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Dopamine depletion affects communicative intentionality in Parkinson's disease patients: Evidence from action kinematics

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ABSTRACT

Appropriate communication is at the heart of successful, healthy social interactions in humans. Deficits in social communication are a hallmark of several neurological and psychiatric disorders. Yet, very little research has been devoted to understanding the mechanisms underlying these issues. It has been suggested that dopamine is a candidate neurotransmitter system involved in stimulating communication in individuals that are not highly motivated to communicate. A typical model to study dopaminergic dysfunctions in humans is represented by Parkinson's disease (PD) patients, who show motor, cognitive and motivational symptoms. Our study aimed to investigate the effects of social communication 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 communicative intention motivating the action to be performed was evaluated both in “on” (with L-Dopa) and “off” (without L-Dopa) states. In two main conditions, participants were requested to reach towards, grasp an object, and either simply lift it (individual condition) or lift it with the intent to communicate a meaning to a partner (communicative condition). Movements' kinematics was recorded using a three-dimensional motion analysis system. The results indicate that kinematics is sensitive to communicative intention and that L-Dopa treatment has positive effects on translating communicative intentions into specific motor patterns in PD patients. Although the to-be-grasped object remained the same both the controls and the PD patients in an ‘on’ state adopted different kinematic patterning for the ‘individual’ and the ‘communication’ conditions. The PD patients in the ‘off’ state, instead, were unable to kinematically differentiate between the two conditions. We contend that social and communicative impairments are associated with abnormalities in dopaminergic pathways.

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1. Introduction

Differently from other species, for human beings the possibility to communicate is not confined to a limited number of signals. Every action can, in principle, become a communicative signal. The only pre-requisite is that the action is intended as communicative by the actor and recognized as such by the partner (Bara, 2010). For example, the action of touching one's earlobe – which is *per se* non-communicative – could become communicative in the context of a poker card game, when two players agree that touching the earlobe means: "Drop out the current hand". In this perspective, every action could become a communicative message from one person to another person (Bara, 2010). Pragmatic models of communication and, in particular the theory of cognitive pragmatics by Bara (2010), place emphasis on 'communicative intentions' as a central characteristic of communicative acts, which can be regarded as a special form of social intentions (Bara, 2010). Indeed, communicative intentions are not only directed towards another agent, like other communicative acts, but require, as part of their content, that the other agent recognizes the speaker's intention to communicate (Grice, 1989). So conceived, communicative intentions (a) always occur in the context of a social interaction with a partner, (b) are overt, in the sense that they are intended to be recognized by the partner and (c) their satisfaction consists precisely in the fact that they are recognized by the partner (Bara, 2010).

Anomalous motor behaviour have been shown to robustly correlate with measures of communicative function, suggesting an involvement of the sensorimotor system in impaired communication. At the neural level this is supported by the evidence that communicative and motor behaviours have all been linked to different areas within the basal ganglia via a series of parallel (yet overlapping) projections from and to frontal cortical regions (Alexander, DeLong, & Strick, 1986; Haber, 2003; Middleton & Strick, 2001). The mapping of cortical-striatal projections has vastly contributed to increased understanding of how the basal ganglia contribute to control both motor and socio-emotional behaviour (Calzavara, Mailly, & Haber, 2007; Middleton & Strick, 2001; Parent & Parent, 2006). The basal ganglia are, in fact, implicated in sensorimotor learning and receive a strong dopaminergic signal, which has been shown to play an important role in communicative behaviour (Plavén-Sigray et al., 2014; Schröder & Dengler, 2013). In this respect, studies in Parkinson's disease (PD) patients 'on' and 'off' their dopaminergic replacement therapy medication suggest that the neurotransmitter plays a crucial role in various forms of emotional communication (for review see Schröder & Dengler, 2013). There is evidence that dopaminergic medication improves emotional speech production (De Letter et al., 2007) and recognition of emotional facial expressions (Sprengelmeyer et al., 2003). Despite this indication, however, how the dopaminergic system can affect the ability to plan and to execute action in a communicative context remains largely unexplored. More studies testing PD patients 'on' and 'off' their dopaminergic replacement therapy are needed for a systematic investigation of the impact of the dopamine neurotransmitter on the function of the neuronal systems involved. They are also required for further elucidation of whether the observed changes are restricted to emotional communication or if rather they extend to socially oriented, communicative behaviours requiring selection and sequencing of actions. Therefore the aims of the present study were then to investigate movement planning and execution by non-demented PD patients intending to communicate and to evaluate the effect of dopaminergic therapy on these patients while in "on" (with L-Dopa) and "off" (without L-Dopa) states to this endeavour. More specifically, we investigate the role that dopamine might play in shaping intentional mechanisms driving an action to a different and yet unexplored form of intentionality, i.e., communicative intentionality. This would provide the first measure of the influence that communicative intentions exert on the level of action kinematics in PD patients and would provide a demonstration of how dopamine modulates such process.

We capitalized on a paradigm which has been able to reveal different kinematic patterning for the same action performed with an individual and a communicative intent in neurologically healthy participants (Sartori, Becchio, Bara, & Castiello, 2009a). In particular, PD patients in 'off' or 'on' states and neurologically healthy control participants were asked to carry out intentional actions in an individual or a communicative context. They performed the same goal-directed action in two different contexts which were operationalized through an individual task and a communicative task. In the individual task, participants were requested to reach towards, grasp and lift either a blue or a green spherical object according to one of five predetermined sequences composed of coloured spheres. The communicative task was identical to the individual task except that participants executed the sequence with a communicative intent. Each of the sequences of blue and green spheres represented a different word meaning (e.g., chair, pen, table). Participants were asked to select a word meaning (and thus a sequence) and to communicate it to a partner by lifting the spheres in the predetermined order. Based on a conversion table, the partner had to interpret the word meaning conveyed by the communicated sequence. What we were interested in was to ascertain whether the intention to communicate reflected on how the spheres were reached towards and grasped.

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 with the intent to communicate. In addition, if the dopamine system plays a role in translating action into social communication, 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

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 years. 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 participant was tested in two counterbalanced sessions carried out in different days. In one session they were tested before receiving his/her first morning dose of Carbidopa–Levodopa, at least 12 h after the last dose (thus in 'off' state). In the second session they were tested at least two hours 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 skeletomotor dysfunctions 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 = 94, $Z = -1.214$, $p = .28$). 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.

2.2. Stimuli

Stimuli were two plastic spheres (diameter: 4 cm, weight: 5 g) one blue and one green positioned on a black table at a 30 cm distance from a hand starting location along the midsagittal plane (Fig. 1).

2.3. Apparatus

The working surface was a rectangular table (100 × 100 cm). The participant was seated on a height adjustable chair. Before each trial, the right hand of each participant rested on a starting pad (brown velvet cloth 7 × 6 cm). The starting pad was attached 3 cm away from the edge of the table on the midsagittal axis 15 cm anterior to the subject's midline (see Fig. 1). Infrared reflective markers (.25 mm diameter) were taped to the following points on the participants' right upper limb: (1) wrist – dorsodistal aspect of the radial styloid process; (2) thumb – ulnar side of the nail; and (3) index finger – radial side of the nail. An additional marker was attached to the top of the object. Markers were fastened using double-sided tape. Movements were recorded using a SMART motion analysis system [Bioengineering Technology & Systems (B|T|S)]. Six infrared cameras (sampling rate 100 Hz) placed in a circle around the table captured the movement of the markers in 3D space. Co-ordinates of the markers were reconstructed with an accuracy of .2 mm over the field of view. The standard

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	UPDRS (on meds)	UPDRS (off meds)	MMSE score	Dopaminergic medication	Clinical signs					
										T	R	B	A	P	F
1	52	M	1	I	L	25	28	29	.5–0–0.5	–	+	+	+	–	–
2	55	F	2	II	R	41	54	30	1–1–1*	–	–	+	+	–	–
3	51	F	1	I	R	37	40	29	.5–0–.5	–	+	R	–	–	–
4	53	M	1	I	L	25	31	30	1–0–1*	–	+	+	+	–	–
5	56	M	2	I	L	44	57	30	1–1–1*	L	+	+	+	–	–
6	51	M	3	II	L	51	62	29	1.5–1.5–1.5*	–	+	R	+	–	–
7	53	F	1	I	L	44	53	30	1–0–1	–	+	+	–	–	–
8	55	M	1	I	R	28	31	30	.5–.5–.5	–	–	+	–	–	–
9	55	F	1	II	R	32	41	30	1–0–1	–	–	R	L	–	–
10	59	F	2	II	L	51	62	30	1–1–1	–	–	+	+	–	–
11	52	F	2	II	L	22	39	30	.5–.5–.5†	L	L	+	+	–	–
12	52	M	1	I	L	40	55	29	1–0–1	–	–	R	–	–	–
13	51	F	3	II	R	30	43	30	1–0–1	–	–	+	+	–	–
14	57	M	3	II	R	26	31	30	.5–.5–.5†	–	+	R	–	–	–
15	51	M	2	I	L	57	61	30	1–1–1	L	+	+	–	–	–
16	53	F	2	I	L	42	51	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, 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. ** The same group of PD patients took part in an another published experiment (Straulino et al., 2015).

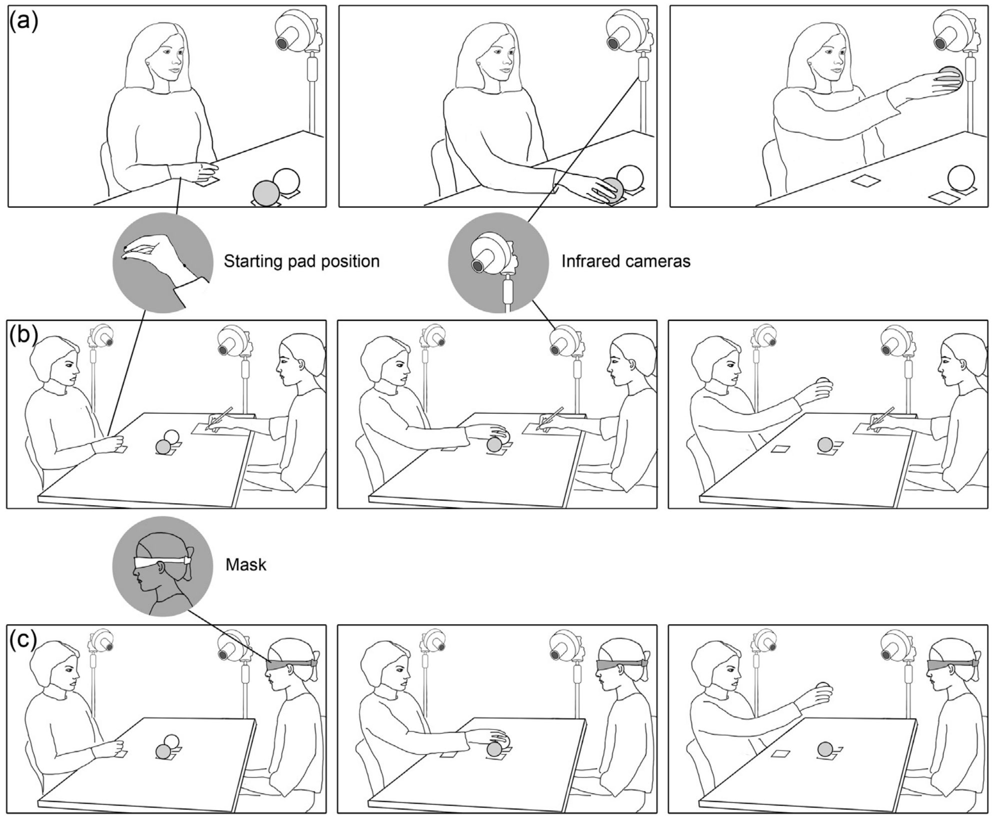

Fig. 1 – Panel 'a' depicts the sequence of events for the 'individual' condition. From left to right, the participant is resting her hand on a starting pad, then she reaches towards, grasps and lifts the object. Panel 'b' depicts the sequence of events for the 'communicative' condition. From left to right, the participant is resting her hand on a starting pad, then she reaches towards, grasps and lifts the object on the basis of the chosen colour sequence as to communicate a specific word, then the co-experimenter writes on a paper sheet the deciphered word. Panel 'c' depicts the sequence of events for the 'control gaze' condition. From left to right, the participant is resting her hand on a starting pad, then she reaches towards, grasps and lifts the object on the basis of the chosen colour sequence as to communicate a specific word, though the co-experimenter is blindfolded.

deviation of the reconstruction error was .2 mm for the vertical (Y) axis and .3 mm for the two horizontal (X and Z) axes.

2.4. *Procedure*

Participants were presented with five different colour sequences drawn on a paper sheet that remained visually available for the entire duration of the session. They were instructed to choose four sequences and decide an order of sequence presentation. Each sequence was characterized by a specific colours combination (e.g., blue, blue, green, green). The task was to reach, grasp and lift the spheres on the basis of the colour order characterizing each sequence. Movement began as soon as a tone (880 Hz/200 msec) was presented. There were four experimental conditions administered to participants in a counterbalanced order:

2.4.1. *Individual condition*

In this condition, a participant, seated alone, was instructed to reach, grasp and lift the spheres in the order dictated by the sequences (see Fig. 1a).

2.4.2. *Communicative condition*

In this condition, two participants (a naïve subject and a co-experimenter) were seated opposite to each other (see Fig. 1b, first panel from the left). Participants were made to believe that the co-experimenter was just another naïve participant (note that for the experimental sessions involving the PD participants the co-experimenter involved in day 1 was different from that involved in day 2). Both were given a conversion table in which each of the five sequences corresponded to a word. The task for the participants was to reach towards, grasp and show to the co-experimenter one of the sequences by using the coloured spheres as to allow her to decipher the word corresponding to the sequence (see Fig. 1b). Once the participant had completed the sequence, the co-experimenter did verbalize the communicated word. To avoid that the co-experimenter could guess the last word by exclusion, five different sequences were included, but only 4 trials were performed.

2.4.3. *Control gaze condition*

To avoid the possibility that participants looked more at their partner when they were in the communicative intent condition affecting their action kinematics, in this condition the eyes of the co-experimenter were covered by a mask (see Fig. 1c). Obviously the co-experimenter was unable to report the word signalled by the sequence implemented by the participants. Nevertheless, it was told to the participant that the co-experimenter will be asked to report the communicated word by looking at a video recording, subsequently. The scope of this condition was to determine whether the intention to communicate remained, being not affected by the time spent in engaging the co-experimenter's gaze.

2.4.4. *Control meaning condition*

In this condition, two participants (a naïve subject and a co-experimenter) were seated opposite to each other as for the ‘communicative’ condition. Both were given a conversion table in which each of the five sequences corresponded to meaningless strings of letters. Each string was created by eliminating one letter or substituting one or two letters from meaningful words (e.g., mbre, ntore). The task for the participants was to reach towards, grasp and show to the co-experimenter one of the sequences by using the coloured spheres as to allow her to decipher the word corresponding to the sequence (see Fig. 1b). Once the participant had completed the sequence, the co-experimenter did write the communicated words. This condition allowed to verify whether action kinematics can be affected by whatever intent to communicate or whether it is only a ‘meaningful’ type of communication that determines the hypothesized effects.

These tasks satisfy the three conditions of communication outlined within the introduction section. The first refers to the idea that an individual cannot carry out a communicative act single-handedly, since it is a social activity that requires more than one participant for it to take place. This condition was assessed by manipulating the possibility of social interaction with the partner. For the communicative condition, but not for the individual and the blindfolded condition, the action sequence occurred in the context of a social interaction with a partner. Furthermore, only for the communicative condition, the action sequence “was intended to be recognized by the partner” (this satisfies the second condition). Finally, we assessed the satisfaction of the third condition by asking the partner to report to the participant the communicated word. This ensured the closing of the loop (Frith & Frith, 2010), i.e., recognition of the communicative intent by the partner (c).

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. No instructions regarding how to perform the movement were given. Following a variable interval (2–4 sec), the subsequent trial started. Preliminary analyses revealed that the stimulus colour (i.e., blue or green) resulted in no significant differences in kinematics, therefore data for ‘blue’ and ‘green’ stimuli were collapsed. This resulted in four trials *per* sequence, for a total of 16 trials *per* participants.

2.5. *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., the threshold for movement onset and offset was ~5 cm/sec). The action was performed in two steps, namely reaching for and grasping the stimulus (‘reach-to-grasp’ phase) and showing the stimulus to the other person (‘show’ phase). 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 ‘show’ phase (i.e., from object grasping to the maximum lift from the table surface), 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). In order to track the displacement of the object during the showing phase the spatial trajectory of the marker positioned at the top of the object was calculated. Separate analyses were performed for each action step. In order to test our specific experimental hypothesis we relied on dependent measure which, as previously demonstrated, show differences when comparing individual versus social attitudes in both neurologically healthy (Georgiou, Becchio, Glover, & Castiello, 2007; Becchio, Sartori, Bulgheroni, & Castiello, 2008a; Becchio, Sartori, Bulgheroni, & Castiello, 2008b; Sartori, Becchio, Bulgheroni, & Castiello, 2009b) and PD patients (Straulino, Scaravilli, & Castiello, 2015). They were 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. For the ‘show’ phase the amplitude of the maximum height of the wrist trajectory from the working surface were calculated. All these variables were also considered to be suited for testing 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 slowness 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).

2.6. *Data analysis*

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 control only once, three separate ANOVAs were conducted. Although this procedure could be considered redundant, it was applied to prevent the failure of ANOVA's assumption (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 was compared with control subjects (between-subjects factor group: PD ‘off’ *vs* controls). In the third ANOVA (A3), PD ‘on’ medication was compared with control subjects (between-subjects factor group: PD ‘on’ *vs* controls). For all three analyses the within-subject factor was experimental condition (individual, communicative, control gaze, control meaning). 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). For the considered dependent measures the performance of patients who performed the first session in the ‘on’ state did not differ from the performance of patients who performed the second session in ‘on’ state ($p_s > .05$). And, the performance of patients who performed the first session in the ‘off’ state did not differ from the performance of patients who performed the second session in the ‘off’ state ($p_s > .05$).

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 summarised.

3.1.1. *Reach-to-grasp phase*

Initiation time [$F(1,15) = 48.06$, $p < .0001$, $|^2_p = .73$; 556 ± 69 *vs* 705 ± 77 msec] and movement duration [$F(1,15) = 44.23$, $p < .0001$, $|^2_p = .81$; 1288 ± 147 *vs* 1712 ± 198 msec] were shorter for PD in the ‘on’ than in the ‘off’ state. For the reaching component, the amplitude of peak reaching velocity was higher [$F(1,15) = 38.72$, $p < .0001$, $|^2_p = .58$; 702 ± 85 *vs* 555 ± 69 mm/sec] and deceleration time was shorter [$F(1,15) = 67.18$, $p < .0001$, $|^2_p = .59$; 52 ± 8 *vs* 56 ± 9%] 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 [$F(1,35) = 41.09$, $p < .0001$, $|^2_p = .68$; 75 ± 7 *vs* 80 ± 9%].

3.1.2. *Show phase*

For the amplitude of maximum trajectory height no differences between PD patients in the ‘on’ than in the ‘off’ state were found [$F(1,15) = 2.02$, $p > .05$, $|^2_p = .12$; 362 *vs* 367 mm].

3.2. *Dopamine availability modulates the motor pattern of communicative intentionality 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 [$F(1,15) = 9.22$, $p < .01$, $|^2_p = .54$], movement duration [$F(1,15) = 50.12$, $p < .0001$, $|^2_p = .72$], the amplitude of peak velocity [$F(1,15) = 32.41$, $p < .0001$, $|^2_p = .82$], deceleration time [$F(1,15) = 46.25$, $p < .0001$, $|^2_p = .63$] and the time of maximum grip aperture [$F(1,15) = 56.21$, $p < .0001$, $|^2_p = .58$]. 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 ($p_s > .05$; Figs. 2 and 3). For the PD in ‘on’ state, however, differences across conditions were noticed. Initiation time and movement duration were longer for the ‘communicative’ and the ‘control gaze’ than for the

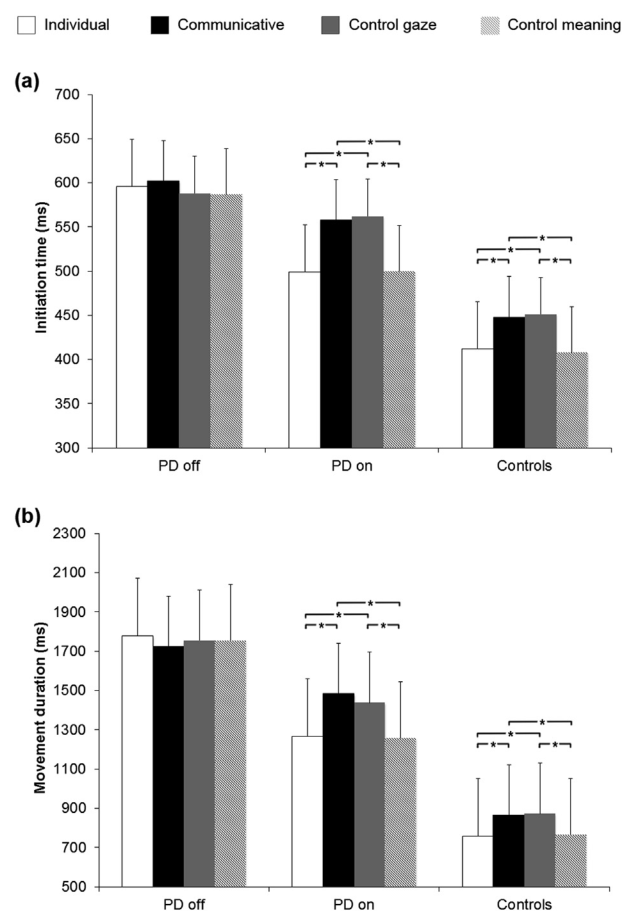

Fig. 2 – Graphical representation of the mean values across the different experimental conditions for initiation time (panel ‘a’) and movement duration (panel ‘b’). Bars represent standard deviation. ms = milliseconds.

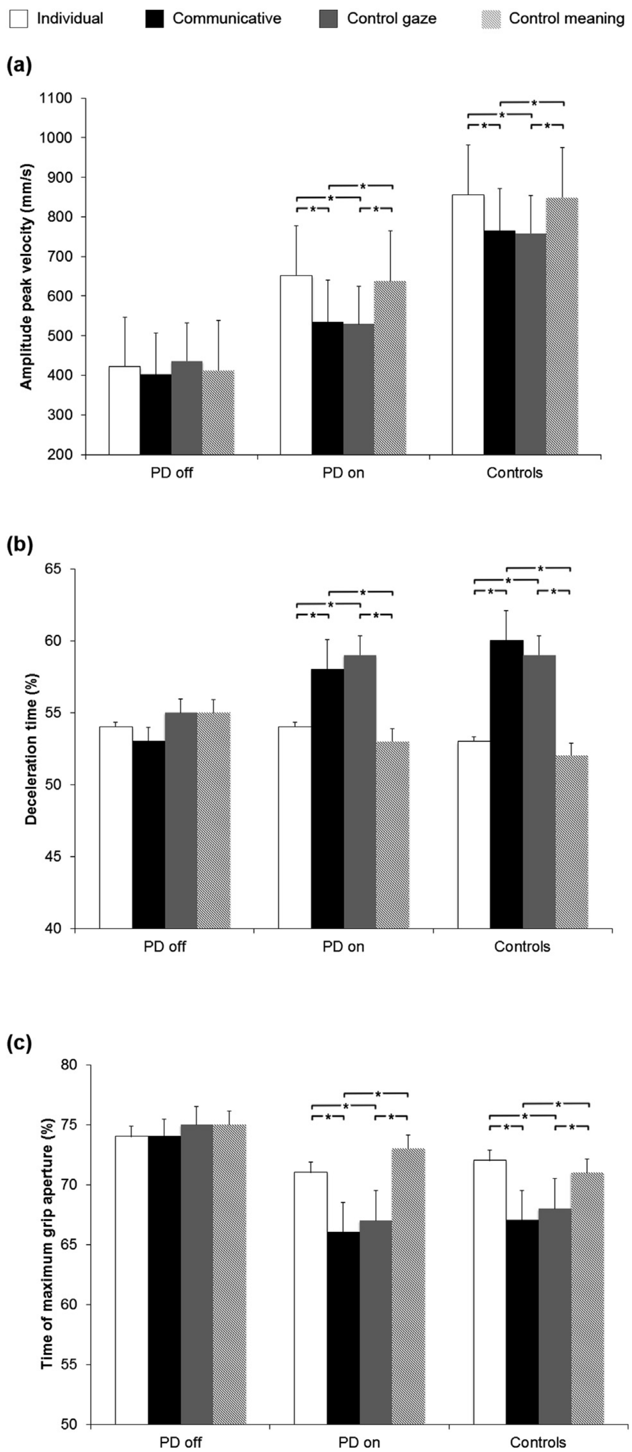

Fig. 3 – Graphical representation of the mean values across the different experimental conditions for the amplitude of wrist peak velocity (panel 'a'), deceleration time (panel 'b') and the time of maximum grip aperture (panel 'c'). Bars represent standard deviation. mm/sec = millimeters by seconds; ms = milliseconds; % = percentage.

'individual' and the 'control meaning' conditions ($p_s < .05$; Fig. 2a, b). For the reaching component, the amplitude of peak velocity was lower (Fig. 3a) and deceleration time was longer (Fig. 3b) for the 'communicative' and the 'control gaze' than for the 'individual' and the 'control meaning' conditions ($p_s < .05$). For the grasping component, the time of maximum grip aperture was anticipated for the 'communicative' and the 'control gaze' than for the 'individual' and the 'control meaning' conditions ($p_s < .05$; Fig. 3c). For the PD patients in the 'on' state, no significant differences between the 'communicative' and the 'control gaze' conditions and between the 'individual' and the 'control meaning' conditions for any of the dependent measures considered were noted (Figs. 2 and 3; $p_s > .05$). For A2 (PD 'off' *vs* controls), the group by experimental condition interaction was significant for initiation time [$F(1,15) = 25.12$, $p < .0001$, $|^2_p = .62$], movement duration [$F(1,15) = 60.31$, $p < .0001$, $|^2_p = .75$], the amplitude of the peak velocity [$F(1,15) = 44.29$, $p < .0001$, $|^2_p = .81$], deceleration time [$F(1,15) = 26.02$, $p < .001$, $|^2_p = .59$] and the time of maximum grip aperture [$F(1,15) = 45.15$, $p < .0001$, $|^2_p = .67$]. Post-hoc comparisons revealed that for the PD patients in 'off' state there were no significant differences across conditions for any the dependent measures considered ($p_s > .05$; Figs. 2 and 3). For the controls initiation time and movement duration were longer (Fig. 2a, b), the amplitude of peak velocity was lower (Fig. 3a), deceleration time was longer (Fig. 3b) and the time of maximum grip aperture was anticipated (Fig. 3c) ($p_s < .05$) for the 'communicative' and the 'control gaze' than for the 'individual' and the 'control meaning' conditions. For this group no significant differences between the 'communicative' and the 'control gaze' conditions and between the 'individual' and the 'control meaning' conditions for any the dependent measures considered were noted (see Figs. 2 and 3; $p > .05$).

3.2.2. *Show phase*

As revealed by A1 (PD 'off' *vs* PD 'on'), the group by experimental condition interaction was significant for the amplitude of maximum trajectory height [$F(1,15) = 60.22$, $p < .0001$, $|^2_p = .70$]. Post-hoc comparisons revealed that when the PD patients were in 'off' state, the amplitude of maximum trajectory height was similar across conditions ($p_s > .05$; Fig. 4).

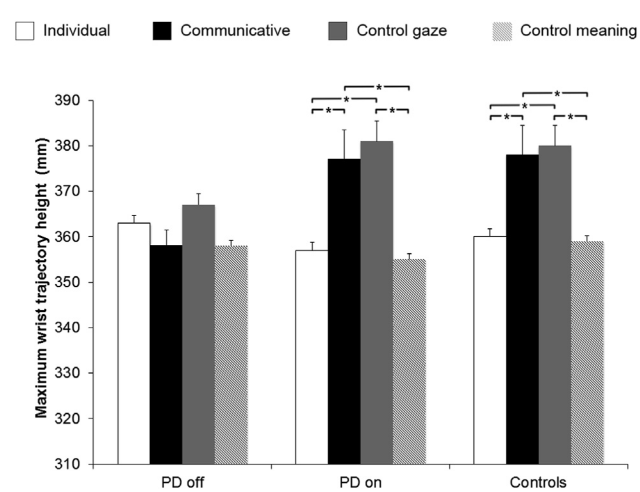

Fig. 4 – Graphical representation of the mean values across the different experimental conditions for the maximum trajectory height. Bars represent standard deviation. mm = millimeters.

When the PD patients were in 'on' state the amplitude of maximum trajectory height was greater for the 'communicative' and the 'control gaze' than for the 'individual' and the 'control meaning' conditions ($p_s < .05$; Fig. 4). No significant differences between the 'communicative' and the 'control gaze' conditions and between the 'individual' and the 'control meaning' conditions were noted ($p_s > .05$; Fig. 4). When contrasting the performance of PD patients in 'off' state and controls (A2), the group by experimental condition interaction was significant for the amplitude of maximum trajectory height, [$F(1,15) = 10.28$, $p < .001$, $|^2_p = .52$]. Post-hoc comparisons revealed that when the PD patients were in 'off' state, the amplitude of maximum trajectory height was similar across conditions ($p_s > .05$; Fig. 4). For the controls, maximum trajectory height was higher for the 'communicative' and the 'control gaze' than for the 'individual' and the 'control meaning' conditions ($p_s < .05$; Fig. 4). No significant differences between the 'communicative' and the 'control gaze' conditions and between the 'individual' and the 'control meaning' conditions were noted ($p_s > .05$; Fig. 4).

3.3. *PD patients in 'on' state and controls share kinematics for action communicative intentions*

3.3.1. *Reach-to-grasp phase*

When considering A3 (PD 'on' *vs* controls), the interaction group by experimental condition was not significant for any of the considered dependent measures ($p_s > .05$). 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 anticipated for the 'communicative' and the 'control gaze' than for the 'individual' and the 'control meaning' conditions (see Figs. 2 and 3).

3.3.2. *Show phase*

The interaction group by experimental condition was not significant for the amplitude of maximum trajectory height [$F(1,15) = 2.03$, $p > .05$, $|^2_p = .12$]. For both controls and PD patients in 'on' state the amplitude of maximum trajectory height was higher for the 'communicative' and the 'control gaze' than for the 'individual' and the 'control meaning' conditions (Fig. 4).

3.4. *Correlation analysis*

During the 'show' phase both the controls and the PD in 'on' state exhibited an higher amplitude of maximum trajectory height for the 'communicative' and the 'control gaze' than for the 'individual' and the 'control meaning' conditions. To ascertain whether these effects were dictated by the need to better show the stimulus to the partner for communicative purposes, we correlated the amplitude of maximum trajectory height with the height of the partner's eyes as measured from the table surface – remember that the partner was a co-experimenter, therefore we were in the position to take this measurement post-hoc. Pearson's correlation coefficients were applied. For both the controls and the PD in 'on' state there was an high correlation ($r = .94$, $p < .01$) between maximum trajectory height and height of the partner's gaze, whereas for the PD in the 'off' state the correlation amongst the same measures were nominally lower ($r = .28$, ns). This pattern was found to be true for all of the subjects studied.

4. Discussion

We set out to investigate whether dopamine depletion affects the ability of PD patients to modulate kinematic parameterization depending on the communicative nature characterizing a goal-directed action. What the present results reveal is that in neurologically healthy participants and PD patients in the 'on' state the imposition of a communicative intent is not neutral with respect to action kinematics: the intention to communicate alters the parameterisation of the movement. Therefore, the very same action – reach towards and grasp a sphere and show it – is executed differently depending on whether it carries a communicative or a purely individual intent. Along these lines, for instance, a longer arm deceleration phase and an anticipated time of maximum grip aperture for the 'communication' condition may signify that when the task was to use the object as to communicate to another person, participants needed more time during the final phase of the movement as to compute a careful approach to the object. This is because how fingers are put on an object changes with respect to the accuracy requirements of action end-goal (e.g., Ansuini, Giosa, Turella, Altoè, & Castiello, 2008; Ansuini, Santello, Massaccesi, & Castiello, 2006). Therefore, when the action of lifting is to show the object to another person a more careful determination of contact points for the fingers might be expected as to optimize the viewing of the object by the partner. In contrast, when the task is executed with a purely individual intention, the object can be grasped in whatever orientation without compromising the goal of the action. Similarly, anticipating the time at which the wrist velocity reaches its peak allows for more time to prepare a suitable hand posture during a longer deceleration phase for the 'communication' condition. Overall, there was a tendency to plan and execute the action differently when the intention was to favour recognition by the partner. That was the intention to communicate rather than other cues to trigger a differential kinematics can also be drawn by the results obtained for the two control conditions. When the eyes of the partner were not available, though the communicative requirement remained, the kinematic features of the action resemble those obtained for the 'communicative' condition. Further strength to our hypothesis comes from the results obtained for the condition in which the 'communicated' word was meaningless. This manipulation proved to be sufficient as to eliminate the 'communicative' effect. This fits well with the idea that communication actions are planned as a function of the partner's recognition (Grice, 1989). It is worth nothing that neither intra-personal nor inter-personal motor constraint account for the present results. First, because the subsequent action was the same for both the communicative and the individual condition (lift the object), this rules out the possibility that differences in kinematics simply reflect differences in motor planning. Whereas such explanation may account for actions executed with different prior intention and thus followed by different actions (e.g., Ansuini et al., 2006), it does not apply to actions motivated by different intentions (communicative *vs* individual) but followed by the same lifting action. Second and more importantly, because in the communicative condition the object was hold by the agent and simply showed to the partner, this eliminates the possibility that differences in kinematics reflect mere inter-personal coordination constraints. Whereas passing an object requires adjusting one's action to the action of another individual (Becchio et al., 2008a; Meulenbroek, Bosga, Hulstijn, & Miedl, 2007), communicating a meaning does not require any motor coordination with others. What is required is simply that the other person recognizes the communicative signal generated by the agents and attributes the correct meaning to it.

The most prominent finding of the present study is that the pattern of results so far described for PD patients in the ‘on’ state and controls changes dramatically when considering PD patients in the ‘off’ state. The kinematics of the PD patients in ‘off’ state seem unaffected by the influence of communicative intentions. As a result, although the PD patients in ‘off’ state retain the motor capacity to perform reach-to-grasp movements, they fail to modulate movements during social interactions. Evidence that dopamine-depleted PD patients are unable to translate communicative intentions into specific motor patterns implies that dopamine projections are indeed necessary in these situations. 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 motivational signals for the motor system (Mazzoni, Hristova, & Krakauer, 2007). 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 patterning.

As postulated by some, engagement in different forms of social interaction in PD patients depends on dopaminergic replacement therapy (Schröder & Dengler, 2013). Dopaminergic medication improves emotional speech production (De Letter et al., 2007), and recognition of emotional facial expression (Sprengelmeyer et al., 2003). Furthermore, previous studies have already shown that dopamine depletion in PD patients affects the ability to put in place prior intentions mechanisms – intentions formed in advance and representing the end-goal of the action (Searle, 1983) – which takes into account the social end-goal of the action in addition to object geometry (Straulino et al., 2015). The present study extends our knowledge on the effects that dopamine might play in shaping intentional mechanism driving an action to a different and yet unexplored form of intentionality, i.e., communicative intentionality. In a pragmatic approach, communicative intentions can be regarded as a special form of social intentions (Bara, 2010). What renders communicative intentions special is that they not only are directed towards another agent, but require, as part of their content, that the other agent recognizes the speaker's intention to communicate (Grice, 1989). So conceived, communicative intentions (a) always occur in the context of a social interaction with a partner, (b) are overt, in the sense that they are intended to be recognized by the partner and (c) their satisfaction consists precisely in the fact that they are recognized by the partner. Implementing these three requirements, the present experiment provides the first measure of the influence that communicative intentions exert on the level of action kinematics in PD patients and how dopamine modulate such process.

The fact that dopamine availability is related to social behaviour echoes previous evidence reported for other disorders characterized by dysfunctional social behaviour (e.g., Plavén-Sigray et al., 2014; Qiu, Adler, Crocetti, Miller, & Mostofsky, 2010). For instance, robust findings suggesting that autism spectrum disorders associated impairments of basic motor control, praxis, and reciprocal social interaction and communicative skill are linked to deformations in basal ganglia regions corresponding to distinct frontal–striatal circuits (Qiu et al., 2010). Further, a relationship of dopamine D2-receptor (D2-R) availability in striatal (Cervenka, Gustavsson, Halldin, & Farde, 2010; Egerton et al., 2010; Huang et al., 2006; Reeves et al., 2007) and extrastriatal brain regions to measurements of social conformity has been consistently documented (Cervenka et al., 2010). Furthermore, data provide circumstantial evidence for the possible role of the dopaminergic system in other abilities that play a central role in human social interactions (Abu-Akel, 2003). For instance, in line with Abu-Akel (2003) the present data provide circumstantial evidence for the possible role of the dopaminergic system in mentalising abilities. First, the dopaminergic system innervates regions that have been showed to be critical for theory of mind (ToM) performance – an ability that plays a central role in human social interaction – such as the prefrontal cortex and the temporo-parietal region (Adolphs, Tranel, & Damasio, 2001). Second, abnormalities in the dopaminergic system lead to the disruption of cognitive abilities that influence ToM performances, such as executive functions (Russell, Mauthner, Sharpe, & Tidswell, 1991). Third, ToM deficits are extensively observed in pathologies where there is a known disruption of the dopaminergic system such as in PD (Mengelberg & Siegert, 2003; Saltzman, Strauss, Hunter, & Archibald, 2000) and schizophrenia (Bosia et al., 2011; Corcoran, Mercer, & Frith, 1995). Altogether, these results suggest that a disruption of neurochemical processes that modulate the dopamine system could contribute to ‘social’ impairments in a variety of neuropsychiatric disorders.

As an another aspect of the present findings, it is important to comment on the relationship between dopamine and language, since in the present task the transmitted communicative act is a word. In this respect, the correlation of degeneration of nigro-striatal networks and language in PD patients has been chiefly investigated in terms of the asymmetric degeneration of dopaminergic neurons (Batens et al., 2015). A variety of studies indicate that the laterality of dopamine depletion influences language deficits in PD and Levodopa intake improves language abilities (e.g., De Letter, Van Borsel, & Santens, 2012). The issue of laterality of dopamine depletion taps also into the idea that pragmatic processes are closely related and associated with dopaminergic networks of the right frontal lobe (Holtgraves, McNamara, Cappaert, & Durso, 2010), suggesting that decreased linguistic complexity reflects a pragmatic deficit of the right frontal cortex. Patients with more severe right-hemispheric dopamine depletion perform worst than patients with more severe left-hemispheric dopamine depletion in language tasks (Holtgraves et al., 2010).

In this perspective our results are consistent with other studies that have focused on pragmatics and social cognition in PD. McNamara and Durso (2003) found that patients with PD were significantly impaired on selected measures of pragmatic communication abilities, including the areas of conversational fluency/appropriateness, speech act production and comprehension, topic-coherence, prosodics and proxemics. Our data carry some relevance for understanding the nature of the communication disorders associated with PD adding to this literature the demonstration that dopamine depletion can affect communicative intentionality.

As a final point, the present findings on the possible relationship between dopamine systems and social behaviour are also in line with animal studies showing that in rats D2-R-related functions balance pro- and antisocial behaviours (Aragona et al., 2006; Couppis, Kennedy, & Stanwood, 2008). In songbirds, individuals which show communicative ‘disorders’ can be motivated to communicate through pharmacological manipulations of dopamine receptors, suggesting dopamine as a candidate neurotransmitter system involved in stimulating social communication (Leblois, 2013).

In conclusion, our results support the view that specific kinematic patterns characterize and distinguish communicative actions from actions executed with a purely individual intent. In line with a pragmatic approach to communication, we interpret this finding as evidence that communicative actions are intended to be recognized by a partner. Whether the partner makes use of kinematic cues in order to distinguish communicative from non communicative actions is an interesting topic for further research. Notably, the results reported here might have implications regarding the role played by the dopamine systems in modulating kinematic parameterization depending on the intention to act. The proposed research might help to identify manipulations that stimulate context-appropriate social communication, which can be used in the design of clinical interventions in humans with deficits in the motivation to communicate.

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