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Research Article

Flexibility of action verbs processing in Parkinson's disease

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Abstract

Objective: This study aims to investigate action language processing abilities in Parkinson's disease (PD) compared to healthy controls (HCs), specifically examining whether the involvement of motor systems is influenced by task context. By focusing on implicit versus explicit task demands, the study evaluates how semantic processing differs in PD and whether these differences align with a flexible embodied cognition framework. **Methods:** The study analyzed the performance of participants on two tasks: an explicit task (semantic judgment task, SJ) and an implicit task (letter detection task, LD). PD outpatients (n = 31, mean age 64.58 years) referred to the Parkinson and Movement Disorders Unit of ICS Maugeri Hermitage were enrolled, along with a group of healthy controls (n = 31, mean age 64.19 years). Performance was measured through reaction times (RTs) and accuracy scores (Acc) during the processing of action verbs and abstract verbs. **Results:** PD patients exhibited slower RTs and lower accuracy when processing action verbs compared to abstract verbs, but only during the SJ task. Slower RTs in the SJ task were predicted by language and executive functioning (semantic fluency) and disease progression (Hoehn and Yahr stages) for both action and abstract verbs. In the LD task, slower RTs were predicted by executive functioning for action verbs and attention (measured by Trail Making Test Part B and Stroop task) for abstract verbs. **Conclusions:** The findings suggest a context-dependent involvement of the motor system in action language processing, supporting a flexible, embodied approach to conceptual semantic processing rather than an automatic one.

Keywords: Embodied cognition; Action language; Parkinson's disease; Semantic processing; Motor system; Flexible embodiment

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Statement of Research Significance

This research provides significant insights into the action language processing in Parkinson's disease (PD). It examines how semantic processing of action versus abstract verbs is modulated by task context, composed by both implicit and explicit tasks, and examines whether these differences support a flexible embodied cognition framework. Overall, our data would support a "flexible," compared to a strong, embodied approach, suggesting that motor and premotor regions could be selectively involved in action language processing only when deep semantic analysis is required. This has implications for developing targeted therapeutic interventions to address language deficits in PD, enhancing patient care and quality of life. Moreover, the research deepens the understanding of how motor and cognitive deficits in PD interact, potentially serving as an early indicator for cognitive interventions. **Research Question(s) or Topic(s):** The study investigates action verbs processing in patients with Parkinson's disease (PD) compared to healthy controls (HCs). Specifically, it examines how task context (implicit vs. explicit) influences semantic processing and whether the involvement of motor systems in action language aligns with a flexible embodied cognition framework. **Main Findings:** PD patients demonstrated slower reaction times (RTs) and lower accuracy in processing action verbs compared to abstract verbs, but only during the explicit semantic judgment (SJ) task. The implicit letter detection (LD) task did not show significant differences in performance between action and abstract verbs. Semantic fluency and disease progression were significant predictors of RTs in the SJ task for both verb types in PD patients. Executive functioning and attention were key predictors of RTs in the LD task. **Study Contributions:** The study supports a flexible embodied cognition framework, indicating that the motor system's involvement in action language processing could be context-dependent; It highlights the selective impairment of action verb processing in PD during tasks requiring deep semantic analysis, which may be linked to fronto-striatal network dysfunction; The findings contribute to understanding cognitive and motor impairments in PD, with implications for early detection and intervention strategies focused on cognitive decline.

Introduction

Recent advances in cognitive neuroscience support that semantic processes interact with neural mechanisms involved in perception and motor control. Embodied cognition theory suggests that high

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cognitive processes, such as language, are deeply rooted in sensory-motor experiences (Hauk, 2016; Pulvermüller & Fadiga, 2010). The meaning of a word derives from modality-specific sensory, emotional, and motor representations (Barsalou et al., 2003) and recalling a word involves the neural re-activation of these sensory-motor experiences as if the brain simulates them (Barsalou, 2008). This framework finds a testing ground in action language, due to its link with the motor system (Pulvermüller, 2005). For example, when an action word like "*running*" is presented, our brain reacts as if simulating that action. Additionally, the somatotopic organization of the motor cortex, allows for predictions regarding the motor representations of word actions, explored through neuroimaging techniques (Hauk et al., 2004). Verbs related to body parts activate the primary motor and premotor cortex in a somatotopic fashion, consistent with the motor simulation (Aziz-Zadeh et al., 2006; Boulenger et al., 2009). Consequently, disruption of the motor system leads to difficulties in understanding action-related concepts. This hypothesis is supported by studies with non-invasive brain stimulation techniques, showing that stimulating motor and premotor cortices disrupts action language processing, indicating interference due to shared neural resources (Buccino et al., 2005; Gijssels et al., 2018). Furthermore, neurological conditions affecting the motor system reinforce the connection between linguistic and motor aspects of action. Among these, Parkinson's Disease (PD) is a neurodegenerative extrapyramidal syndrome characterized by motor symptoms such as rigidity, resting tremor, bradykinesia, and postural instability along with a spectrum of non-motor symptoms ranging from cognitive and behavioral disturbances to autonomic and somatosensory dysfunction (Schapira et al., 2017). Due to the involvement of fronto-striatal networks modulated by dopamine, attention/working memory and executive functions are predominantly impaired in PD (Aarsland et al., 2010; Dirnberger & Jahanshahi, 2013; Williams-Gray et al., 2009). Understanding executive deficits requires deeper knowledge of the basal ganglia (BG) role in motor and cognitive processes, including language (Cardona et al., 2013; Houk, 2005).

For these reasons, PD provides a valuable model for testing the embodied cognition hypothesis in action language. Although linguistic deficits in PD have often been related to a primary executive dysfunction (Angwin et al., 2006; Bastiaanse & Leenders, 2009), some evidence revealed that these deficits may also stem from an embodied perspective due to a specific action semantic processing impairment (Bocanegra et al., 2015; Cardona et al., 2013). Action processing in PD has been studied through several tasks (e.g., implicit and explicit) and stimuli (e.g., verbs and nouns). Findings indicate that PD patients perform worse on action-related tasks than on object-naming tasks (Cotelli et al., 2007; Péran et al., 2009). For instance, Boulenger et al. (2008) reported that PD patients off medication showed reduced priming effects for action verbs. In contrast, other findings suggest that these difficulties may arise from the grammatical complexity of verbs rather than from an action-specific semantic deficit (Bertella et al., 2002; Cotelli et al., 2007). Indeed, the comparison between action verbs and non-action nouns is problematic since verbs are syntactically and semantically more complex than nouns and processed differently at the brain level (Faroqi-Shah et al., 2018; Lukic et al., 2021 Zhao et al., 2017). Only two studies compared semantically diverse verbs in PD. Herrera et al. (2015) found that PD patients off medication produced significantly fewer verbs with high motor specificity compared to healthy controls. However, when on medication, their performance matched that of healthy controls, highlighting the role of the dopamine network from basal ganglia to brain motor areas in retrieving action verbs with specific semantic representations. Fernandino et al. (2013) showed a selective impairment in action verbs processing in PD patients during both implicit (i.e., lexical decision task, LD) and explicit (i.e., semantic similarity judgment) tasks. However, the heterogeneity of stimuli and tasks does not allow a clear view of the mechanisms underlying action language in PD. In particular, whether motor system involvement is automatic and occurs at an early stage of language processing (e.g., action language deficit during implicit tasks such as lexical decision task) or is task- and context-related (e.g., action language deficit during explicit tasks such action naming or verb generation) is unclear. In this regard, the "strong" embodied perspective suggests that the motor system engagement during action language processing is automatic and non-voluntary, and it will occur during both explicit and implicit tasks (Gallese & Lakoff, 2005; Pulvermüller et al., 2005). Recently, a "flexible" perspective argues that the motor system is only involved during explicit tasks when attention is explicitly focused on the meaning of the action word (Giacobbe et al., 2022; Pulvermüller, 2018).

This study aims to elucidate the differences in action language processing abilities between individuals with PD and healthy controls (HCs). Specifically, it examines how semantic processing of action versus abstract verbs is modulated by task context, using both implicit (letter detection, LD) and explicit (semantic judgment, SJ) tasks. We assessed performance on action verbs versus matched abstract verbs to evaluate word meaning processing (i.e., action vs abstract), avoiding the influence of linguistic complexity (i.e., nouns vs verbs). The choice of using these two tasks (i.e., SJ and LD) is motivated by several factors. First, it avoids the confusing effect of the grammatical class, as verbs have been shown to be notoriously more complex to be processed compared to nouns (Druks, 2002; Crepaldi et al., 2011). Moreover, semantic judgment tasks place greater demands on semantic processing and typically do not require oral or verbal responses such as semantic and phonemic fluency (Salmazo-Silva et al., 2017), being able to discriminate a purely semantic deficit from a lexical retrieval deficit. Additionally, the study explores the relationships between language processing and clinical or neuropsychological variables in PD, providing a deeper understanding of how cognitive and motor impairments influence semantic comprehension.

Method

Participants

Consecutive PD outpatients referred to the Parkinson and Movement Disorders Unit of ICS Maugeri Hermitage, Naples, Italy, were enrolled. To be included in the study, each PD patient had to meet the following inclusion criteria: i) diagnosis of idiopathic PD according to the clinical diagnostic criteria of Movement Disorders Society (Postuma et al., 2015); ii) an adequate global cognitive status defined as total age- and education-adjusted score ≥15.5 on the Italian version of the Montreal Cognitive Assessment (MoCA, see Santangelo et al., 2015 for normative values) and lack of Mild Cognitive Impairment (MCI) according to MoCa Italian cut-off value and according to the level 1 Litvan et al.'s (2012) criteria for Mild Cognitive Impairment (MCI) in PD; iii) lack of significant cerebrovascular lesion or concomitant neurological diseases based on available MRI or CT together with an objective neurological evaluation which might explain the

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presence of cognitive or psychiatric disturbances. Demographic features (i.e., gender, age, years of schooling) and clinical aspects (i.e., disease duration; Levodopa Equivalent Daily Dose, LEDD; severity of motor symptoms assessed by Unified Parkinson's Disease Rating Scale part III, UPDRS-III; Hoehn and Yahr staging, H&Y) were recorded. In addition, healthy controls (HCs) matched to patients for demographic features were enrolled. They had to meet the same selection criteria as the PD group. For the HCs group, the inclusion decision for the 3rd criterion (i.e., lack of significant cerebrovascular lesion or concomitant neurological diseases) was made based on their clinical history about neurologic or psychiatric diseases. HCs were recruited from among patients' friends and employees at the clinic or university centers and churches. We enrolled HCs matched with PD patients for demographic features.

For all participants, handedness was assessed with the Edinburgh Handedness Inventory (Oldfield, 1971). An a priori power analysis conducted with G*Power 3.1, set the minimum total sample size at 54 participants to conduct repeated measures ANOVAs with one within-subjects factor and one between-subjects factor to detect an effect size of 0.25, with a power of 0.95, and an alpha of 0.05. All participants gave their written informed consent to participate in the study, which was approved by the Ethics Committee of the Psychology Department of University of Campania "Luigi Vanvitelli" and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Procedure and measures

PD patients were tested after their regular neurologist visit at the clinic center while they were in ON state. The neurologist administered the UPDRS and H&Y scales at the end of the clinical visit. All participants underwent the handedness questionnaire and the MoCA for the evaluation of the global cognitive functioning at the beginning of the testing session. Then, they performed the action language tasks (i.e., SJ and the LD tasks). The order of the two tasks varied randomly and were interspersed with an extended neuropsychological assessment.

Action language stimuli

An initial set of 200 action and 200 abstract related verbs in their infinitive form were selected from a written Italian database (COLFIS; Laudanna et al., 1995; 3.798.000 words) using psycholinguistic criteria. According to the criteria of linguistic tradition (Taylor, 1977), action verbs referred to a movement/physical acts performed both with and without an object, while abstract verbs (state, psychological verbs) referred to mental processes without any reference to a physical act. Stimuli were then rated by 50 right-hand healthy Italian volunteers (N = 37 females; mean age = 57.12 years; SD = 6.81). They were all monolinguals native Italian speakers with comparable level of education (mean = 14.62 years; SD = 2.52). Participants were asked to judge for each word belonging to both action and abstract stimuli group: i) word familiarity (i.e. "how much each word is familiar to you?") on a scale ranging from 1 (very little) to 5 (very much); ii) word imaginability (i.e., "how quickly and easily each word arouses mental images for you?") on a scale ranging from 1 (very hardly) to 5 (very easily); iii) concreteness (i.e., "how concrete do you think the meaning of the following words is?") on a scale ranging from 1 (very little) to 5 (very much). Moreover, the participants rated how much the action word refers to a physical act/movement on a scale ranging from 1 (very little) to 5 (very much) and, if the word was judged as referred to a movement, which part of the body was involved in that movement (i.e., upper body part movement, lower body part movement, whole body, none of previous answers, no movements). For the abstract stimuli group, participants judged how much the abstract word refers to a psychological/mental state on a scale ranging from 1 (very little) to 5 (very much). To create stimuli lists for action and abstract words, non-ambiguous words were selected if they reached a relevance rating (i.e., "how much the word refers to a physical act/movement?"/ "how much the abstract word refers to a psychological/mental state?") of three or higher for the critical features. The selected verbs resulted in a list of 104 actions (58 associated with upper limbs movement and 46 associated with lower body part movement or with all body movement) and 104 abstract verbs.

Action stimuli differed from abstract ones in terms of imaginability and concreteness (respectively, t (206) = 18.38, $p < .001$ and t (206) = 32.2, $p < .001$). In addition, the selected action and state verbs were matched for familiarity (average familiarity were 4.29 (SD = .33) for action and 4.3 (SD = .26) for abstract verbs, $p > .05$, n.s.), for length (average lengths were 8.9 (SD = 1.64) letters for action and 8.85 (SD = 1.69) letters for abstract verbs, $p > .05$, n.s.) and for age of acquisition (average years of acquisition were respectively 4.5 (SD = .89) and 4.67 (SD = 9.93) for action and abstract verbs, $p > .05$, n.s.). The written frequencies did not significantly differ across conditions (means 140.84 (SD = 389.02) for action verbs and 245.2 (SD = 483.39) for abstract verbs, $p > .05$, n.s.).

Action language tasks procedure

The previously validated action language stimuli were used for both SJ and LD tasks. For both tasks, a laptop PC running E-prime software (version 3.0, Psychology Software Tools, Inc.) was used for stimuli presentation and response recording. Responses were given using the laptop keyboard. Both tasks started with a practice block composed of 26 stimuli (13 action and 13 abstract verbs) not included in the experimental part. After the practice block, the main experimental task started, which included 208 trials without any feedback and lasted approximately 15 minutes. Each trial began with a fixation cross that was presented in the center of the screen for 500 ms. Then, the target stimulus appeared, which remained on the screen until the participant responded. The target stimulus was presented centered on the screen, with upper case font and expressed in its infinitive form. In the SJ task, participants were asked to silently read verbs and to judge as quickly and as accurately as possible if the word presented on the screen represented an action or a movement executable with the body, or if it was not. The yes-no question must be responded by pressing one of two response buttons using the preferred hand (all participants used their right hand). The relative position of the two response buttons (left-right to indicate action-nonaction) was counterbalanced across participants (Figure 1a). In the LD task, participants were asked to silently read verbs and to respond if the letter "I" was present or not in the word. The yes-no question must be responded by pressing one of two response buttons using the preferred hand (all participants used their right hand). The relative position of the two response buttons (left-right to indicate "I"-without "I") was counterbalanced across participants. The letter "I" was present in 58% of the items (57% of the action verbs and 58% of the abstract verbs, $p > .05$, n.s.) (Figure 1b)

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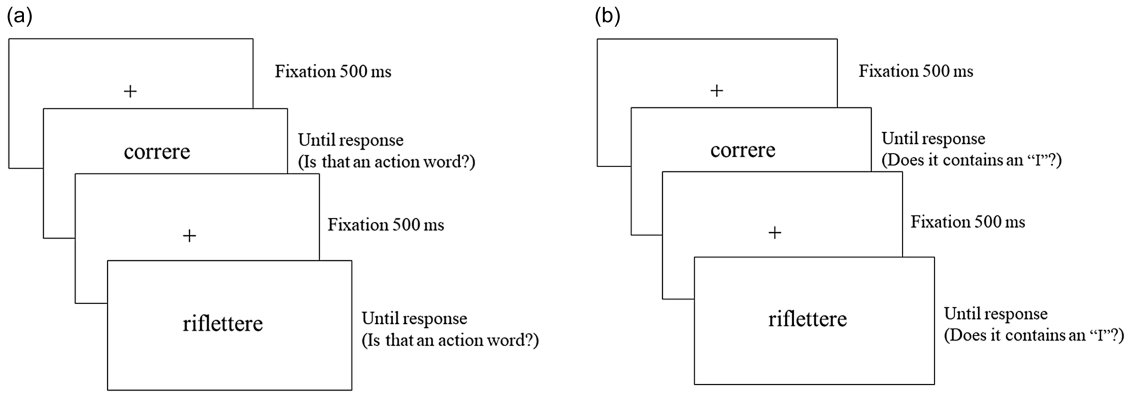


Figure 1. Experimental procedure for (a) Semantic judgment task and (b) Letter detection task. Stimuli are presented in italian, and they should be translated in english as follows: correre = to run; riflettere = to reflect.

Neuropsychological evaluation

Attention and processing speed was evaluated by Trail Making Test-part A (TMT-A) and the digit matrix cancelation test; executive functions were assessed by means of TMT-B and TMT B-A, brief version of Stroop task; semantic and phonological verbal fluency, modified version of Wisconsin Card Sorting Test (MCST). Verbal memory was assessed by means of a short story recall task (e.g., the short story of Anna Pesenti); language (i.e., naming) and semantics were assessed by means of the Boston naming test-15 (BNT-5). Depression and apathy were respectively measured by means of the Beck Depression Inventory-II (BDI-II) and the Dimensional Apathy Scale (I-DAS). The complete list of bibliographical references of tools is available in Supplementary material 1.

Statistical analyses

Demographic, clinical, behavioral, and cognitive variables were compared between PD group and HCs by independent samples *t*-test (the chi-squared test was used, as appropriate, to compare categorical variables). To compare PD and HCs groups on both SJ and LD performance in terms of Reaction Times (RTs) and Accuracy scores (Acc) according to the Type of Verb presented (action or abstract), we performed two 2 X 2 repeated-measures ANOVA once with RTs and once with Acc as the dependent variable, with one within-subjects factor [Verb Type (action, abstract)] and one between-subjects factor [Group (patient, healthy participants)]. Bonferroni post hoc test was performed to control for the type I error. Before proceeding with ANOVA, trials of both SJ and LD tasks with RTs exceeding 4000 ms were discarded from further analyses. Trials for which accuracy was close to chance level (< .6) were also removed. Subsequently, to investigate the possible influence of clinical (i.e., UPDRS, H&Y, LEDD, disease duration), and cognitive variables on RTs and Acc of LD and SJ tasks within PD and HCs group, we performed Pearson' correlational analyses. Then, linear regression analyses (by stepwise method) were performed by entering as independent variables the ones attaining a significant correlation with RTs and Acc scores at a level of $p < .05$ in the Pearson's test, and RTs and Acc scores as dependent variables. Finally, to control the increase of type I error due to multiple hypothesis testing, the p values for correlational analyses were also corrected using the False Discovery Rate method (FDR, Benjamini and Hochberg, 1995). Statistical analyses were performed with IBM SPSS-26 and JASP (version 0.18) computer softwares.

Results

Demographic, clinical, behavioral, and cognitive variables

In the present study, 31 PD patients and 31 HCs were enrolled. The two groups did not differ on demographic variables, nor on BDI-II. A significant difference between the two groups was found on DAS total score: patients with PD reported significantly higher scores than HCs on DAS (Table 1). Moreover, HCs and PD groups significantly differed on some cognitive variables; specifically, the two groups differed on TMT part A and TMT part B: patients with PD performed significantly worse compared to HCs (Table 1).

SJ task

A total of 7.35% of trials were removed in the HCs group (2.65% for action, 3.14% for abstract), and a total of 11% of trials were removed in PD group (7.7% for action, 14.3% for abstract). The 2-way ANOVA about RTs (Figure 2a) revealed a main effect of Verb Type, where RTs were longer for action (mean RTs = 1868.89 ms, SD = 493.42) than for abstract verbs (mean RTs = 1699.23 ms, SD = 378.59), $F(1,60) = 24.605$, $p < .001$, $\eta_p^2 = .291$. There was also a main effect of Group, as PD group showed slower RTs (mean RTs = 1913.42 ms, SD = 461.4) compared to HCs group (mean RTs = 1658.48 ms, SD = 313.52), $F(1,60) = 7.599$, $p < .05$, $\eta_p^2 = .112$). There was no significant interaction effect between Verb Type and Group, $F(1,60) = 3.696$, $p = .059$, $\eta_p^2 = .058$. Concerning the 2-way ANOVA on accuracy scores (Figure 2b), results revealed a main effect of Verb Type where Acc was lower for Action (mean action Acc = .93, SD = .06) compared to Abstract verbs (mean abstract Acc = .96, SD = .04), $F(1,60) = 5.635$, $p < .05$, $\eta_p^2 = .086$. There was a significant main effect of Group, $F(1,60) = 12.552$, $p = .001$, $\eta_p^2 = .173$, where PD patients showed less accuracy scores (mean Acc = .93, SD = .02) compared to HCs group (mean Acc = .96. SD = .02). There was no significant interaction effect between Verb Type and Group, $F(1,60) = 3.51$, $p = .66$, $\eta_p^2 = .055$.

LD task

A total of 5.31% of trials were removed in the HCs group (6.33% for action, 4.31% for abstract), and a total of 7.33% of trials were removed in PD group (9.24% for action, 5.43% for abstract). The 2-way ANOVA about RTs (Figure 2c) did not reveal any significant main effect for Verb Type ($F(1,60) = 2.233$, $p = .140$, $\eta_p^2 = .036$), nor for Group ($F(1,60) = 3.93$, $p = .052$, $\eta_p^2 = .062$) or for Group X

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Table 1. Comparisons between PD and HCs groups on demographic, clinical, cognitive, and behavioral variables

	PD group	HCs group	χ^2/t	p
	Mean ± SD/ number	Mean ± SD/ number		
Age (*ys*)	64.58 ± 8.87	64.19 ± 6.44	-.197	.845
Education (*ys*)	13.87 ± 4.02	13.35 ± 3.8	-.619	.538
Gender (M:F)	16:15	10:21	1.676	.196
Disease Duration (*ys*)	8.74 ± 4.46	–	–	–
UPDRS-III	15.57 ± 9.99	–	–	–
H&Y	1.97 ± 0.66	–	–	–
LEDD *(mg)*	586.61 ± 353	–	–	–
MoCA	23.26 ± 3.76	23.58 ± 3.67	.342	.734
Digit matrix cancelation test	48.97 ± 9.14	52.06 ± 7.25	1.478	.145
TMT A	56.58 ± 20.75	43.03 ± 20.51	−2.586	**.012**
TMT B	156.9 ± 70.96	117.1 ± 56.73	−2.44	**.018**
TMT B-A	99.61 ± 59.42	73.42 ± 46.06	−1.94	.57
Stroop – time	25.87 ± 27.37	22.29 ± 9.09	-.691	.492
Stroop – errors	0.9 ± 2.82	0.19 ± 0.61	−1.37	.176
FAS	37.64 ± 13.95	41.52 ± 7.26	1.370	.176
Semantic fluency	19.71 ± 5.3	25.24 ± 14.34	2.015	.48
MCST – Acc	5.55 ± 1.09	5.71 ± 1.1	.579	.564
MCST – PE	1.45 ± 2.29	0.77 ± 1.43	−1.396	.168
Recall of a short story	11.74 ± 3.5	13.06 ± 2.89	1.623	.110
BNT-15	12.26 ± 2.28	13.26 ± 1.82	1.906	.61
DAS total score	19.87 ± 7.9	14.68 ± 8.61	−2.474	**.016**
BDI-II	8.1 ± 8.45	6.16 ± 4.8	−1.109	.272

UPDRS-III = Unified Parkinson's Disease Rating Scale part III; H&Y = Hoehn and Yahr; MoCA, LEDD = Levodopa Equivalent Daily Dose; Montreal Cognitive Assessment; FAS = Phonemic fluency; TMT = Trail Making Test; MCST = Modified Wisconsin Card Sorting Test; Acc = Accuracy; PE = Perseverative Errors; BNT = Boston Naming Test; DAS = Dimension Apathy Scale; BDI = Beck Depression Inventory; values for p < .05 are displayed in bold.

Verb interaction (F (1,60) = .023, $p = .881$, $\eta^2_p = .000$). Concerning the 2-way ANOVA on accuracy scores, results did not reveal any significant main effect for Verb Type (F (1,60) = .360, $p = .551$, $\eta^2_p = .360$), nor for Group (F (1,60) = .595, $p = .444$, $\eta^2_p = .010$) or for Group X Verb interaction (F (1,60) = .014, $p = .905$, $\eta^2_p = .000$).

Correlational analyses

Results for the significant Pearson's correlational analyses for PD patients are presented in Supplementary material 2. No correlation was significant in the HCs group.

Relationship between SJ task and clinical and neuropsychological variables within PD group

Pearson's correlation analysis did not reveal any significant correlation between Acc scores for both action and abstract verbs with any other clinical and neuropsychological variables in SJ task. Regarding the RTs, correlation analysis revealed that RTs for action verbs during SJ task significantly correlated with H&Y (r = .495, $p = .03$), MoCA (r = -.500, $p = .03$), Semantic Fluency (r = -.536, $p = .03$), BNT-15 (r = -.436. $p = .04$), TMT-A (r = .444, $p = .04$), TMT-B (r = .538, $p = .02$), TMT B-A (r = .477, $p = .03$), Stroop – time (r = .451, $p = .04$) and MCST – accuracy (r = -.487, $p = .03$). Moreover, linear stepwise regression analyses showed that the semantic fluency task (β = -.439, t = -2.883, $p = .008$) and H&Y (β = .373, $t = 2.453$, $p = .021$) were significant predictors of slower RTs for action verbs in SJ task (Figure 3a and 3b). Regarding the RTs for abstract verbs, correlation analysis revealed a significant correlation with H&Y (r = .476, $p = .04$), MoCA (r = -.462, $p = .04$), Semantic Fluency (r = -.567, $p = .03$), BNT-15 (r = -.533. $p = .03$), TMT-B (r = .481, $p = .04$), MCST-perseverative errors (r = 510, $p = .03$) and MCST – accuracy (r = -.454, $p = .04$). Moreover, there was a trend towards a significant correlation between RTs for abstract verbs during SJ task and FAS (r = -.431, $p = .053$), TMT-A (r = .426, $p = .053$), TMT B-A (r = .420, $p = .053$). Finally, linear stepwise regression analyses showed that Semantic Fluency task (β = -.475, t = -3.149, $p < .001$) and H&Y (β = .344, $t = 2.280$, $p = .03$) were significant predictors of slower RTs for abstract verbs in SJ task (Figure 3c and 3d).

Relationship between LD task and clinical and neuropsychological, variables within PD group

Pearson's correlation analysis did not reveal any significant correlation between Acc scores for both action and abstract verbs with any other clinical and neuropsychological variables in LD task.

Concerning RTs, correlation analyses revealed that RTs for action verbs during LD task significantly correlated with TMT-A (r = .518, $p = .03$), TMT-B (r = .541, $p = .03$), Stroop – time (r = .534, $p = .03$) and MWCST – perseverative errors (r = .501, $p = .03$). Moreover, linear stepwise regression analyses showed that TMT-B was a significant predictor of slower RTs for action verbs during LD task (β = .541, $t = 3.466$, $p = .002$) (Figure 4a). As regard as RTs for abstract verbs, correlation analyses revealed that RTs for abstract verbs during LD task significantly correlated with TMT-B (r = .458, $p = .02$), TMT B-A (r = .493, $p = .04$), and Stroop – time (r = .629, $p = 004$). Finally, linear stepwise regression analyses showed that the interference time-effect for Stroop task was a significant predictor of slower RTs for abstract verbs during LD task (β = .629, $t = 4.355$, $p < .001$) (Figure 4b).

Discussion

This study aimed to elucidate action language abilities in PD patients compared to HCs by examining the processing of action verbs during an explicit semantic judgment (SJ) and an implicit letter detection (LD) task containing action and abstract verbs, combined with their respective psycholinguistic variables.

First, action and abstract verbs only differed in imaginability and concreteness properties, as action verbs have more elaborate perceptual and motor features (Grossman et al., 2002). Second, PD patients were slower and less accurate than HCs in processing action compared to abstract verbs only during the explicit SJ task but not the LD task. While general slowing in PD was expected (Low et al., 2002), patients showed a specific deficit for action semantic processing when the context explicitly required attention to the word meaning. This suggest that the action verb deficit could selectively occur during explicit tasks, requiring a deeper level of semantic processing.

This only partially aligns with a previous study, where PD patients showed deficits on action verbs processing during both explicit and implicit tasks (Fernandino et al., 2013). In our study, LD task required identifying a certain letter within the displayed word, while the implicit task of Fernandino's study involved judging if a stimulus was a word or non-word (i.e., lexical decision task). Moreover, the items were primed by either the same word (displayed in capitalized letters) or by a sequence of consonants. Thus, their result on the implicit task was due to a priming effect which is known to reflect the activation of lexico-semantic information at the word level (Ferrand et al., 1994). Therefore, we can assume that our LD task required sufficient attention to suppress word meaning activation, which explains the lack of performance differences between groups based on semantics.

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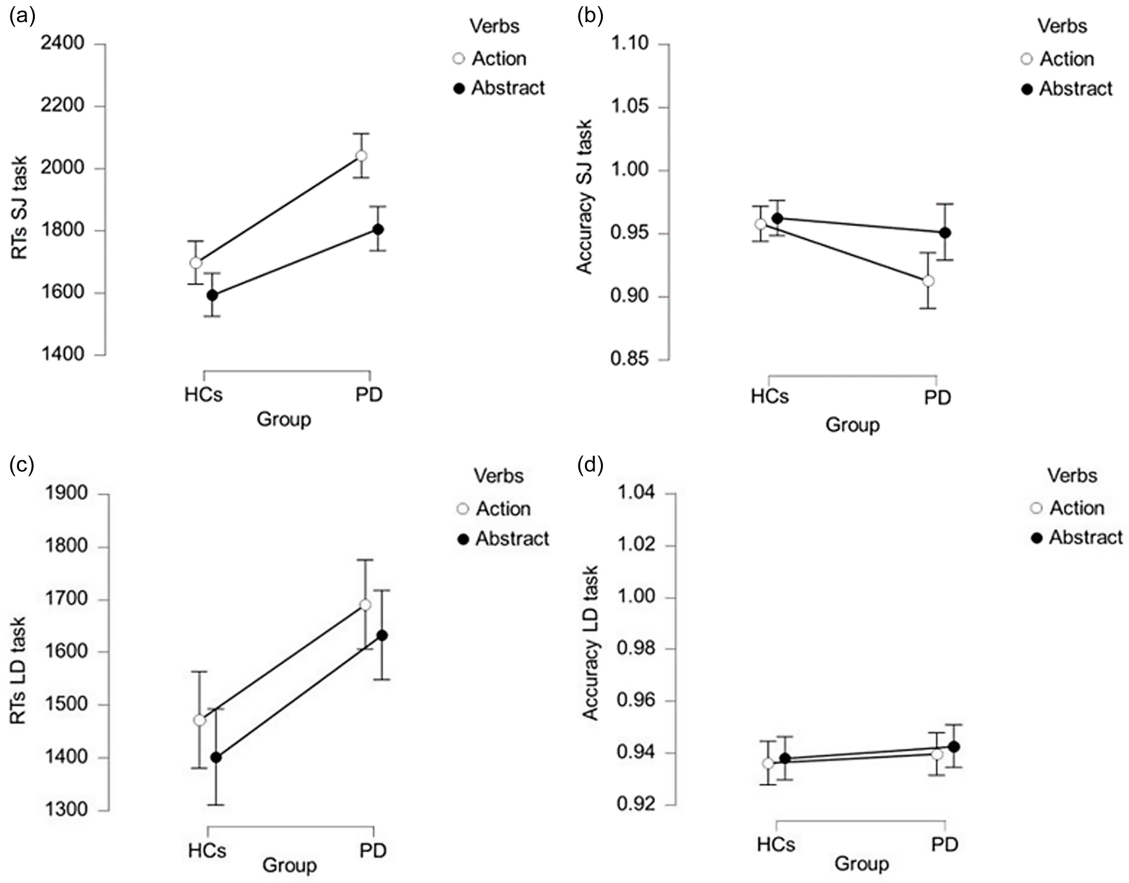


Figure 2. Average (a) Reaction times and (b) Accuracy results during SJ task and average (c) Reaction times and (d) Accuracy during LD task for both HCs and PD group.

Overall, our data would support a "flexible" embodied approach (Giacobbe et al., 2022; Pulvermüller, 2018), suggesting that motor and premotor regions could be selectively involved in action language processing only when deep semantic analysis is required. This difficulty in PD patients might indicate that impaired fronto-striatal networks are recruited for action language processing only if context demanding. In particular, the BG-thalamocortical circuit, with its projections to frontal areas including premotor and sensorimotor cortices, is crucial for motor planning and execution (Grezes & Decety, 2001; Pobric & Hamilton, 2006), action observation (Tremblay & Small, 2011), verbal processing (Pulvermüller & Fadiga, 2010; Pulvermüller, 2005) and action language (Cardona et al., 2013). Conversely, when attention is focused on word letters during the LD task, different neural circuits may be engaged. Abrevaya et al. (2016) found that, during passive listening to action and non-action words, the primary motor region (M1) showed more anterior connectivity in controls and more posterior connectivity in PD patients. Moreover, PD patients' BG atrophy correlated with increased reliance on M1-posterior connectivity during action-verb processing, suggesting that PD patients may process action verbs using non-motor cortical networks subserving on different lexico-semantic mechanisms (Birba et al., 2017). Similarly, our findings might reflect a compensatory mechanism involving networks other than the impaired fronto-striatal motor areas.

When investigating the relationship between SJ task and clinical and neuropsychological variables, we found that semantic fluency and disease progression (H&Y stages) predicted RTs for both action and abstract verbs in the SJ task for PD patients. Semantic fluency is linked to frontal-executive control for alternating attention and inhibiting irrelevant responses (Ellfolk et al., 2014). Thus, our data suggest that the explicit word processing requires deep semantic analysis and response control, as well as a switch between different semantic categories (i.e., action and abstract), with significant associations to PD patients' performance.

Semantic deficits in PD, specifically action semantic ones, are considered as an important marker for detecting early PD stages (Bocanegra et al., 2015) as well as an increased risk for dementia (Williams-Gray et al., 2007, 2009).

As regards H&Y stages, previous studies reported a positive link between PD progression and cognitive impairment (Nie et al., 2019; Pedersen et al., 2013). The significant relationship between H&Y stages and performance on the SJ task suggests that, as symptom severity progresses, cognitive difficulties are likely to increase as well (Modestino et al., 2018; Siciliano et al., 2017). Monitoring motor dysfunction may provide a potential means of identifying patients who could benefit from early cognitive interventions.

Moreover, our results showed that RTs on the LD task were predicted by TMT-B scores for action verbs and by Stroop-time for abstract verbs. The TMT is a comprehensive neuropsychological test requiring several cognitive skills, including selective attention, processing speed, sequencing, mental flexibility and visual–motor skills (Bowie & Harvey, 2006). Thus, because it probes both motor speed and attention, performance on those measures can be sensitive to various brain dysfunctions (Reitan, 1971). Our results suggest that the LD task could require a stronger attention, especially for words visual scanning.

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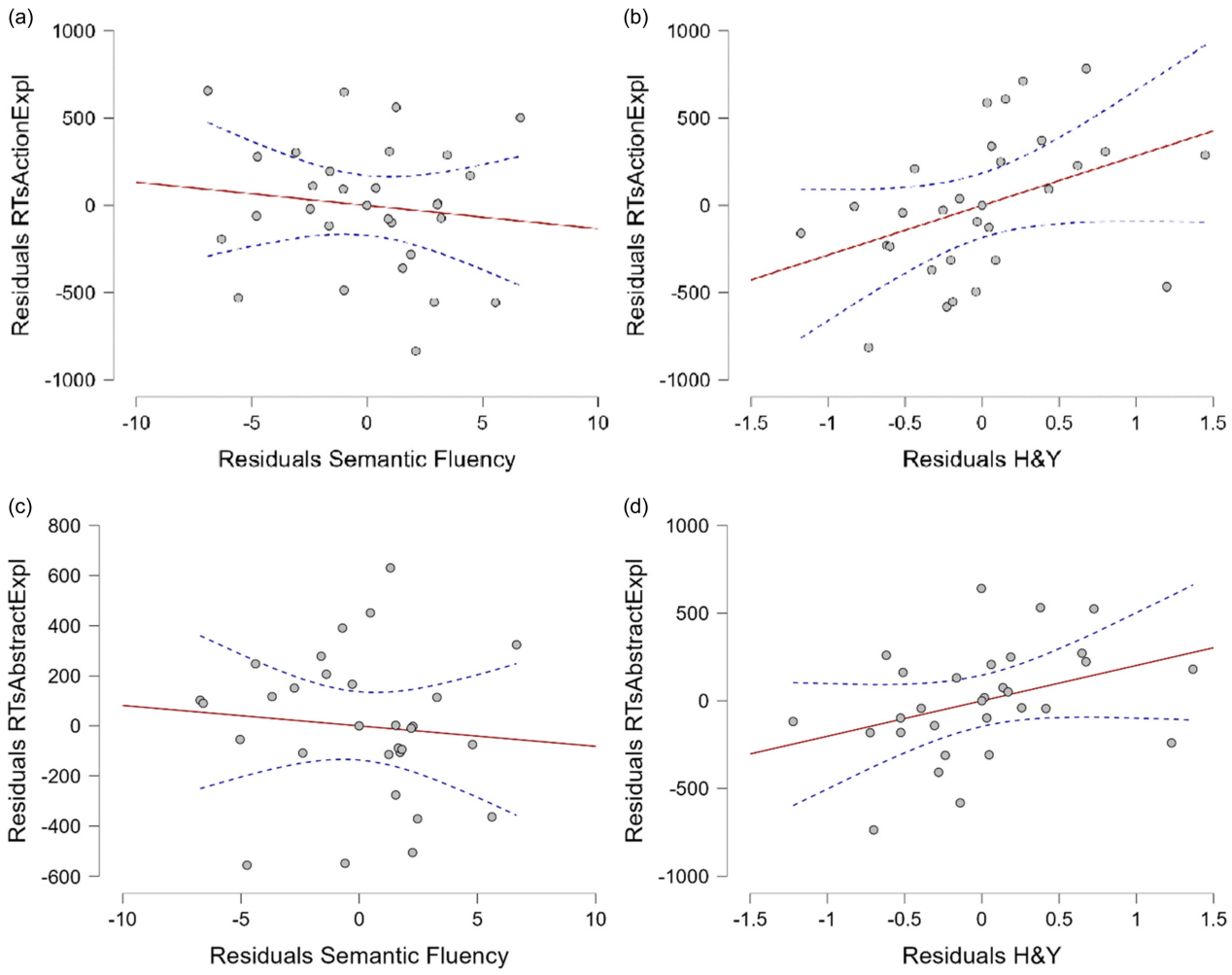


Figure 3. Partial correlation plots of linear regression analyses. Residual plot of RTs for (a) action verbs during SJ task and semantic fluency; (b) action verbs during SJ task and H&Y stages; (c) abstract verbs during SJ task and semantic fluency; (d) action verbs during SJ task and H&Y stages.

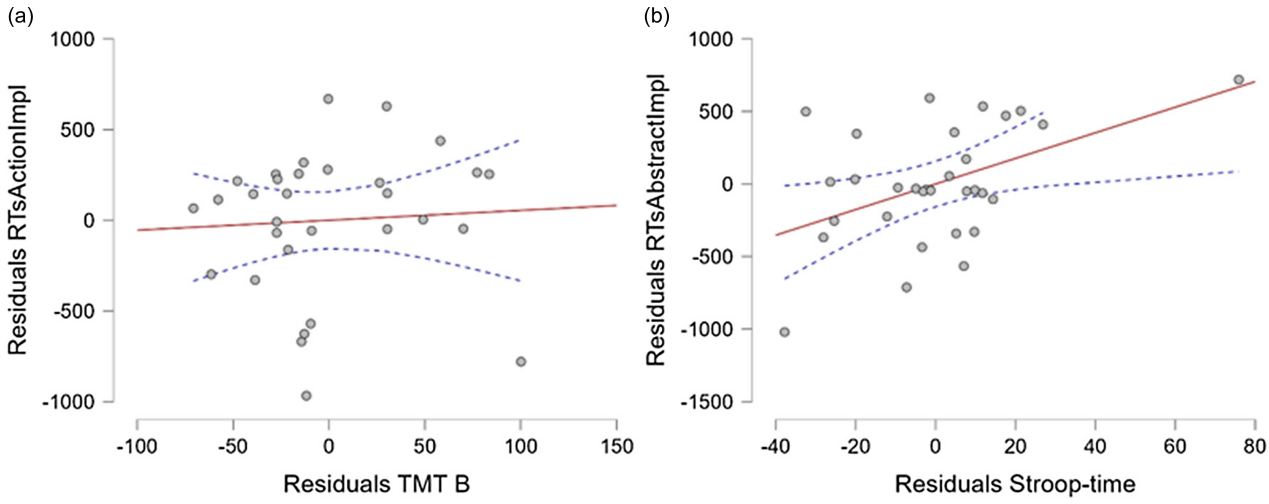


Figure 4. Partial correlation plots of linear regression analyses. (a) Residual plot of RTs for action verbs during LD task and TMT-B; (b) Residual plot of RTs for abstract verbs during LD task and Stroop-time.

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Finally, we found relationships between the Stroop task time interference and abstract verb processing in the LD task. Stroop task is associated with phonological processing, especially when vocal responses are required (Kinoshita et al., 2017). Meanwhile, implicit processing of abstract words involves brain areas related to linguistics (i.e., phonological) rather than semantic processing (Binder et al., 2005). Therefore, our results suggest the two tasks rely both on attention related to word composition rather than semantics, especially in PD patients, due to their lower RTs (Low et al., 2002).

This study has some limitations. First, our results are limited by several variables such as exiguity of samples, which could reduce their generalizability, but also source of participants (clinic vs. community). Moreover, education and ethnicity could represent a limiting factor in generalizing results. Additionally, we did not explore how motor symptoms in PD might affect action language performance. It would be useful to categorize PD patients according to their motor subtype or specific symptoms. Longitudinal studies are also needed to track language processing impairments over time in PD, providing valuable insights into the trajectory of cognitive decline in this population.

In conclusion, the present study showed the presence of a selective deficit in processing action verbs in PD patients during an explicit task, suggesting a specific deficit in action semantics. This could support a flexible embodied approach to semantic processing, showing a deep link between the motor system and action word semantics. Our findings also highlight the possible relevance of attention, executive functions and clinical features of PD in verbs processing, with implications for early detection of cognitive decline.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S135561772500013X.

Authors contribution. Chiara Giacobbe: Conceptualization, Methodology, Data Collection, Data curation, Writing-Original draft preparation, Funding Acquisition; Chiara Baiano: Methodology, Data curation, Formal analysis, Writing-Original draft preparation, Funding Acquisition; Carmine Vitale: Writing – Review & Editing, Supervision; Marianna Amboni: Writing – Review & Editing, Supervision; Gabriella Santangelo: Conceptualization; Writing – Review & Editing, Supervision.

Chiara Giacobbe and Chiara Baiano share first authorship.

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Competing Interests. None.

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