure were calculated for all experimental conditions. Given that the patients were assessed twice ‘off’ and ‘on’ medication, whereas the controls only once, three separate ANOVAs were conducted. Although this procedure could be considered redundant, it was applied to prevent the failure of ANOVA’s assumptions (i.e., independence of cases), which would invalidate the analysis. In the first ANOVA (A1), the effects of ‘off’ versus ‘on’ effects in PD are compared with ‘group’ as the within subjects factor (PD ‘off’ vs PD ‘on’). In the second ANOVA (A2), PD ‘off’ medication were compared with control subjects (between-subjects factor group: PD ‘off’ vs PD ‘on’). In the third ANOVA (A3), PD ‘on’ medication were compared with control subjects (between-subjects factor group: PD ‘on’ vs controls). For all three analyses the within-subject factor was experimental condition (individual, social, passive observer). Preliminary analyses were conducted to check for normality, sphericity (i.e., Mauchly test), linearity, univariate and multivariate outliers, the homogeneity of variance-
covariance matrices, and the multicollinearity. No concerning violations were noted. Post-hoc comparisons were conducted using simple effects and Bonferroni’s correction was applied (alpha level = .05).

3. Results

3.1. The global motor effects of dopaminergic medication in PD patients

As revealed by the A1 analysis, the main factor ‘group’ (PD ‘off’ vs PD ‘on’) was significant for a number of dependent measures. These results mirror those of studies where the effects of dopaminergic medication on the organisation of the reach-to-grasp movement in PD in ‘off’ and ‘on’ states were assessed (Castiello, Bennett, Bonfiglioli, & Peppard, 2000a, Castiello, Bonfiglioli, & Peppard, 2000b). Thus, for the sake of brevity, these results will be briefly summarised.

3.1.1. Reach-to-grasp phase

Initiation time \([F(1,15) = 31.06, p < .0001; 528 \pm 78 \text{ vs } 591 \pm 65 \text{ ms}]\) and movement duration \([F(1,15) = 44.23, p < .0001; 1327 \pm 156 \text{ vs } 1665 \pm 176 \text{ ms}]\) were shorter for PD in the ‘on’ than in the ‘off’ state. For the reaching component, the amplitude of peak reaching velocity was higher \([F(1,15) = 44.23, p < .0001; 690 \pm 84 \text{ vs } 598 \pm 78 \text{ mm/sec}]\) and deceleration time was shorter \([F(1,15) = 44.23, p < .0001; 52 \pm 7 \text{ vs } 54 \pm 6 \%]\) for patients in the ‘on’ than in the ‘off’ state. For the grasping component, the time of maximum grip aperture occurred earlier for PD patients in the ‘on’ than in the ‘off’ state \([F(1,15) = 37.21, p < .0001; 72 \pm 8 \text{ vs } 75 \pm 9 \%]\).

3.1.2. Place phase

Movement duration \([F(1,15) = 21.45, p < .0001; 1363 \pm 154 \text{ vs } 1746 \pm 189 \text{ ms}]\) and deceleration time \([F(1,15) = 30.25, p < .0001; 54 \pm 7 \text{ vs } 52 \pm 9 \%]\) were shorter for the PD patients in the ‘on’ than in the ‘off’ state.

3.2. Dopamine availability modulates the motor patterns of social intentions in PD patients

3.2.1. Reach-to-grasp phase

As revealed by A1 the group by experimental condition interaction was significant for initiation time \([F(1,15) = 31.48, p < .0001], \text{ movement duration } [F(1,15) = 47.36, p < .0001], \text{ the amplitude of peak velocity } [F(1,15) = 56.21, p < .0001], \text{ the time to peak velocity } [F(1,15) = 53.18, p < .0001], \text{ deceleration time } [F(1,15) = 52.12, p < .0001] \text{ and the time of maximum grip aperture } [F(1,15) = 44.35, p < .0001]. \text{ Post-hoc comparisons revealed that for the PD patients in ‘off’ state there were no differences across conditions for any of the considered dependent measures } (p < .05; \text{ Figs. 2 and 3}). \text{ For the PD in ‘on’ state, however, differences across conditions were noticed. Initiation time and movement duration were longer for the ‘social’ than for the ‘individual’ and the ‘passive observer’ conditions } (p < .05; \text{ Fig. 2a,b}). \text{ For the reaching component, the amplitude of peak velocity was lower } (\text{ Fig. 3a}) \text{ and deceleration time was longer } (\text{ Fig. 3b}) \text{ for the ‘social’ than for the ‘individual’ and the ‘passive observer’ conditions } (p < .05). \text{ For the grasping component, the time of maximum grip aperture was anticipated for the ‘social’ than for the ‘individual’ and the ‘passive observer’ conditions } (p < .05; \text{ Fig. 3c}). \text{ For the PD in the ‘on’ state, no significant differences between the ‘individual’ and the ‘passive observer’ condition for any of the dependent measures considered were noted } (\text{ Figs. 2 and 3}; p > .05). \text{ For A2 (PD ‘off’ vs controls), the group by experimental condition interaction was significant for initiation time } [F(1,15) = 37.06, p < .0001], \text{ movement duration } [F(1,15) = 52.32, p < .0001], \text{ the amplitude of the peak velocity } [F(1,15) = 48.13, p < .0001], \text{ the time to peak velocity } [F(1,15) = 41.22, p < .0001], \text{ deceleration time } [F(1,15) = 50.82, p < .0001] \text{ and the time of maximum grip aperture } [F(1,15) = 39.75, p < .0001]. \text{ Post-hoc comparisons revealed that for the PD patients in ‘off’ state there were no significant differences across conditions for any of the dependent measures considered } (p > .05; \text{ Figs. 2 and 3}). \text{ For the controls initiation time and movement duration were longer } (\text{ Fig. 2a,b}), \text{ the amplitude of peak velocity was lower } (\text{ Fig. 3a}), \text{ deceleration time was longer } (\text{ Fig. 3b}) \text{ and the time of maximum grip aperture was anticipated } (\text{ Fig. 3c}) \text{ for the ‘social’ than for the ‘individual’ and the ‘passive observer’ conditions } (p < .05). \text{ For this group no significant differences between the ‘individual’ and the ‘passive observer’ condition for any the dependent measures considered were noted } (\text{ see Figs. 2 and 3}; p > .05).
3.2.2. Place phase

As revealed by A1 (PD ‘off’ vs. PD ‘on’), the group by experimental condition interaction was significant for movement duration \([F(1, 15) = 48.11, p < .0001]\) and deceleration time \([F(1, 15) = 34.28, p < .0001]\). Post-hoc comparisons revealed that when the PD patients were in ‘off’ state, both movement duration and deceleration were similar across conditions \((p_s > .05; \text{Fig. 4a,b})\). When the PD patients were in ‘on’ state movement duration and deceleration time were longer for the ‘social’ than for the ‘individual’ and the ‘passive observer’ conditions \((p_s < .05; \text{Fig. 4a,b})\). And no significant differences between the ‘individual’ and the ‘passive observer’ conditions for movement duration and deceleration time were noted \((p_s > .05; \text{Fig. 4a,b})\). When contrasting the performance of PD patients in ‘off’ state and controls (A2), the group by experimental condition interaction was significant for both movement duration \([F(1, 15) = 41.09, p < .0001]\) and deceleration time \([F(1, 15) = 28.31, p < .0001]\). Post-hoc comparisons revealed that no differences for the PD patients in ‘off’ state across conditions were found \((p_s > .05; \text{Fig. 4a,b})\). For the controls movement duration and deceleration time were longer for the ‘social’ than for the ‘individual’ and the ‘passive observer’ conditions \((p_s < .05; \text{Fig. 4a,b})\). And no significant difference between the ‘individual’ and the ‘passive observer’ condition was noted \((p > .05; \text{Fig. 4a,b})\).

3.3. PD patients in ‘on’ state and controls share kinematics for action intention

3.3.1. Reach-to-grasp phase

When considering A3 (PD ‘on’ vs. controls), the interaction group by experimental condition was not significant for initiation time \([F(1, 15) = 2.01, p > .05]\) and movement duration \([F(1, 15) = 1.21, p > .05]\). For both controls and PD patients in ‘on’ state initiation time and movement duration were longer, the amplitude of peak velocity was lower, deceleration time was longer and the time of maximum grip aperture was

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**Fig. 3** — Graphical representation of the mean values for the amplitude of peak velocity (panel ‘a’), deceleration time (panel ‘b’) and the time of maximum grip aperture (panel ‘c’) per group and experimental condition for the ‘reach-to-grasp’ phase. Conventions as for Fig. 2.

**Fig. 4** — Graphical representation of the mean values for movement duration (panel ‘a’) and deceleration time (panel ‘b’) per group and experimental condition for the ‘place’ phase. Conventions as for Fig. 2.
anticipated for the ‘social’ than for the ‘individual’ and the
‘passive observer’ conditions (see Figs. 2 and 3).

3.3.2. Place phase
The interaction group by experimental condition was not
significant for movement duration \( F(1,15) = 1.19, p > .05 \) and
deceleration time \( F(1,15) = 3.34, p > .05 \). For both controls and
PD patients in ‘on’ state movement duration and deceleration
time were longer for the ‘social’ than for the ‘individual’ and
the ‘passive observer’ conditions (Fig. 4).

4. Discussion
This study investigated the effect of intention in PD patients
who were asked to grasp an object and to move it from one
place to another in two main conditions: in the first, an object
was simply displaced (individual condition); in the second, the
participant handed an object to a person (social condition).
These effects were tested in PD patients undergoing dopami-
nergic treatment in ‘on’ or ‘off’ states, as well as in neuro-
logically healthy participants.

Consistent with our initial hypothesis, neurologically
healthy participants and PD patients in ‘on’ state exhibited
different motor patterns for the individual versus social con-
ditions. Both planning and execution of movement were
found to be sensitive to the experimental conditions. The participants took longer to initiate the ‘social’ with respect to
the ‘individual’ action and both the ‘reach-to-grasp’ and the
‘place’ phases were found to be sensitive to the experimental
conditions. The kinematic parameters of the reach-to-grasp
phase were found to be different for the ‘social’ condition:
the longer movement duration, the lower peak velocity
amplitude and the longer deceleration times imply that this
phase required a more careful approach when the object was
handed to another person. In the same way, an anticipated
maximum grip aperture time for the social condition implies
that a longer ‘closing’ time is needed to grasp an object when
it has to be handed to another person. When the object was
placed in the concave frame (‘individual’ condition), finger
hand shaping and manipulation might be less crucial as the
object could be placed there from any direction without
compromising the action goal. In kinematic terms, these re-
results are consistent with recent evidence showing that hand-
shaping modulation depends on the need for end-goal accu-

Just as for the ‘reach-to-grasp’ phase, the kinematics of the
‘place’ phase were different for the ‘social’ with respect to the
‘individual’ and the ‘passive-observer’ conditions. Study re-
results suggest that movements are more careful when the goal
is linked to a social interaction. Longer movement duration
longer deceleration phase were, in fact, observed. In other
words, handing an object to another person entails a more
careful action with respect to placing the same object in an
inanimate container (Becchio et al., 2008a, 2008b, Becchio
et al., 2010; Sartori et al., 2009). Taken together, the findings
in the control participants and in the PD patients in ‘on’ state
show how different intentions are mirrored in action kine-
matics: specific patterns connote and distinguish actions
executed with a social goal from those motivated by an indi-

The study’s most significant finding is that the kinematics of
the PD patients in ‘off’ state seem unaffected by the influ-
ence of social intentions. Evidence that dopamine-depleted
PD patients are unable to translate social intentions into
specific motor patterns implies that dopamine projections are
indeed necessary in these situations. As postulated by some,
engagement in social interaction and processing of rewards
requires BG involvement (Izuuma, Saito, & Sadato, 2008;
Lebréton et al., 2009; Pfeiffer et al., 2014; Spreckelmeyer
et al., 2009) and dopamine neurons play a central role in the
reward circuit (Schultz, 2002; Wise, 2002). Behavioural and
pharmacological studies on dopamine pathways have
described associations between the mesolimbic and nigro-
striatal pathways, reward and motor activity (Kobb & Le Moal,
1997; Panksepp, 1998; Phillips, Blaha, Pfau, & Blackburn,
1992; Shizgal, 1997; Wise, 2004). Much of the causal evidence
that the dopamine systems mediate rewards is rooted in
studies on the pharmacological blockade of dopamine re-
ceptors in animals. Multiple evidence have shown that
dopamine antagonists reduce reward-directed behaviour in a
subtle although clear way that cannot be explained by
sensorimotor impairments alone (for review see Berridge
& Robinson, 1998; Berridge, Robinson, & Aldridge, 2009).
Positron emission tomography (PET) and functional magnetic
resonance imaging (fMRI) studies in humans have revealed
that the presentation of rewards modulates activity in dopa-
mine target sites such as the nucleus accumbens, neostriatum
or the prefrontal cortex (Breiter et al., 1997; Firestone et al.,
1996; Koepp et al., 1998; Volkow et al., 1996). It follows that
dopamine depletion might be associated to impaired reward
components. As a result, although the PD patients in ‘off’ state
retain the motor capacity to perform reach-to-grasp move-
ments, they fail to modulate movements during social in-
teractions, which may represent a reward in itself.

At this stage, the question is why do the kinematics of
the PD patients in ‘off’ state seem unaffected by the influ-
ence of social intentions? A possible explanation is that
dopaminergic therapy not only significantly improves clinical
scores on the UPDRS and the intensive aspects of the
movements (e.g., speed), but it also encodes implicit moti-
vational signals for the motor system (Mazzoni, Hristova,
& Krakauer, 2007). This would be in line with the role of
tonic levels of ventral striatum dopamine in reward-seeking.
In this framework, the fact that dopaminergic therapy re-
establishes the ability to modulate movement kinematics
depending on the kind of intentions guiding the action
might indicate a role of tonic dopamine levels in encoding
the motivation to act socially, which in turn translate into a
different kinematic pattern.

Taken together, the results reported here might have im-
lications regarding the effect of dopaminergic medication on
the ability to modulate kinematic parameterization depend-
ing on the intention to act. Furthermore, they strengthen the
idea that the engagement in social interaction and the pro-
cessing of rewards share common anatomical substrates.
Sectors of the BG encoding reward components may also be
involved in motivating interactions in social contexts, thus
supporting the hypothesis that the social nature of human
primates is based on the rewarding nature of the active participation in social interaction.

5. Limitations of the present study

Despite the novelty of our findings, there are a few limitations that need to be addressed with respect to study design and the interpretation of the results. First of all, it must be emphasized that given the highly complex functional anatomy of, for example, the frontostriatal connections and loops and also considering that PD compromises not only the dopaminergic neurotransmitter system, our findings might be taken with caution and be opened to different interpretations. One possibility is that neurotransmitters other than dopamine help mediate motor adaptation to social situations, since patients with PD are known to have deficits in multiple non-dopaminergic neurotransmitter systems (Fox, Brotchie, & Lang, 2008; Fifl et al., 2013) which contribute to the parkinsonian motor disorder. Second, the patients were always tested in the ‘off’ and then in the ‘on’ state. For recruitment problems the opposite order was never used. Although there is a possibility that the results obtained in the ‘on’ state could have been influenced by patients having already performed the task in the ‘off’ state, given the well-rehearsed nature of the task (i.e., people reach to grasp objects at all occasions), we feel that this might not be the case. Finally, we were not in the position to track the gaze of participants during the different tasks. Gaze direction is a potent social cue, which is indicative of other persons’ goals. In everyday life, it is intuitively apparent that gaze may provide an important cue when acting on a shared goal. A possibility that we cannot exclude is that the effects reported for the PD patients in the ‘off’ state has to be partly ascribed to the fact that somewhat they were not engaging gaze with the partner during the social task and this produced a lack of understanding of the motor intention of others. In this respect, it is known that brain activity in the VS decreases when eye gaze is directed away during face processing (Kampe, Frith, Dolan, & Frith, 2001). Depending on the direction of gaze, face processing can activate dopaminergic regions that are strongly linked to reward prediction, indicating once again, that central reward systems may be engaged during the initiation of social interactions (Kampe et al., 2001). In future studies, it would be informative to further explore this aspect.

 Altogether, we believe that in light of the scarcity of studies investigating the role played by subcortical structures during social encounters in real-time and, despite the limitations discussed above, the present study provides important insights into the mechanisms underlying the subjective experience of engagement in social interaction.

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