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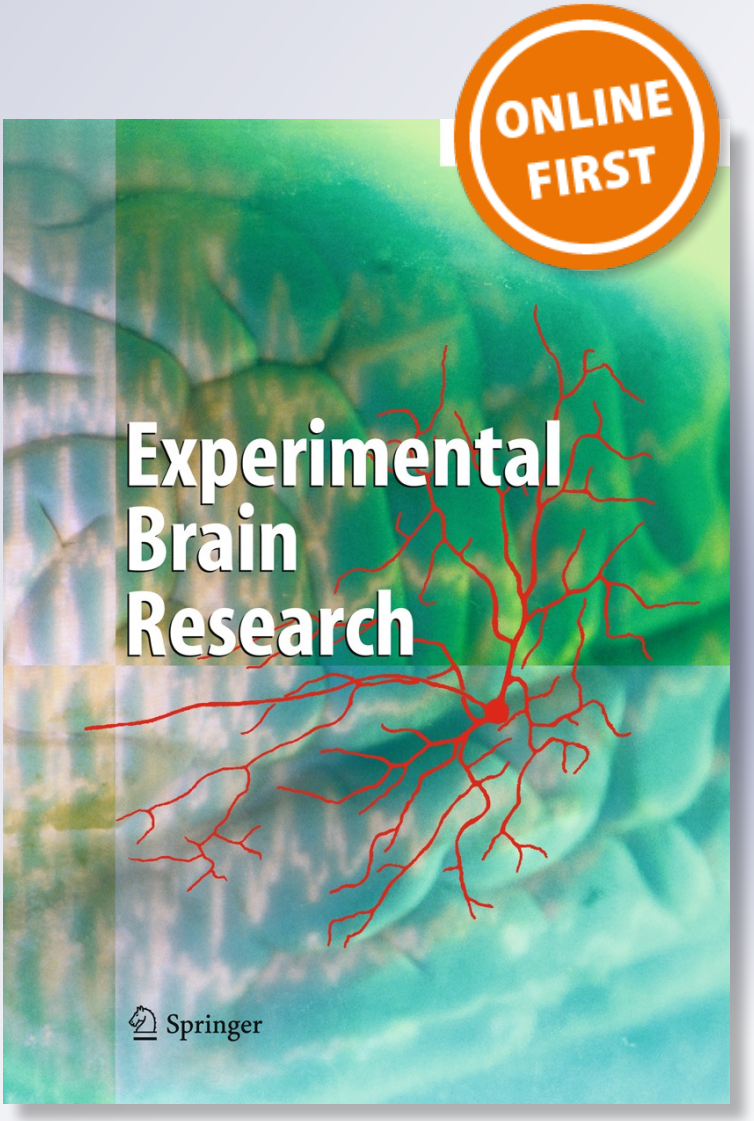

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RESEARCH ARTICLE

The role of the basal ganglia in action imitation: neuropsychological evidence from Parkinson's disease patients

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Abstract Though previous studies have suggested that the basal ganglia are necessarily involved in action imitation, their precise role is unclear. An important source of evidence concerns patients with Parkinson's disease (PD) who suffer basal ganglia impairments. Some studies report poor execution of observed meaningful (MF) transitive (tool-related) actions but normal performance with intransitive (non-tool-related) MF and meaningless (ML) actions (Leiguarda et al. in Brain 120:75–90, 1997; Leiguarda 2001 in Neuroimage 14:137–141). In other cases, though, patients with lesions involving the basal ganglia appear impaired in imitating ML as compared to meaningful MF transitive pantomimes. Here, we tested a group of PD patients in a full 2 × 2 design with MF transitive and intransitive pantomimes and matched ML movements. PD patients generated higher scores when imitating MF transitive actions than ML-matched actions. On the other hand, ML than MF intransitive actions did not differ significantly. The performance of the patients on imitating ML transitive actions also correlated with their performance on the Corsi block test of visuospatial memory and their scores at the test of verbal fluency for phonemic categories (FAS) while MF intransitive actions correlated with FAS and the neurological evaluation (UPDRS) The results are discussed in terms of the factors that load on visual memory for action reproduction, as well as the possible role of the basal ganglia in communicative actions (for MF intransitive actions).

Keywords Parkinson's disease · Basal ganglia · Imitation · Ideomotor apraxia · Transitive actions · Intransitive actions

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Introduction

Previous studies have suggested that the basal ganglia are necessarily involved when participants perform actions on verbal command or on imitation (e.g., Leiguarda et al. 1997; Leiguarda 2001; Pramstaller and Marsden 1996; Roy 2000; Tessari et al. 2007). For instance, Leiguarda et al. (1997) and Leiguarda (2001) reported that PD patients were impaired when producing transitive MF pantomimes both on imitation and on verbal command, while their performance on MF intransitive actions and ML actions was normal. Performance on ML actions matched to the transitive stimuli was not tested. On the other hand, Tessari et al. (2007) described two right-brain-damaged patients

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(RBD) with lesions involving the basal ganglia that were impaired at ML gestures but spared when making meaningful MF transitive pantomimes (i.e., tool-related actions).

Rumiati and Tessari (2002) proposed a "dual route" model of action imitation in which learned actions can be imitated via either of two "routes"—(1) a lexical route based on the recognition of a learned action and the retrieval of a learned action program, and (2) a non-lexical route based on direct mapping between perceived motor actions and output motor commands that does not depend on having learned representations for the actions (see Fig. 1). While the basal ganglia seem to modulate the direct (non-lexical) route to action (Tessari et al. 2007), the lexical route seems to operate through posterior parietal and prefrontal brain regions, particularly in the left hemisphere (see also Peigneux et al. 2001; Rothi et al. 1991; Rothi and Heliman 1997, for similar accounts). These arguments are supported by neuroimaging studies (e.g., Kareken et al. 1998; Peigneux et al. 2004; Rumiati et al. 2005) and lesion overlap analyses of patients with problems in imitating MF or ML actions (Tessari et al. 2007). On the other hand, the data from Leiguarda et al. (1997) and Leiguarda (2001) suggest that the basal ganglia are necessary for the imitation of transitive actions, while imitation of intransitive actions may be supported by cortical regions spared in PD.

However, none of the mentioned studies directly compared the performance in imitation of transitive and intransitive gestures in their MF and ML versions.

To provide an analysis of the full set of action types in this study, we tested imitation in PD patients using an orthogonal manipulation of the meaningfulness of the actions, and whether the actions were transitive or intransitive in nature—using meaningless actions matched to each meaningful action type. Is the involvement of the basal ganglia most apparent in the performance of ML relative to MF actions, regardless of whether the gestures are transitive or intransitive, or are the basal ganglia required in order to carry out transitive gestures in general, having a major role when the transitive gestures are unknown (i.e., ML)? The performance of these different actions was tested here using sets of matched stimuli, and the relations between imitation scores and a variety of other measures were considered including object and action recognition and visuospatial short-term memory.

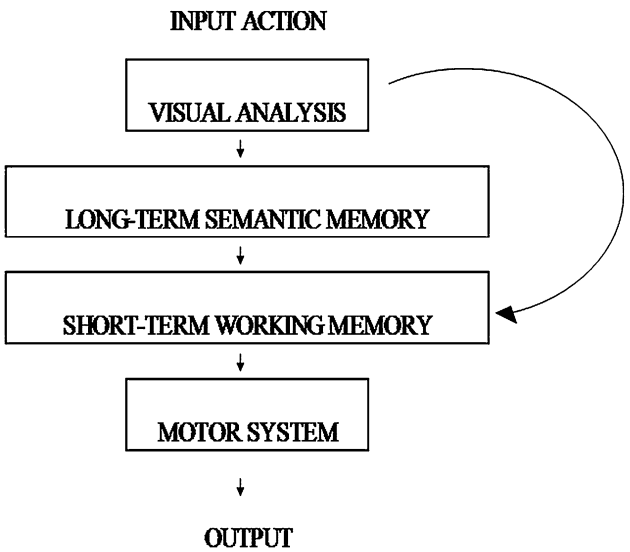

Fig. 1 The dual route model (Rumiati and Tessari 2002)

General methods

Patients

Nineteen native Italian-speaking PD patients (mean age = 66.37, SD = 6.95) participated in the study. The patients were recruited according to the following criteria: diagnosis for idiopathic (unknown etiology) PD, absence of major cognitive decline, presence of asymmetric symptoms, having normal or corrected to normal vision. The diagnosis was made by a neurologist on the basis of the patients' symptoms as well as of the results of anatomical scans of their brains (SPECT) proving the presence and the asymmetry of the lesion. Twelve patients showed more pronounced symptoms on the left and seven were more impaired on the right side of the body. Only one PD patient obtained a Mini Mental State Examination (MMSE) score that was just below the cut off for the normal Italian population (cut off = 24) when corrected for age and education (raw score = 26; score corrected for age and education = 23.2); however, as his performance on all the other tests (see Table 1 in Appendix) was in the normal range, he was not excluded from the sample. All patients were under pharmacological treatment with L-Dopa and all were right handed.

Controls

Two different groups of healthy participants were used to compare the PD patients' scores on the intransitive and transitive actions imitation tasks.

1. *Controls—Transitive gesture, action and object recognition:* For the transitive actions, 21 healthy participants (mean age = 63.35 years, SD = 7.30; 14 were native Italian speaking and seven native English speaking[1]) with no neurological and/or psychiatric

[1] There was no significant difference ($p = 0.64$) between the overall scores of native Italian-speaking and native English-speaking subjects. The same result was obtained when scores for MF ($p = 0.54$) and ML ($p = 0.77$) actions were independently compared.

disorders served as controls. All controls had normal or corrected to normal vision, and all but one were right handed. The controls did not differ in age from the PD patients ($p < 0.1$). The 14 Italian controls were also given the actions and object recognition tasks.

2. *Controls—Intransitive gestures:* The control group for the intransitive action imitation task had been tested prior to the present examination (Tessari et al., in press). The data are reported by courtesy of Dr Tessari in order to make comparisons with our patients' performance. From the original database of Tessari et al. (in press), only the scores of those participants matching our patients' age and education were selected. After the selection, the control sample consisted of 31 Italian native-speaking controls, 10 female and 21 male (range = 53–75; mean age = 65.35; SD: 6.5). A *t* test comparing the age of the PD patients and the controls did not reveal any significant difference ($p < 0.1$). None of the controls had a history of neurological or psychiatric disorder, and all had normal or corrected to normal vision. All individuals in this control group were right handed.

The experimental study

Transitive action imitation task

Stimuli

The stimuli were 20 MF pantomimes of objects being used (e.g., hammering or drinking from a glass) and 20 ML control actions derived from the MF actions (e.g., an action maintaining the grasp and arm configuration for hammering but performed in an unusual direction; for details see Tessari and Rumiati 2004).

Procedure

The MF and ML actions were presented in separate blocks to maximize the use of differential imitation processes, with the order of presentation randomized within each list. The MF actions were administered before the ML stimuli in order to reduce the likelihood of selecting a common "direct" route for imitation of ML as well as MF actions, given that MF actions could be reproduced using the same, direct imitative route as ML actions (Tessari and Rumiati 2004).

Each action was demonstrated individually by the experimenter using the right hand. Use of the right (dominant) hand here was done to maximize the consistency of stimulus presentation across participants without incorporating the data reduction problems that might follow from the use of video stimulus presentations. Participants were instructed to reproduce the action as similarly as possible to the model. The PD patients used the hand that was less affected by the disease to execute both the transitive and the intransitive actions. Twelve PD patients performed the imitation task, each using his/her right arm/hand, while each of the seven remaining patients imitated using his/her left (non-dominant) arm/hand. The fourteen controls tested in the present study with the transitive actions were asked to imitate using their dominant hand, while seven used their non-dominant hand. This was done in order to control for the possible influence of the hand used to perform the task. However, a *t* test showed that there was no difference ($p > 0.1$) between PD patients imitating with their dominant or non-dominant hand and the same result was obtained with the control group.

The performance of each participant was video-recorded and later scored by two independent raters blind to the experimental conditions.[2] Each participant's action was rated 1 if correct and 0 if containing an error.

A gesture was scored as incorrect if the participant performed: (1) a spatial error using his/her hand or arm; (2) a visual error (i.e., the action was: i) a combination of two items included in the list; ii) an action that was visually similar to the target; iii) a meaningful action, visually similar to the meaningless target); or (3) an omission (for a detailed description of the errors see Tessari and Rumiati 2004).

Intransitive action imitation task

PD patients were tested for their ability to imitate intransitive gestures using a neuropsychological test assessing ideomotor apraxia that was set up prior to the present examination by Tessari et al. (in press). The cut offs were calculated by Tessari et al. (in press) based on the scores of Italian healthy participants divided into three age ranges (30–50; 51–70; ≥71) and corresponding to the fifth percentile for each condition (MF, ML, Total) within each age range. The cut offs from the control participants tested by Tessari et al. (in press) served to provide an initial description of the PD sample and to individuate whom among this group was clinically apraxic and who was not. The raw scores for the controls from Tessari et al. (in press) were also used here for the comparisons between the PD patients and a controls population.

[2] The Cohen's k agreement coefficient was calculated on the scores provided by the two independent raters. The coefficient was computed for MF and ML actions taken separately, and for the total action scores. The analysis was performed separately for PD and controls. As the coefficient was ≥0.80 in all the cases considered, the scores of only one rater (the same for PD and controls) were used.

Stimuli

The intransitive stimuli were 18 MF and 18 ML actions, with the ML actions again derived from the MF actions. One half of the MF and the ML actions involved the movement of the hand (i.e., distal), while the other half involved the use of an arm (i.e., proximal). The intransitive MF actions were commonly used for communication (e.g., waving "hallo"). The intransitive ML actions matched the MF actions for complexity of execution, based on the component movements involved. Tessari et al. (in press) selected the MF actions on the basis of their being easily recognized by 10 independent raters. The ML actions were selected on the basis that these actions were all judged as unrecognizable by the same raters.

Procedure

The test was administered using the procedure indicated by Tessari et al. and partially overlapped the procedure used for transitive actions (i.e., blocked presentation with the MF presented first by the experimenter using her dominant hand, with performance being video-recorded for later scoring by two independent raters).

However, differently from the transitive actions that were presented only once, the intransitive actions were presented twice, as instructed by the test authors (Tessari et al., in press). From the intransitive action imitation test, we obtained two sets of scores. At first, each participant's action was rated across the two presentations as follows: (1) 2 if correct at the first attempt; (2) 1 if correct at the second attempt; (3) 0 if incorrect at both first and second attempt. Also, scores were given taking into account the first imitation attempt only (1 = correct at first attempt; 0 = incorrect at first attempt). An action was considered incorrect if containing one of the errors already described for the transitive actions.

As for the transitive gestures, twelve PD patients imitated with their right arm/hand and seven used their left (non-dominant) arm/hand. A t test did not show any effect of the hand within the PD patients ($p > 0.1$ for both the first attempt and for the data across 2 trials). The healthy participants tested by Tessari et al. (in press) and used here as a control sample always performed the task with the right dominant hand.

Action and object recognition

In addition to carrying out the gesture imitation tasks, we also assessed the ability of the PD patients to recognize actions and objects. PD patients and controls were presented with the same MF actions they imitated previously (20 MF transitive and 18 MF intransitive) and asked to describe the action taking place and/or the meaning of the action. Moreover, the participants were presented with the 20 real objects for which the 20 MF transitive actions were appropriate (see Table 1).

Neuropsychological assessment

Finally, the PD patients were given a battery of neuropsychological tests assessing general intelligence, attention, language functions, visual perception, short-term memory for verbal material and locations in space. The tests used are described in the "Appendix", and a summary of the results is reported in Table 1.

Results

The performance of the PD patients on the intransitive gesture imitation test was first compared to the available cut offs from controls (Tessari et al., in press) in order to identify, at a single patient level, those who were clinically apraxic. As the cut offs were calculated on the basis of the scores of the controls given up to 2 presentations per stimulus, the set of scores using the double item test procedure was used here.

Ten out of nineteen patients had a score under the cut off for the normal population. Of these, six showed impairment only when imitating MF stimuli, while four reported scores below the cut off for both MF and ML actions. None showed impairment for the ML movements alone.

Table 1 shows which patients were apraxic and which were not. The cut offs for the different age and education levels are also reported in Table 1 in the form of both raw and proportional accuracy scores (see below).

The PD patients scored at ceiling on the object recognition task. The patients also correctly identified all of the 18 MF intransitive actions although one mistakenly answered "Two" to the gesture for "Victory" (index and middle finger in a V-shaped posture). For the intransitive MF stimuli, performance varied a bit more for both patients and controls; however, PD patients did not differ from controls ($t(31) = 1.15$, $p = 0.13$) with both groups having on average an accuracy higher than 80 % (PD: mean = 0.83, SD = 0.06; controls: mean = 0.86, SD = 0.06). This indicates that any problems in imitating MF actions were unlikely to be due to poor perceptual processing or impaired access to stored visual-perceptual knowledge (percentages of correct answers from PD patients are in Table 1).

Proportional accuracy scores

As the scores on the transitive and intransitive actions tasks were based on different scales, a proportional score was

calculated based on accuracy relative to the total maximum score for transitive and intransitive actions (1st attempt and second presentation), summed over the MF and ML stimuli (maximum scores: transitive = 40; intransitive 1st attempt = 36; intransitive double presentation = 72). This allowed us to directly compare performance with the two types of gestures.

Figure 2 plots the proportion of transitive and intransitive, MF and ML, actions correctly imitated at the first attempt, for the PD patients and the controls. The PD patients scored at ceiling on the action and object recognition tasks (see Table 1). This indicates that any problem in imitating MF actions was unlikely to be due to poor perceptual processing or impaired access to stored visual-perceptual knowledge.

Analyses at group level

Since different control groups were used for the transitive and intransitive actions, we ran separate analyses to compare the PD patients to each control group. The proportional scores in imitating transitive gestures were compared for the PD and control groups. For the intransitive actions, the two sets of proportional scores (for the 1st and 2nd presentations) were analyzed in order to compare the PD patients with the controls and to see whether MF and ML actions benefited differently from the double presentation.

Finally, the proportional accuracy responses to transitive actions and those to intransitive actions, at the first attempt, were compared within each group.

Imitating transitive (object-related) actions

The proportional scores for transitive action imitation were entered in the repeated measures ANOVA with Action Meaning (MF vs. ML) as a within-subject factor and Group (PD vs. controls) as a between-subject factor. The analysis revealed a significant effect of Group ($F(1, 38) = 12.68$; $p = 0.001$), with the controls generating higher overall scores (mean = 0.69; SD = 0.11) (PD patients, mean = 0.57; SD = 0.1) (Fig. 2b). There was also a significant within-subject effect of Action Meaning ($F(1, 38) = 10.6$; $p = 0.002$), with MF actions (mean = 0.33, SD = 0.05) performed better than ML actions (mean = 0.30, SD = 0.08) (Fig. 2a, b), and there was also a significant Action Meaning × Group interaction ($F(1, 38) = 7.95$; $p = 0.008$). While controls performed similarly with the two kinds of action ($t(20) < 2.09$, 2-tailed), the PD patients had poorer performance with ML compared with MF actions, ($t(18) = 3.78$; $p = 0.001$, 2-tailed) (mean MF actions = 0.31; SD = 0.05; mean ML actions = 0.26; SD = 0.07).

Relative to the controls, the PD patients were worse both when imitating MF actions ($t(38) = -2.38$; $p = 0.01$; 1-tailed; mean PD = 0.31; SD = 0.05; mean control = 0.35; SD = 0.05) and ML actions ($t(38) = -3.8$; $p = 0.0005$, 1-tailed; mean PD = 0.026; SD = 0.07; mean controls = 0.34; SD = 0.07).

Imitation of transitive actions and UPDRS III scores

The proportional accuracy scores when the patients imitated transitive actions were correlated with the scores they

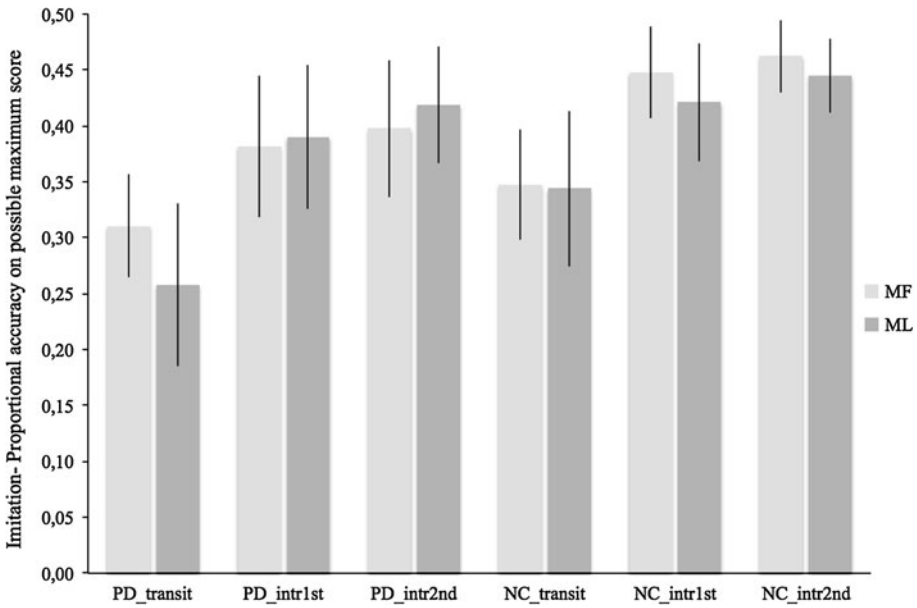

Fig. 2 Shows the mean proportional accuracy for the PD patients on the MF and ML, transitive and intransitive actions imitation tasks (left half of the graph); control data are shown on the right: PD_transit = PD accuracy with the transitive actions; PD_intr1st = PD accuracy with the intransitive actions, 1st attempt; PD_intr2nd = PD accuracy with the intransitive actions, double presentation; NC_transit = controls' accuracy with the transitive actions; NC_intr1st = controls' accuracy with the intransitive actions, 1st attempt; NC_intr2nd = controls' accuracy with the intransitive actions, double presentation

obtained on scale III of the United Parkinson Disease Rating Scale (see Table 1) that assesses neurological and motor symptoms (i.e., tremor or rigidity). As it was plausible that patients with more severe neurological symptoms had poorer imitation performance, a 1-tailed test of significance was used. Higher UPDRS scores correspond to more severe symptoms, so negative correlations were expected. There were no reliable correlations for total scores (Pearson correlation ($N = 19$) $= -0.23$; $p = 0.18$, 1-tailed) and also not for either MF actions (Pearson correlation ($N = 19$) $= -0.22$; $p = 0.18$, 1-tailed) or ML actions (Pearson correlation ($N = 19$) $= -0.18$; $p = 0.24$, 1-tailed) considered separately.

Imitating intransitive actions

The two sets of raw scores for the PD patients and the controls were transformed into proportional accuracy scores as described above and entered in an ANOVA with Group (PD and Controls) as a between-subject factor and Action Meaning (MF and ML) and Attempt (1st attempt and double presentation) as a within-subject factors. There was a significant between-subject effect of Group ($F(1, 48) = 14.41$; $p \leq 0.0001$), with PD patients (mean = 0.79; SD = 0.11) obtaining lower total scores than controls (mean = 0.89; SD = 0.07), and a significant main effect of Attempt ($F(1,48) = 84.34$; $p \leq 0.0001$)—not surprisingly, participants had higher scores after the second versus the first presentation (means = 0.87 and 0.83, respectively). There was no overall effect of Action Meaning ($F(1, 48) = 0.35$; $p = 0.56$). However, Action Meaning interacted significantly with Group ($F(1, 48) = 7.73$; $p < 0.01$) as well as with Attempt ($F(1, 48) = 5.50$; $p = 0.02$).

T-tests were run in order to clarify the interaction between Group and Action Meaning. Two independent sample t-tests comparing PD and controls confirmed the effect of Group for both MF ($t(df\ corr = 54{,}22) = 5.85$; $p < 0.0001$, 1-tailed) and ML actions (t($df\ corr = 62.48$; $p = 0.008$, 1-tailed). The PD patients were less accurate than the controls for both types of action (MF: PD = 0.39, SD = 0.06, controls = 0.46, SD = 0.04; ML: PD = 0.4, SD = 0,06, controls = 0.43, SD = 0.05). The interaction between Action Meaning and Group emerged because, while controls executed MF actions better than ML actions ($t(61) = 3.77$, $p < 0.0001$, 2-tailed), PD patients actually showed a trend for the opposite result ($t(37) = 1.85$, $p = 0.07$, 2-tailed as not predicted) (ML > MF).

Finally, the interaction between Action Meaning and Attempt was decomposed using two-paired sample t-tests, comparing (i) scores after 1 and 2 attempts for MF actions, and (ii) scores after 1 and 2 attempts for ML actions. This confirmed that participants generally improved their performance after 2 attempts for both MF ($t(49) = 7.48$, $p < 0.0001$, 2-tailed) and ML actions ($t(49) = 7.12$, $p < 0.0001$, 2-tailed). The change across the 2 attempts was greater for the ML actions than for the MF actions ($t(49) = 2.89$, $p = 0.006$, 2-tailed), with the ML actions showing a bigger increase in accuracy (mean = 0.03, SD = 0.03) than the MF (mean = 0.02, SD = 0.02).

The three-way interaction of Group, Action Meaning and Attempt was not significant.

Intransitive actions and UPDRS III scores

The proportional accuracy scores for PD patients imitating intransitive actions were correlated with the UPDRS scores (see the scores in Table 1). Negative correlations were predicted (the worse the motor performance, the poorer the imitation performance). However, no significant correlations were apparent with the exception of the imitation of MF actions after two attempts ($N = 19$) $= -0.39$, $p = 0.05$, 1-tailed).

Comparison between transitive actions and intransitive actions (1st attempt only)

As the transitive actions were administered only once, the data at the intransitive actions at the first attempt only were used in a comparison of performance with transitive and intransitive actions. Also, because the control data for the transitive and intransitive actions came from two different samples, the data for the PD patients and the controls were analyzed separately. The aim was to see whether PD patients imitated transitive and intransitive actions differently, and whether this pattern of performance was confirmed by the controls. The patients' proportional accuracy scores were subjected to 2 × 2 analysis of variance (ANOVA), with Type of Action (transitive vs. intransitive) and Action Meaning (MF vs. ML) as within-subjects factors. The analysis revealed significant main effects of both the Type of Action ($F(1, 18) = 58.77$; $p < 0.0001$) (transitive mean = 0.57; SD = 0.1; intransitive mean = 0.77; SD = 0.12) and Action Meaning ($F(1, 18) = 6.68$; $p = 0.02$) (MF mean = 0.35; SD = 0.07; ML mean = 0.32; SD = 0.01). The interaction between Type of Action and Action Meaning was also significant ($F(1, 18) = 9.07$; $p = 0.008$). For transitive actions, there was more accurate performance with MF than ML actions ($t(18) = 3.78$; $p = 0.001$, 2-tailed), while for intransitive actions, the difference between MF and ML was not significant ($t(18) = -0.71$); $p < 0.49$, 2-tailed).

The data for the controls were first transformed as for the patients and then entered into a 2-factor ANOVA with Action Meaning (MF vs. ML) as a within-subject factor and Type of Action (transitive vs. intransitive) as a between-subjects factor. The analysis revealed a significant

between-subject effect of Type of Action ($F(1, 50) = 43.08$; $p < 0.0001$) and a significant within-subject effect of Action Meaning ($F(1, 50) = 4.13$; $p = 0.047$). The interaction between the two factors was not significant ($F(1, 50) = 2.30$; $p = 0.14$). Intransitive actions (mean = 0.87; SD = 0.08) were imitated more accurately than transitive actions (mean = 0.69; SD = 0.11), and generally, MF actions were reproduced more accurately than ML actions (mean MF = 0.41; SD = 0.07; mean ML = 0.39; SD = 0.07).

Action imitation and neuropsychological assessment

The relations between imitation performance and the general neuropsychological screening tests were also considered. Relative to the norms established for the standard neuropsychological tests, the PD patients did not show impairment when evaluated for general intelligence, language functions, visual perceptive functions, short-term memory for verbal material and locations in space, or attention (see Table 1). However, 2 PD patients showed a borderline score at the Corsi block task, and 3 showed borderline performance at the verbal fluency test (FAS). Also, those two tasks showed a significant correlation with the patients' UPDRS scores (UPDRS and FAS: Pearson correlation $(19) = -0.6$, $p = 0.01$, 1-tailed; UPDRS and Corsi: Pearson correlation $(19) = -0.39$, $p = 0.05$, 1-tailed). For this reason, we conducted correlations between these tests and performance on the imitation tasks. For both the Corsi and the FAS, missing data were replaced by the mean score of the PD patients who completed the tests.

Corsi block task, FAS and action imitation

We predicted that lower scores at the FAS and the Corsi block task would correspond to lower accuracy on actions imitation. Correlations were performed only for the PD patient group. Total scores on imitating transitive actions correlated significantly with both the Corsi test (Pearson correlation $(n = 19) = 0.49$; $p = 0.02$, 1-tailed) and the FAS (Pearson correlation $(n = 19) = 0.43$, $p = 0.03$, 1-tailed). Both these results were found when ML transitive actions were considered alone (ML and Corsi: Pearson correlation $(n = 19) = 0.48$; $p = 0.02$, 1-tailed; ML and FAS: Pearson correlation $(n = 19) = 0.41$, $p = 0.04$, 1-tailed), and they were not reliable for MF transitive actions (MF and Corsi: Pearson correlation $(n = 19) = 0.31$; $p = 0.10$, 1-tailed; MF and FAS: Pearson correlation $(n = 19) = 0.31$, $p = 0.10$, 1-tailed).

For the intransitive actions, reliable correlations emerged between imitation of MF actions and FAS, both at first attempt (Pearson correlation $(19) = 0.40$, $p = 0.05$, 1-tailed) and after two attempts (Pearson correlation $(19) = 0.38$, $p = 0.05$). The correlations between the FAS and total intransitive actions and ML intransitive actions alone (after the 1st attempt and second attempt) were not significant (all $p > 0.1$). Similarly, the correlations between the Corsi block scores and the total intransitive action scores, the MF and the ML intransitive action scores (for the first and second attempts) were not significant (all $p > 0.1$).

Discussion

The present results were collected from a group of PD patients who were impaired at action imitation despite being able to recognize the actions and the objects used in transitive actions. Our results match previous findings and they also paint a more complex picture of imitation deficits in PD than previously indicated. Similarly to Tessari et al. (2007), we found that patients with lesions in the basal ganglia (in our case PD patients) were more impaired at imitating ML relative to MF transitive actions. Tessari et al. (2007) interpreted their result arguing that their RBD patients, with lesions involving the basal ganglia, had an impaired direct, non-lexical route in imitation that may operate through subcortical structures. Leiguarda et al. (1997) and Leiguarda (2001) further reported that PD patients were impaired at imitating transitive relative to intransitive actions. Consistent with this, our PD patients were poor at transitive actions and obtained higher accuracy scores on intransitive actions, although generally performing worse than controls also with the intransitive (both at the first attempt and when the performance was scored taking into account the double presentation). Our data go beyond the previous findings, though, by assessing both the Type of Action (transitive or intransitive) and the familiarity of the action (MF vs. ML). This showed that, for PD patients, the effect of the meaningfulness of the action held only for transitive actions. This pattern of results goes against a simple account of PD patients as having either an impaired direct, non-lexical route to imitation or a deficit specific to transitive actions. We consider both points.

While the results for transitive actions concur with the argument that PD patients have damage to a direct, non-lexical route to imitation (MF > ML), the results for intransitive actions do not. The interaction between Group and Action Meaning that we found for the intransitive actions highlighted that, while controls imitated MF actions better than ML actions, PD did not show this pattern (even tending to show effects in the opposite direction). This result indicates that MF and ML actions are impaired differently in PD patients according to the actions being transitive or intransitive. The data for the controls, where there were higher accuracy scores with the MF relative to

the ML intransitive actions, are consistent with the use of stored knowledge in reproducing these actions. The loss of the MF advantage for intransitive stimuli in the PD patients suggests that damage to the basal ganglia relatively affects MF actions in this case, consistent with the basal ganglia playing a role in learned communicative (intransitive) actions. Against this argument, the patients showed an overall advantage for intransitive over transitive actions. However, this could be due to the intransitive actions being less complex than transitive actions, despite our attempts to match them for complexity. The argument for differences in complexity is compatible with previous reports of both patients and healthy controls generally imitating better intransitive actions than transitive actions (see also Carmo and Rumiati 2009; Rumiati et al. 2009). Note that the advantage here held across the meaningfulness of the gestures, suggesting that differential familiarity with transitive and intransitive gestures was not critical.

Additional information on the imitation of different action types comes from the correlations between imitation, UPDRS III scores, FAS and the Corsi block task. The ability to imitate ML transitive actions correlated with performance on the Corsi blocks task—a test of visuospatial memory. The Corsi task did not relate to performance with MF transitive actions, nor did it correlate with the MF and ML intransitive actions. This last finding suggests that transitive ML stimuli placed a particular load on visuospatial memory, and the PD patients may have had difficulty reproducing these actions because of limitations in visuospatial memory. The lack of correlation for ML intransitive actions, then, may have occurred because these actions placed a smaller load on visuospatial memory, consistent with them being less complex. A previous study, using a n-back task tapping visuospatial memory, failed to find impairments in visuospatial memory in PD patients on medication with L-Dopa (Costa et al. 2003). However, Lange et al. (1992) reported that medicated PD patients were defective when compared to controls in a spatial recognition task where participants had to identify the correct location of a previously presented shape. Furthermore, the same authors noted that PD performance on a computer version of the Corsi block task worsened significantly when the L-Dopa therapy was interrupted (off therapy) (Lange et al. 1992). A deficit in visuospatial working memory in PD was also reported by Owen et al. (1997), with performance related to the stage of the disease. These results suggest that there can be a subtle deficit in visuospatial short-term memory in PD that emerges as a function of task difficulty (e.g., when time intervals are introduced between stimulus presentations) or the disease state (e.g., after withdrawing L-Dopa treatment). Consistent with these previous findings, the majority of the current patients did not show scores below the cut off for the normal population on the Corsi block task (Table 1). Nevertheless, the correlation we found indicates that visuospatial short-term memory is a key function in reproducing complex ML actions and that the deficit in this function can be found in PD under demanding circumstances.

The scores obtained by the patients at reproducing ML transitive actions also correlated significantly with FAS scores that can be considered a measure of executive function. FAS scores also correlated with the PD scores at imitating MF intransitive actions after two attempts. This correlation suggests that the PD patients with less efficient executive function benefited less from the second presentation of the intransitive MF actions. This suggests a link between executive function and communicative gesturing. Interestingly, a previous study has reported that PD patients are impaired in their pragmatic communication abilities, and this deficit correlates with measures of frontal lobe functions, linked to executive abilities (McNamara and Durso 2003). It is to be noticed that the scores for the MF intransitive actions after two presentations also correlated with the UPDS and so with the severity of the disease. From this, we suggest that the basal ganglia support both the production of complex ML actions (linked to visuospatial memory) and a separate role in communicative gesture. The role in communicative gesture is also moderated by the severity of the disease.

In sum, the current data do not suggest account of initiation deficits in this sample of PD patients purely in terms of a loss of a direct, non-lexical route to action. Rather, the data indicate that problems relate to deficits in visual short-term memory and/or the requirements either to make communicative actions. More detailed analysis of the particular aspects of meaningless actions that render them difficult for PD will be informative in future work.

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Appendix: Tests

Mini Mental State Examination: The Italian version of the Mini Mental Estate Examination (Magni et al. 1996) was administered to both PD patients and controls to evaluate the integrity of their general cognitive abilities. All participants who scored (corrected for age and education) less than 27 were discarded.

Corsi block test (*Italian normative data,* Orsini and Laicardi 1997): Evaluating short-term memory for locations in space.

Forward and reverse Digit Span (*from the Italian version of the WAIS-R*, Orsini and Laicardi 1997): Evaluating the short-term memory and the working memory for verbal material, words retrieval ability.

VOSP screening test and VOSP object decision from Visual Object and Space Perception Battery (*VOSP*) (Warrington and James 1991): Assessing visual perception abilities.

Verbal Fluency for Phonemic Categories (*Standardizzazione e taratura italiana dei test neuropsicologici* , Spinler and Tognoni 1987): Assessing words retrieval ability.

Token and Naming subtest from the Aachener Aphasie Test (*Italian version*, Luzzati et al. 1994): Evaluating patients' language comprehension and naming abilities.

Trail Making Test A and B (*Italian normative values*, Giovagnoli et al. 1996): Evaluating spatial and visual attention and the abilities to switch from alphabetical to numerical stimuli.

See Table 1.

Table 1 PD scores at the neuropsychological tests and UPDRS III scores

PD	MMSE	VOSP		AAT		Digit		Corsi	Trail making			FAS	UFDRS III	Recognition (% accuracy)			Imitation (intransitive)		
		Screening	Object decision	Token	Naming	Fwd	Bwd		A	B	B–A			Actions		Objects	Proportional accuracy		
														Transitive (%)	Intransitive (%)		MF	ML	TOT
1	29	20	18	78	80	na	na	na	na	na	na	40	12	90	100	100	0.47	0.44	0.92
2	29	16	15	na	na	na	na	na	na	na	na	**18**	31	75	100	100	**0.25**	**0.33**	**0.58**
3	30	20	19	74	80	5	3	**4**	45	130	85	31	10	80	100	100	0.46	0.50	0.96
4	30	20	17	70	80	na	na	na	na	na	na	28	15	80	100	100	**0.35**	**0.40**	**0.75**
5	30	20	15	70	71	na	na	na	na	na	na	**28**	16	80	100	100	**0.36**	0.40	**0.76**
6	29	20	17	74	80	5	3	5	38	239	**201**	**20**	25	85	100	100	0.44	0.43	0.88
7	30	19	17	74	76	4	4	na	na	na	na	34	16	90	100	100	**0.39**	**0.33**	**0.72**
8	28	20	15	67	71	6	3	**4**	57	na	na	28	15.24	85	100	100	0.44	0.50	0.94
9	28	19	17	74	78	6	4	4	65	210	145	35	33	80	100	100	0.44	0.44	0.89
10	**26**	19	17	72	78	na	na	na	na	na	na	36	10	85	100	100	**0.36**	0.42	**0.78**
11	28	20	19	74	76	5	5	5	na	na	na	na	6	85	100	100	**0.36**	0.39	**0.75**
12	29	20	19	72	80	4	4	5	47	111	64	39	12	85	100	100	**0.42**	0.44	0.86
13	29	20	18	67	80	6	4	5	na	na	na	na	12	70	100	100	0.43	0.49	0.92
14	30	20	20	78	80	6	5	5	40	88	48	41	8	95	100	100	0.49	0.47	0.96
15	30	19	20	78	80	4	6	6	30	110	80	57	8	75	100	100	**0.42**	**0.36**	**0.78**
16	30	20	17	70	80	5	4	4	49	174	125	49	11	80	100	100	**0.38**	**0.39**	**0.76**
17	27	19	19	66	80	6	5	4	41	116	75	38	15.24	90	100	100	**0.35**	**0.39**	**0.74**
18	27	18	17	65	80	4	3	4	55	146	91	25	26	85	100	100	**0.31**	**0.36**	**0.67**
19	29	20	18	74	80	5	4	5	54	141	87	na	8	80	94	100	0.44	0.46	0.90

Imitation of intransitive actions (Tessari et al., in press)
Cut off for the normal Italian population:[a]

Age	Cut off MF	Cut off ML	Cut off total
30–50	≤0.44 (≤32)	≤0.43 (≤31)	≤0.88 (≤63)
51–70	≤0.43 (≤31)	≤0.39 (≤28)	≤0.82 (≤59)
≥71 (eduction ≥7)	≤0.42 (≤30)	≤0.33 (≤24)	≤0.81 (≤58)
≥71 (eduction ≤6)	≤0.35 (≤25)	≤0.33 (≤24)	≤0.69 (≤50)

The table contains the raw scores at the MMSE, VOSP (screening and object decision), Digit Span, Corsi block task, Trial Making (A, B, B–A), the T scores at the AAT (token and naming) and FAS. PD scores at object recognition, meaningful (MF) and meaningless (ML) transitive and intransitive actions. The last column reassumes the patients' performance with the intransitive actions (MF, ML and total performance). For the intransitive action imitation tasks, different cut offs were assigned according to the patients' age and education level on the basis of the double presentation, as indicated by the test authors (Tessari et al., in press)

[a] The cut offs for the intransitive action imitation task both in their raw (in brackets) and proportional form. Performances falling below the cut off for the normal population are in bold

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