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Research report

Syntax, action verbs, action semantics, and object semantics in Parkinson's disease: Dissociability, progression, and executive influences

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ABSTRACT

Several studies have recently shown that basal ganglia (BG) deterioration leads to distinctive impairments in the domains of syntax, action verbs, and action semantics. In particular, such disruptions have been repeatedly observed in Parkinson's disease (PD) patients. However, it remains unclear whether these deficits are language-specific and whether they are equally dissociable from other reported disturbances —viz., processing of object semantics. To address these issues, we administered linguistic, semantic, and executive function (EFs) tasks to two groups of non-demented PD patients, with and without mild cognitive impairment (PD-MCI and PD-nMCI, respectively). We compared these two groups with each other and with matched samples of healthy controls. Our results showed that PD patients exhibited linguistic and semantic deficits even in the absence of MCI.

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However, not all domains were equally related to EFs and MCI across samples. Whereas EFs predicted disturbances of syntax and object semantics in both PD-nMCI and PD-MCI, they had no impact on action-verb and action-semantic impairments in either group. Critically, patients showed disruptions of action-verb production and action semantics in the absence of MCI and without any executive influence, suggesting a *sui generis* deficit present since early stages of the disease. These findings indicate that varied language domains are differentially related to the BG, contradicting popular approaches to neurolinguistics.

1. Introduction

A massive body of evidence gathered in the last fifteen years indicates that high-order cognition is rooted in lower-level sensorimotor systems. This view, which lies at the core of the embodied cognition framework (e.g., Barsalou, 1999; Gallese & Lakoff, 2005), has inspired novel approaches to the study of language. In short, the underlying question is whether language-specific distinctions (for example, at the semantic and lexical levels) are grounded in non-verbal perceptual and motor mechanisms.

Several reports have demonstrated distinctive associations between varied noun types and relevant perceptual systems. For example, Gonzalez et al. (2006) observed that odor-related words, as opposed to odor-neutral terms, activate smell-related structures in the primary olfactory cortex. Similarly, noun comprehension has been shown to rapidly activate modality-specific networks supporting shape (Wheatley, Weisberg, Beauchamp, & Martin, 2005) and color (Simmons et al., 2007) perception.

Even more studies have focused on the relationship between motor skills and language processing. In particular, researchers from varied fields have used linguistic tasks to examine referential motor resonance, namely, the relationship between the contents of verbal stimuli and relevant motor circuitry (Fischer & Zwaan, 2008). Of particular importance to this line of research is the study of linguistic and semantic skills in Parkinson's disease (PD), the second most prevalent neurodegenerative disorder worldwide (Tanner & Goldman, 1996). Available findings are highly relevant to constrain neurolinguistic models, establish early markers of the disease, and delineate therapeutic programs (García & Ibáñez, 2014). However, critical questions remain unanswered regarding the nature, dissociability, and progression of linguistic and semantic impairments in this population. The exploration of these issues could be used to constrain models of language embodiment and eventually hone their clinical relevance.

PD is associated with basal ganglia (BG) dysfunction, resulting from progressive degeneration of dopaminergic neurons projecting from the substantia nigra to striatal motor loci (Fearnley & Lees, 1991; Rodriguez-Oroz et al., 2009). Its main clinical feature is the loss of voluntary movement control, including resting tremor, postural instability, and bradykinesia (Helmich, Hallett, Deuschl, Toni, & Bloem, 2012; Liu et al., 2006; Rosin, Topka, & Dichgans, 1997). In addition to motor symptoms, PD involves deficits in high-order cognitive domains, such as attention, working memory (WM), and other executive functions (EFs) (Dubois & Pillon, 1996; Green et al., 2002; Hochstadt, Nakano, Lieberman, & Friedman, 2006). Furthermore, from early stages of the disease, patients manifest dysfunctions in two specific linguistic domains: syntax and action verbs (the latter at both the lexical and the semantic levels).

First, PD patients are impaired in processing sentences of varied syntactic complexity, as observed in both monolingual (Lee, Grossman, Morris, Stern, & Hurtig, 2003; Lieberman et al., 1992) and bilingual (Zanini et al., 2004) samples. Such deficits seem to be task-independent, as they were separately observed in self-paced reading, auditory comprehension (Angwin, Chenery, Copland, Murdoch, & Silburn, 2006), and sentence-picture matching (Hochstadt et al., 2006) tasks. Syntactic affectations in PD patients have been associated with abnormal P600 modulations (Friederici, Kotz, Werheid, Hein, & von Cramon, 2003) and reduced activations in bilateral fronto-temporal and striatal sites (Grossman et al., 2003).

Second, PD involves marked deficits in action verbs with relative preservation of noun processing. This was shown in tasks tapping semantic and/or lexical processes, such as object versus action picture naming (Bertella et al., 2002; Herrera & Cuetos, 2012; Rodriguez-Ferreiro, Menendez, Ribacoba, & Cuetos, 2009), related-word production (Peran et al., 2003), and lexical decision (Boulenger et al., 2008). Moreover, when the production of both action verbs and nouns is affected in PD, deficits are larger in the former word class (Cotelli et al., 2007; Crescentini, Mondolo, Biasutti, & Shallice, 2008). Strikingly, action-verb processing may be compromised even when abstract verbs are spared (Fernandino et al., 2013). High-order deficits involving action-related information in PD have also been revealed at a strictly semantic level, through picture-association tasks (Ibáñez et al., 2013). The latter paradigms are useful to disentangle conceptual and lexical factors in the observed deficits (see Vigliocco, Vinson, Druks, Barber, & Cappa, 2011), as semantic representations of pictures can be presumed to largely overlap with those evoked by their verbal labels (Bak & Hodges, 2003). Neural correlates of impaired action-verb processing in PD involve aberrant frontotemporal connectivity (Melloni et al., 2015) and damage to a BG-cortico-subcortical motor network (Cardona et al., 2014), including the prefrontal cortex, Broca's area, and the anterior cingulate cortex (Péran et al., 2009), and the subthalamic nucleus (Silveri et al., 2012).

Taken together, the above findings indicate that syntax, action verbs, and action semantics are specifically compromised in PD. Thus, BG circuits seem to be key components of the networks underlying these domains, as observed in clinical (Murray, 2000; Teichmann, Dupoux, Cesaro, & Bachoud-Levi, 2008; Teichmann et al., 2005) and neurotypical (Moro et al., 2001) samples. The role of BG in syntactic processing has been proposed to reflect their specialization for the acquisition and execution of hierarchical and sequential motor/cognitive routines (Ullman, 2001), their role in EFs (Grossman, 1999; Grossman, Lee, Morris, Stern, & Hurtig, 2002; Lee et al., 2003), and their involvement in cue-guided predictions (Kotz, Schwartze, & Schmidt-Kassow, 2009). Similarly, the crucial engagement of frontobasal structures during action-verb processing is highlighted by selective semantic and lexical deficits observed in multiple neurodegenerative motor diseases, such as motor neuron disease (Bak, 2013; Bak & Hodges, 2004; Bak, O'Donovan, Xuereb, Boniface, & Hodges, 2001; Bak et al., 2006; Hodges & Bak, 1997), amyotrophic lateral sclerosis (Bak & Hodges, 2004; Neary, Snowden, & Mann, 2000), progressive supranuclear palsy (Bak et al., 2001, 2006), corticobasal degeneration (Cotelli et al., 2006; Silveri & Ciccarelli, 2007), and Huntington's disease (Kargieman et al., 2014).

The role of the BG in action-verb processing supports embodied approaches to cognitive modeling. For example, Cardona et al. (2013) and Ibáñez et al. (2013) postulate that action-verb processing and motor-language coupling depend on a network involving loops from cortical areas to BG/thalamic structures and back to the cortex. Hence, BG affectation in early PD would lead to the selective disruption of this language domain.

Note, at this juncture, that virtually all studies on language processing in PD have been conducted with non-demented patients (Bertella et al., 2002; Boulenger et al., 2008; Cotelli et al., 2007; Grossman, Carvell, Stern, Gollomp, & Hurtig, 1992; Grossman et al., 2003; Herrera & Cuetos, 2012; Lieberman, Friedman, & Feldman, 1990; Lieberman et al., 1992). However, recent clinical research demonstrates that PD patients can manifest cognitive impairment even without reaching levels of dementia. Such a stage is known as mild cognitive impairment (MCI) (Aarsland et al., 2010; Caviness et al., 2007; Janvin, Larsen, Aarsland, & Hugdahl, 2006; Litvan et al., 2011; Yu et al., 2012). Prospective studies suggest that a considerable percentage of PD patients without cognitive impairment develop MCI just a few years after diagnosis (Broeders et al., 2013; Hobson & Meara, 2015). Following the onset of MCI, PD patients have a higher risk of developing dementia (Aarsland, Andersen, Larsen, Lolk, & Kragh-Sørensen, 2003; Buter et al., 2008; Janvin, Aarsland, & Larsen, 2005; Reid, Hely, Morris, Loy, & Halliday, 2011; Williams-Gray et al., 2013). These findings indicate that the course of PD involves continuum that goes from normal cognition to MCI to dementia. Consequently, the difference between absence and presence of MCI can be taken as a proxy of disease progression.

These prolegomena motivate three important questions regarding syntactic, action-verb, and action-semantic skills in PD and their relation to EFs and MCI. First, is the affectation of these skills domain-specific, or does it depend on executive or otherwise cognitive impairment? Second, is their disturbance equally dissociable from other deficits (viz., processing of object semantics)? Third, do such potential relationships vary as cognitive impairment worsens throughout the course of disease?

Whereas the latter two questions have not been directly assessed in the literature, the first one has yielded contradictory views. Some authors contend that syntactic deficits in PD are epiphenomenal to executive dysfunction (Angwin et al., 2006; Hochstadt et al., 2006; Longworth, Keenan, Barker, Marslen-Wilson, & Tyler, 2005) or impairments of selective attention (Lee et al., 2003). In a similar vein, action-verb deficits in PD have been attributed to underlying inhibitory control (Copland, 2003) or WM (Colman et al., 2009) deficits. However, the non-demented PD patients tested by Rodriguez-Ferreiro et al. (2009) exhibited significant impairments in action (but not in object) naming without concurrent executive impairment. Similarly, the early PD patients assessed by Ibáñez et al. (2013) evinced deficits in both action semantics and the ability to integrate action-verb and motor information, but these deficits were not associated with executive or general cognitive impairment.

The above questions give rise to distinct empirical predictions. First, following Rodriguez-Ferreiro et al. (2009) and Ibáñez et al. (2013), such linguistic deficits should not be caused by executive dysfunction. Second, if they are secondary to overall cognitive deficits, they should be absent in patients without MCI. Finally, if they are distinctively *sui generis*, they should differentially occur independently of MCI and executive dysfunction —the same should not be the case for deficits in non-action-related domains, such as object semantics.

To test such predictions, we assessed syntax, action verbs, action semantics, object semantics, and EFs in two patient groups: PD patients with and without MCI (PD-MCI and PD-nMCI, respectively). This way, we examine the dissociability and progression of linguistic and semantic disturbances in PD and their relation with executive performance and MCI.

2. Methods and materials

2.1. *Participants*

Forty non-demented PD patients and 40 healthy volunteers participated in this study. Clinical diagnosis of PD was made by two neurologists (B.O. and V.A.) in accordance with the United Kingdom PD Society Brain Bank criteria (Hughes, Daniel, Kilford, & Lees, 1992). Motor impairments were assessed with the motor section of the Unified Parkinson's Disease Rating Scale (UPDRS) (Fahn & Elton, 1987). Disease stage was rated with the Hoehn & Yahr scale (H&Y) (Hoehn & Yahr, 1967). All the patients were undergoing antiparkinsonian therapy and were evaluated during the "on" phase of their medication. None of them presented with other neurological disorders or major psychiatric conditions.

The patients were divided into two groups: PD-nMCI ($n = 23$) and PD-MCI ($n = 17$). A cognitive screening evaluation was carried out through the Montreal Cognitive Assessment

(MoCA) (Nasreddine et al., 2005). This instrument has proved to have reliable psychometric properties (Dalrymple-Alford et al., 2010) and be useful to detect PD-MCI (Gill, Freshman, Blender, & Ravina, 2008; Hoops et al., 2009; Nazem et al., 2009; Zadikoff et al., 2008). Additionally, functional skills were evaluated with the Barthel Index (Mahoney & Barthel, 1965) and the Lawton & Brody Index (Lawton & Brody, 1969). MCI diagnosis was based on Movement Disorder Society (MDS) Task Force recommendations for MCI Level I criteria (Litvan et al., 2012); these criteria have been proposed to favor timely identification of MCI and to homogenize methodological approaches in clinical research.

The control group was composed of 40 healthy volunteers matched for age, gender, and years of education. These subjects reported no history of drug abuse or previous neurological or psychiatric disorders. All controls showed functional independence, scored 26 or higher on the MoCA test, and possessed IQs above 90—as determined by the vocabulary and similarities subtests of the Wechsler Abbreviated Scale of Intelligence (WASI) (Wechsler, 1999). Control participants were then divided into two subgroups closely matched for demographic variables to each PD group. The PD-nMCI control group ($n = 23$) had a mean age of 56.74 ($SD = 10.1$) and a mean educational level of 12.43 ($SD = 4.69$) years of schooling. For the PD-MCI control group ($n = 17$), the mean age was 61.35 ($SD = 8.5$) and the mean level of education was 11.82 ($SD = 9.56$) years of schooling.

All participants gave written informed consent. The study was carried out in accordance with the principles of the Declaration of Helsinki and was approved by the Ethical Research Committee of Antioquia University.

2.2. Materials

2.2.1. Neuropsychological assessment

All the participants completed a two-hour neuropsychological evaluation tapping executive and linguistic domains known to be affected since early stages of the disease (Goldman, Weis, Stebbins, Bernard, & Goetz, 2012; Ibáñez et al., 2013; Janvin et al., 2006).

2.2.1.1. EFs. EFs were assessed through the INECO Frontal Screening (IFS) battery (Torralva, Roca, Gleichgerrcht, Lopez, & Manes, 2009), a sensitive tool for neurodegenerative disease assessment (Gleichgerrcht, Roca, Manes, & Torralva, 2011; Torralva, Roca, Gleichgerrcht, Bekinschtein, & Manes, 2009), in general, and medial frontal EFs (Roca et al., 2011), in particular. Over a maximum total score of 30 points, a 25-point cut-off IFS score has shown a sensitivity of 96.2% and a specificity of 91.5% in detecting patients with dysexecutive syndrome (Torralva, Roca, Gleichgerrcht, Lopez, et al., 2009). This test includes eight tasks: (1) motor programming: subjects perform the Luria series ("fist, edge, palm"), first by copying the administrator and then on their own; (2) conflicting instructions: subjects are required to tap the table once when the administrator taps it twice, or twice when the administrator taps it once; (3) motor inhibitory control: subjects are told to tap the table only once when the administrator taps it once, but to do nothing when the examiner taps it twice; (4) numerical WM: subjects are asked to repeat a progressively longer string of digits in the reverse order; (5) verbal WM: subjects are asked to list the months of the year backwards, starting with December; (6) spatial WM: the examiner presents four cubes and points at them in a given sequence; the subject is asked to repeat the sequence in reverse order; (7) abstraction capacity: subjects are read proverbs and asked to explain their meaning; (8) verbal inhibitory control: this task, based on the Hayling test, measures the ability to inhibit an expected response; in the first part, subjects are read three sentences and asked to complete them correctly, as quickly as possible; in the second part, they are asked to complete another three sentences with a syntactically correct but semantically incongruous word.

2.2.1.2. Language skills. We assessed linguistic (syntactic processing, action-verb production) and semantic (action—action and object—object association) skills using tasks which have proven sensitive to subtle impairments in neurodegenerative motor disorders, including PD (Cardona et al., 2013; Colman, Koerts, Stowe, Leenders, & Bastiaanse, 2011; Cotelli et al., 2007; Ibáñez et al., 2013; Lieberman et al., 1990), Huntington's disease (Kargieman et al., 2014; Saldert, Fors, Stroberg, & Hartelius, 2010), and motor neuron disease (Bak & Hodges, 2004; Cobble, 1998). All tasks were administered in Spanish, the participants' mother tongue.

2.2.1.2.1. Syntax. We examined syntactic comprehension using two subtests of the Boston Diagnostic Aphasia Examination (BDAE) (Goodglass, Kaplan, & Barresi, 2001): "touching A with B" and "embedded sentences". Each trial in these subtests includes four pictures. Participants are asked to point to the picture that best represents the utterance read by the examiner.

In the first subtest, each picture shows the hand of a person holding or touching objects. The examiner reads phrases including the verb *tocar* [*touch*] in present participle form and two nouns which vary in syntactic function. In some phrases, both nouns constitute the direct object of *tocar* (e.g., *tocando la cuchara y las tijeras* [*touching the spoon and the scissors*]). In others, one of the nouns is an instrumental adjunct and the other one is a direct object (e.g., *tocando las tijeras con el peine* [*touching the scissors with the comb*]). The second subtest measures complex-sentence processing skills. Verbal stimuli are sentences including a restrictive relative clause as part of their subject (e.g., *La mujer que es gorda está besando a su esposo* [*The woman who is fat is kissing her husband*]) or direct object (e.g., *la niña está persiguiendo al niño que lleva botas* [*The girl is chasing the boy who is wearing boots*]). Thus, each task taps different aspects of syntactic processing.

2.2.1.2.2. Action verbs. At the lexical level, action verbs were further assessed through the action-naming subtest of the BDAE. This task taps access to the lexical representations of action verbs by having subjects name ten pictures depicting motor actions.

2.2.1.2.3. Action semantics. Semantic representation of actions was assessed through the Kissing and Dancing Test (KDT) (Bak & Hodges, 2003), an instrument devised as a

complement to the Pyramids and Palm Trees (PPT) test. It comprises 52 triads of images depicting motor actions. Each triplet is composed of a cue action-picture and two semantically related pictures. Participants are required to point to the picture that is the most closely related to the cue picture. The maximum score is 52.

2.2.1.2.4. Object semantics. Finally, to evaluate semantic representation of objects, we used the PPT test (Howard et al., 1992). It consists of 52 triplets of pictures depicting different objects. Each triplet is composed of a cue object-picture and two semantically related pictures. Participants must point to the picture that is most closely related to the cue. The maximum score is 52. Note that PPT and the KDT have been shown to possess similar difficulty levels (Bak & Hodges, 2003), which renders them suitable to compare processing of object semantics and action semantics.

2.3. Data analysis

Clinical and demographic variables were analyzed using descriptive statistics. Group comparisons in terms of clinical and demographic variables were performed through two-tailed Student's *t* tests or Chi-square tests, as needed. Neuropsychological measures were compared between groups using a Mann–Whitney test. Additionally, we calculated effect sizes using Cohen's *d*. Subsequently, to determine the influence of EFs on linguistic performance, we applied an ANCOVA test adjusted for the total IFS score. In order to assess the modulatory effect of EFs, we report the effects before and after co-variation. Finally, we conducted a linear regression analysis to explore whether EFs independently predicted performance on language tasks. We estimated models in which the different language measures were separately considered as dependent variables for each group (PD-MCI, PD-nMCI); and total IFS score was included as predictor. In a subsequent analysis group was included as a second predictor (dummy variable). Alpha values were set at <.05. All statistical analyses were carried out with SPSS 20.0 statistical software.

3. Results

3.1. Demographic data and clinical evaluation

The control group and the PD patients were similar in age [$t(78) = -.65$, $p = .51$], education level [$t(78) = .75$, $p = .45$], and gender [$\chi 2\ (1) = .05$, $p = .82$]. Relative to their corresponding control subgroups, neither PD-nMCI nor PD-MCI showed significant differences in age [$t(44) = -.49$, $p = .62$, and $t(32) = -.46$, $p = .65$, respectively] and education level [$U = 258.5$, $p = .89$, and $U = 131.5$, $p = .65$, respectively]. The PD-nMCI and PD-MCI groups did not differ significantly in terms of age [$t(38) = -1.15$, $p = .25$], education level [$U = 160.5$, $p = .34$], or clinical variables, namely, years since diagnosis [$U = 193.5$, $p = .96$], UPDRS score [$U = 193.5$, $p = .90$], and H&Y stage [$U = 190.5$, $p = .89$]. See Table 1 for a summary of the participants' demographic and clinical data.

3.2. EFs

As expected, the PD group showed significant executive impairments. Their total IFS score was significantly lower than that of controls [$U = 280.5$, $p < .001$]. Total IFS scores were lower for both PD-nMCI [$U = 82.5$, $p < .001$] and PD-MCI [$U = 48.5$, $p < .005$] than for their respective controls. Also, PD-nMCI patients outperformed PD-MCI patients on the IFS [$U = 119.9$, $p = .04$]. In sum, EFs were impaired in PD patients, and these deficits were greater when they had MCI. Further data on the performance of each group on the EF tasks are offered in Table 2. Fig. 1(A) and Fig. 2(A) show the comparison of executive performance across groups.

3.3. Linguistic and semantic measures

The groups' performance on linguistic and semantic tasks is described below. For further data, see Table 2. The comparison of all groups' performance is shown in Fig. 1(B–F) and Fig. 2(B–F).

Table 1 – Demographic data and clinical evaluation.

		PD		Controls		PD versus controls	PD-nMCI		PD-MCI		PD-nMCI versus PD-MCI
		$n = 40$		$n = 40$		p value	$n = 23$		$n = 17$		p value
Demographic variables	**Age (years)**	60.28	(11.81)	58.70	(9.62)	.52[a]	58.43	(13.13)	62.76	(9.60)	.26[a]
	Education (years)	11.38	(4.91)	12.18	(4.57)	.45[a]	11.87	(5.01)	10.71	(4.90)	.34[c]
	Gender (F:M)	20:20		19:21		.82[b]	11:12		9:08		.75[b]
Clinical variables	**Years diagnosed**	7.42	(4.80)				7.10	(3.91)	7.90	(5.83)	.96[c]
	UPDRS III	29.78	(14.70)				30.04	(16.01)	29.41	(13.14)	.90[c]
	H&Y	2.33	(.61)				2.34	(.61)	2.32	(.63)	.89[c]

Note: Values are expressed as mean (*SD*) with the exception of gender.
PD = Parkinson's disease; PD-nMCI = Parkinson's disease without mild cognitive impairment; PD-MCI = Parkinson's disease with mild cognitive impairment; UPDRS III = Unified Parkinson's Disease Rating Scale, part III; H&Y = Hoehn & Yahr scale.
[a] *p* values were calculated through *t* test for independent samples.
[b] *p* values were calculated through chi-square test ($\chi 2$).
[c] *p* values were calculated through Mann–Whitney *U* test.

Table 2 – Performance of each group on the linguistic, semantic, and EF tasks.

	PD	Controls	PD versus controls	*d*
	n = 40	*n* = 40	*p* value	
Total IFS score	19.78 (3.86)	23.72 (2.05)	**<.001**[a*]	**1.26**
Touching A with B	10.05 (1.66)	11.72 (.55)	**<.001**[b*]	**1.27**
Embedded sentences	9.33 (1.27)	9.95 (.22)	.37[b]	
KDT	47.50 (3.70)	51 (1.30)	**<.005**[b*]	**1.28**
Action naming	10.88 (1.36)	12 (.20)	**<.005**[b*]	**1.11**
PPT	48.30 (2.98)	51.13 (2.98)	**<.005**[b*]	**1.26**
	PD-nMCI	Controls	PD-nMCI versus controls	*d*
	n = 23	*n* = 23	*p* value	
Total IFS score	21.09 (2.67)	24.48 (2.02)	**<.001**[a*]	**1.46**
Touching A with B	10.22 (1.68)	11.87 (.46)	**<.005**[b*]	**1.39**
Embedded sentences	9.65 (1.03)	10 (.00)	.58	
KDT	48 (3.80)	51.26 (1.21)	**.05**[b*]	**1.20**
Action naming	11.10 (1.30)	11.96 (.21)	**.05**[b*]	**.99**
PPT	49.17 (2.59)	51.43 (.95)	**.03**[b*]	**1.16**
	PD-MCI	Controls	PD-MCI versus controls	*d*
	n = 17	*n* = 17	*p* value	
Total IFS score	18.00 (4.54)	22.71 (1.65)	**<.005**[a*]	**1.40**
Touching A with B	9.82 (1.67)	11.53 (.62)	**.05**[b*]	**1.37**
Embedded sentences	8.88 (1.45)	9.88 (.33)	.24	
KDT	46.70 (3.40)	50.59 (1.28)	**.01**[b*]	**1.56**
Action naming	10.60 (1.40)	12.00 (.00)	**.02**[b*]	**1.46**
PPT	47.12 (3.14)	50.71 (1.21)	**.02**[b*]	**1.58**
	PD-nMCI	PD-MCI	PD-nMCI versus PD-MCI	*d*
	n = 23	*n* = 17	*p* value	
Total IFS score	21.09 (2.67)	18 (4.54)	**.04**[a*]	**.89**
Touching A with B	10.22 (1.68)	9.82 (1.67)	.99	
Embedded sentences	9.65 (1.03)	8.88 (1.45)	.30	
KDT	48 (3.80)	46.70 (3.40)	.85	
Action naming	11.10 (1.30)	10.60 (1.40)	.66	
PPT	49.17 (2.59)	47.12 (3.14)	.19	

Note: Values are expressed as mean (SD). Each patient group (PD-nMCI and PD-MCI) had its own control group, specifically matched for age, gender, and years of education.
PD = Parkinson's disease; PD-nMCI = Parkinson's disease without mild cognitive impairment; PD-MCI = Parkinson's disease with mild cognitive impairment; UPDRS III = Unified Parkinson's Disease Rating Scale, part III; H&Y = Hoehn & Yahr scale; IFS = INECO Frontal Screening; PPT = Pyramids and Palm Trees; KDT = Kissing and Dancing Test.
d = Cohen's effect size.
* Alpha level set at .05.
[a] *p* values were calculated through Mann–Whitney *U* test.
[b] Values obtained after adjusting for total IFS score.

3.3.1. *Syntactic processing*

PD patients evinced syntactic comprehension deficits. Relative to controls, they obtained significantly lower scores on both the "touching A with B" subtest [$U = 297$, $p < .001$] and the "embedded sentences" subtest [$U = 552$, $p < .001$]. The same was true for each patient subgroup individually. Both subtests revealed impaired performance in PD-nMCI [$U = 106$, $p < .001$, and $U = 207$, $p = .04$, respectively] and PD-MCI [$U = 49$, $p < .005$, and $U = 80$, $p = .01$, respectively] as compared to their respective control subgroups. Performance in these two tasks was similarly impaired between PD-nMCI and PD-MCI [$U = 167.5$, $p = .44$, and $U = 134$, $p = .06$, respectively].

The difference between PD patients and controls in "touching A with B" remained after adjusting for EFs [F (1, 78) = 14.52, $p < .001$]. The pattern of results observed in this task was also preserved when comparing PD-nMCI with matched controls [F (1, 44) = 10.64, $p < .005$] and PD-MCI with matched controls [F (1, 32) = 4.02, $p = .05$]. As before, no differences were found between PD-nMCI and PD-MCI [F (1, 38) = .001, $p = .99$]. On the contrary, differences in the "embedded sentences" subtest disappeared after covariate analysis when comparing PD patients with controls [F (1, 78) = .802, $p = .37$], PD-nMCI patients with controls [F (1, 44) = .30, $p = .58$], and PD-MCI with controls [F (1, 32) = 1.41, $p = .24$]. Both patient groups remained without significant differences after covariation [F (1, 38) = 1.09, $p = .30$].

In sum, the patients revealed two patterns of syntactic impairment, even with absent MCI. Their deficits to identify functional roles within predicates were independent from EFs. Conversely, their difficulties in complex-sentence processing skills appear to be related to their executive impairments.

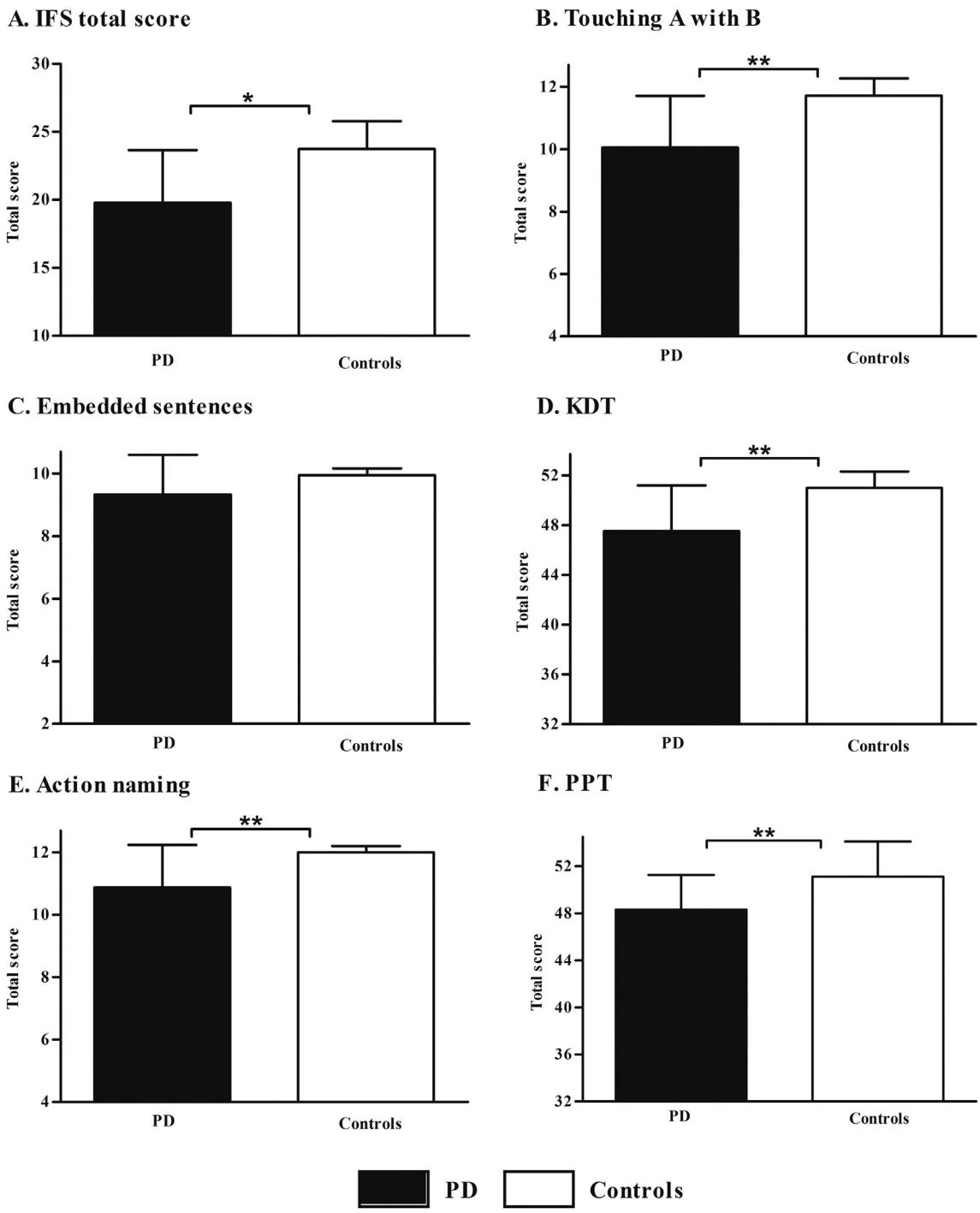

Fig. 1 – Performance of PD patients and controls on executive, linguistic, and semantic tasks. The graphs show the comparison between all PD patients ($n = 40$) and all controls ($n = 40$) as a whole. Error bars represent SDs. Statistically significant differences are indicated by * (executive task) and ** (after covariation with EFs). (A) INECO Frontal Screening (IFS) battery total score. (B) Touching A with B test total score. (C) Embedded sentences test total score. (D) Kissing and Dancing Test (KDT) total score. (E) Action-naming test total score. (F) Pyramids and Palm Trees (PPT) test total score.

3.3.2. *Action-verb production*

PD patients were outperformed by controls on the action-naming task [$U = 412.5$, $p < .001$]. Impairments were observed in both PD-nMCI [$U = 169$, $p < .005$] and PD-MCI [$U = 51$, $p < .001$] relative to their respective controls. Action-naming skills were similar between the patient subgroups [$U = 149.5$, $p = .18$]. The differences between PD patients and controls persisted after controlling for EFs [F (1, 78) = 9.61, $p < .005$]. Likewise, further analyses with EFs as a covariate showed the same action-verb production deficits in PD-nMCI

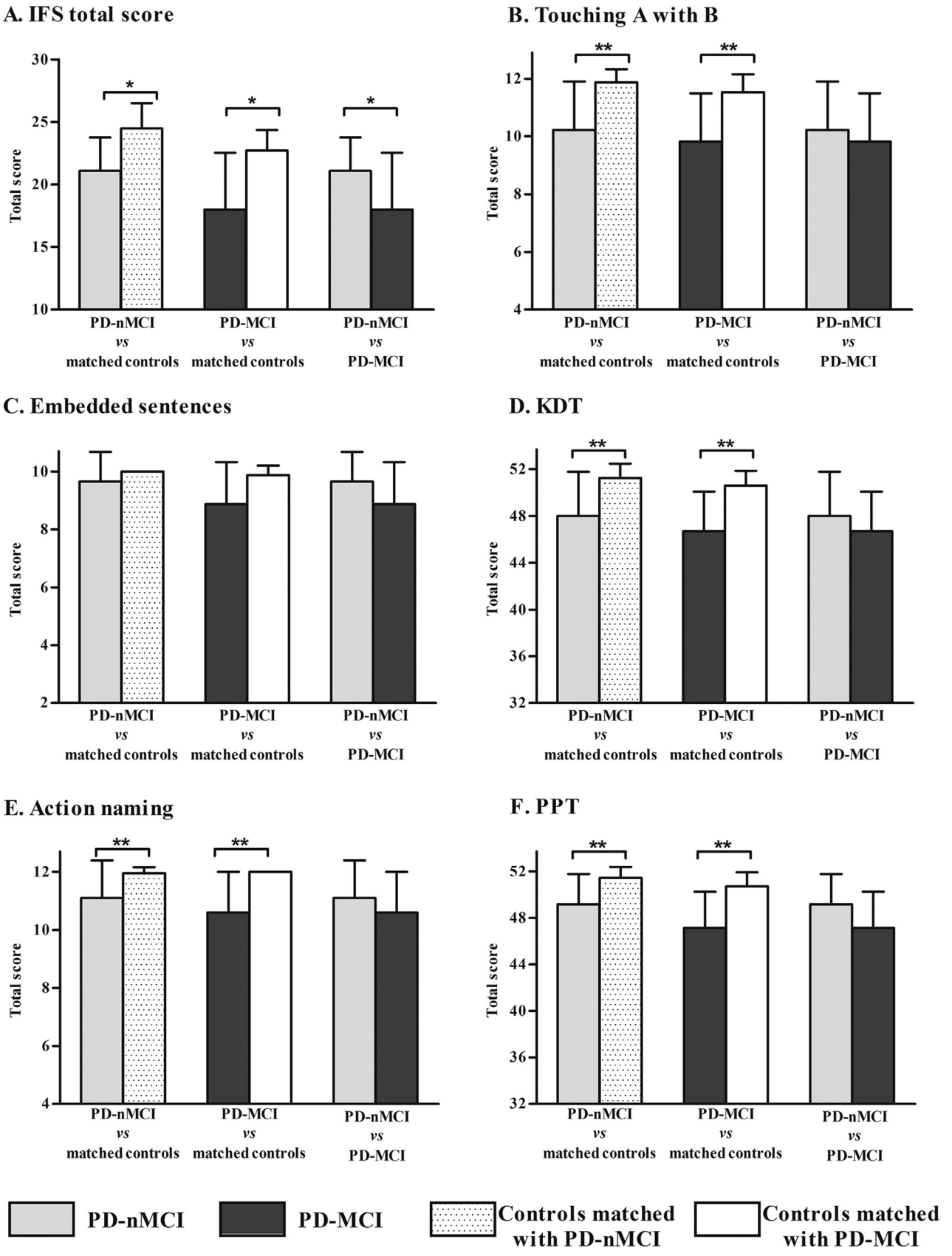

Fig. 2 – Comparison of executive, linguistic, and semantic performance across groups (PD-nMCI versus controls, PD-MCI versus controls, PD-nMCI versus PD-MCI). Each patient group (PD-nMCI and PD-MCI) had its own control group, specifically matched for age, gender, and years of education. Error bars represent SDs. Statistically significant differences are indicated by * (executive task) and ** (after covariation with EFs). (A) INECO Frontal Screening (IFS) battery total score. (B) Touching A with B test total score. (C) Embedded sentences test total score. (D) Kissing and Dancing Test (KDT) total score. (E) Action-naming test total score. (F) Pyramids and Palm Trees (PPT) test total score.

[F (1, 44) = 4.02, $p = .05$] and PD-MCI [F (1, 32) = 6.27, $p = .02$] relative to their respective controls. Finally, impaired performance of PD-nMCI and PD-MCI remained similar after adjusting for EFs [F (1, 38) = .20, $p = .66$]. In brief, impairments of action-verb production in PD patients occurred since early stages and independently of EF skills.

3.3.3. *Action semantics*

Performance patterns in the KDT were completely congruent with those observed in action naming. Overall, PD patients were outperformed by controls [$U = 227$, $p < .001$]. Such action-semantic deficits were observed separately in PD-nMCI [$U = 76.5$, $p < .001$] and PD-MCI [$U = 32.5$, $p < .001$] relative to their respective controls. No difference was found between the patient subgroups [$U = 133.5$, $p = .09$]. The differences between PD patients and controls persisted after controlling for EFs [F (1, 78) = 10.87, $p < .005$]. Further analyses with EFs as a covariate showed the same action-semantic deficits in PD-nMCI [F (1, 44) = 4.17, $p = .05$] and PD-MCI [F (1, 32) = 6.88, $p = .01$] relative to their respective controls. Finally, impaired performance of PD-nMCI and PD-MCI remained similar after adjusting for EFs [F (1, 38) = .04, $p = .85$]. In brief, as was the case with action-verb production deficits, impairments of action-verb semantics in PD patients occurred since early stages and independently of EF skills.

3.3.4. *Object semantics*

Comparisons between PD patients and controls revealed a significant difference in the PPT test [$U = 250.5$, $p < .001$]. Relative to their corresponding control subgroups, both PD-nMCI [$U = 85.5$, $p < .001$] and PD-MCI [$U = 30.5$, $p < .001$] evinced significantly poorer performance on this task. The comparison between PD-nMCI and PD-MCI revealed significantly lower scores in the latter group [$U = 107.0$, $p = .01$]. The differences between PD patients and controls in the PPT test remained significant after adjusting for EFs [F (1, 78) = 9.12, $p < .005$]. Similarly, the differences remained when comparing the PD-nMCI group with controls [F (1, 44) = 5.02, $p = .03$] and the PD-MCI group with controls [F (1, 32) = 6.64, $p = .02$]. However the differences between PD-nMCI and PD-MCI disappeared after co-varying for EFs [F (1, 38) = 1.83, $p = .19$]. Therefore, the patients exhibited disturbances of object semantics. Such deficits became greater after the onset of cognitive impairment, but this effect was partially influenced by executive dysfunction.

4. Are linguistic and semantic deficits predicted by executive impairment?

We estimated different models in which each language measure was separately considered as a dependent variable while the total IFS score (indexing EF skills) was framed as a predictor. In a subsequent analysis, the group variable (nMCI, MCI) was also introduced as a second predictor. For further data, see Table 3.

4.1. *Syntactic processing*

In the control group, EF skills were not significantly related to performance on the "touching A with B" [$\beta = .07$, F (1, 38) = 2.99, $p = .09$] or the "embedded sentences" [$\beta = .01$, F (1, 38) = .74, $p = .39$] tasks. Contrariwise, in the case of PD-nMCI, EFs did significantly predict performance on both the "touching A with B" [$\beta = .21$, F (1, 21) = 8.52, $p = .01$] and the "embedded sentences" [$\beta = .08$, F (1, 21) = 4.10, $p = .05$] tasks. Similarly, EFs in the PD-MCI group were also significantly associated with performance on the syntactic comprehension measures ["touching A with B": $\beta = .22$, F (1, 15) = 19.11, $p < .001$; "embedded sentences": $\beta = .14$, F (1, 15) = 10.95, $p < .005$]. When group was introduced as a second predictor (i.e., as a dummy variable), it was not significantly associated with performance on either test. In sum, EFs predicted syntactic processing performance in PD patients with or without MCI.

4.2. *Action-verb production*

When action-naming results were introduced as a dependent variable, EFs did not predict performance in either controls [$\beta = -.00$, F (1, 38) = .02, $p = .89$], PD-nMCI [$\beta = .08$, F (1, 21) = .48, $p = .50$], or PD-MCI patients [$\beta = .10$, F (1, 15) = 1.97, $p = .18$]. When group was introduced as a second predictor, it was not significantly associated with the action-naming performance. Therefore, action-verb processing was fully independent from EFs.

4.3. *Processing of action semantics*

A similar pattern was observed when the KDT action-naming performance was framed as a dependent variable: EFs showed no significant effects in either the controls [$\beta = .10$, F (1,

Table 3 – Linear regression models of performance on linguistic and semantic tasks.

	Dependent variable	Controls		PD-nMCI		PD-MCI	
		B	*p* value	β	*p* value	β	*p* value
Model I	**Touching A with B**	.07	.09	.21	**.01***	.22	**<.001***
Model II	**Embedded sentences**	.01	.39	.08	**.05***	.14	**<.005***
Model III	**KDT**	.10	.31	.50	.10	.29	.12
Model IV	**Action naming**	−.00	.89	.08	.50	.10	.18
Model V	**PPT**	.21	**.01***	.37	**<.005***	.42	**<.001***

Note = INECO Frontal Screening (IFS) total score was considered as a predictor variable.
PD-nMCI = Parkinson's disease without Mild Cognitive Impairment; PD-MCI = Parkinson's disease with mild cognitive impairment; PPT = Pyramids and Palm Trees test; KDT = Kissing and Dancing Test.
β = beta coefficient.
* Alpha level set at .05.

38) = 1.06, $p = .31$], PD-nMCI [$\beta = .50$, F (1, 21) = 2.91, $p = .10$], or the PD-MCI patients [$\beta = .29$, F (1, 15) = 2.66, $p = .12$]. When group was introduced as a second predictor, it was not significantly associated with the KDT results. Therefore, the groups' abilities to associate actions at a semantic level were fully independent from EFs.

4.4. *Processing of object semantics*

EFs were a significant predictor of PPT test performance in controls [$\beta = .21$, F (1, 38) = 6.65, $p = .01$], PD-nMCI [$\beta = .37$, F (1, 21) = 13.09, $p < .005$], and PD-MCI [$\beta = .42$, F (1, 15) = 15.95, $p < .001$]. As a result, EFs appeared to be a good predictor of object association abilities. When group was introduced as a second predictor, it was significantly associated with performance in this test.

In conclusion, not all linguistic and semantic domains were equally related to EFs in PD patients. Specifically, in both PD-nMCI and PD-MCI, EFs predicted disturbances of syntax and object semantics, but they did not predict impairments of action naming or action semantics.

5. Discussion

The present study examined the dissociability and progression of linguistic and semantic deficits in PD and their relation with EFs. To this end, we administered syntactic, action-naming, semantic association, and executive tasks to two samples of non-demented PD patients differing in their level of cognitive impairment (PD-nMCI and PD-MCI). We compared these two groups with each other and with matched samples of healthy controls. In particular, we explored whether linguistic and semantic deficits in each patient group were influenced by executive skills. Our results showed that PD patients exhibited linguistic and semantic deficits even in the absence of MCI. However, not all domains were equally related to EFs and MCI across groups. EFs predicted syntactic and object-association deficits in both PD-nMCI and PD-MCI; instead, they had no impact on action-naming or action-association difficulties in either group. Critically, action-verb production and action semantics were disrupted in the absence of MCI and without any executive influence, suggesting a *sui generis* deficit present since early disease stages. Despite accruing evidence highlighting syntactic and action-verb deficits as a hallmark of non-demented PD, these domains have not been heretofore examined in connection with EFs across different levels of cognitive impairment. Therefore, this study provides novel results for both clinical research on PD and theoretical models of the role of the BG in language processing. Below we discuss our key findings separately.

5.1. *Syntactic deficits in PD depend on EFs but not on MCI*

We found two patterns of syntactic impairment in PD, both occurring even without concomitant MCI. The patients exhibited difficulties to identify the syntactic function of nouns within verb phrases and to process complex sentences. Such results are consistent with previous reports showing that PD patients are impaired at comprehending sentences of diverse syntactic complexity (Angwin et al., 2006; Hochstadt et al., 2006; Lieberman et al., 1992).

While not related to general cognitive state, syntactic deficits in our patients were associated with EFs. Similar findings have been reported in other studies with PD patients (Angwin et al., 2006; Colman et al., 2011; Grossman, 1999; Grossman, Lee, et al., 2002; Grossman, Zurif, et al., 2002; Hochstadt et al., 2006; Lee et al., 2003) and healthy participants (Boudewyn, Long, & Swaab, 2012; Gernsbacher & Faust, 1991; Moser, Fridriksson, & Healy, 2007).

In our study, EFs were related with performance on the "embedded sentences" task but not with "touching A with B" results. This discrepancy likely reflects the tests' different demands. EF involvement in the former is to be expected, since it involves long-distance dependencies in sentences with relative clauses. For instance, in a subject-relative sentence like *La mujer que es gorda está besando a su esposo* (*The woman who is fat is kissing her husband*), the agreement between the head of the first noun phrase (*mujer*) and the conjugated verb (*está*) cannot be resolved until the relative clause (*que es gorda*) has been processed. This taxes executive (viz., WM) mechanisms. Conversely, no such demands are part of the "touching A with B" test. Its stimuli involve no agreement or long–distance relationships and the syntactic function of each noun phrase can be established by reference to its immediately preceding word (a noun phrase following the verb is necessarily a direct object; a noun phrase following the preposition *con* [*with*] is necessarily an instrumental adjunct; a noun phrase following *y* [*and*] will manifest the same function as its preceding noun phrase). Thus, the executive demands of this task are comparatively negligible.

Notably, both PD-MCI and PD-nMCI evinced poor syntactic processing skills, and the group variable did not explain syntactic performance. Consequently, syntactic disturbances in PD may occur before the onset of MCI. More generally, our results indicate that early BG deterioration compromises EFs and leads to syntactic deficits.

To summarize, there is general agreement that non-demented PD patients are characterized by syntactic deficits. Our study demonstrates that such deficits may occur even in patients without MCI. Additionally, the evidence suggests that some executive domains, such as attentional resources and WM, are essential to comprehend constructions of varied syntactic complexity. Therefore, in PD, syntactic deficits seem secondary to executive dysfunction. These findings suggest that a BG-cortical circuit may recruit executive resources which are critical for syntactic processing.

5.2. *Action-naming and action-semantic deficits in PD are independent of EFs and MCI*

All PD patients exhibited impairments of both action-verb production and action semantics, as previously reported elsewhere (Bertella et al., 2002; Boulenger et al., 2008; Colman et al., 2009; Herrera & Cuetos, 2012; Péran et al., 2009; Peran et al., 2003; Rodriguez-Ferreiro et al., 2009). Similarly, our

finding that processing of action-related information in PD is impaired even at a strictly semantic level replicates previous results by Ibáñez et al. (2013). The crucial implication of the BG in these domains is further highlighted by reports of similar impairments in other neurodegenerative motor disorders (Bak et al., 2006; Cotelli et al., 2006; Daniele et al., 2013; Kargieman et al., 2014; Silveri & Ciccarelli, 2007).

More specifically, these deficits occurred independently of EFs and cognitive impairment. Note that other studies have reported contradictory results. For example, Crescentini et al. (2008) found a relation between error rate on a verb-production task and EF measures. Similarly, Colman et al. (2009) claimed that in PD some executive domains, such as WM and set-switching, were associated with action-verb production skills.

Such a discrepancy may reflect methodological differences. The findings reported by Crescentini et al. (2008) stemmed from a related-word generation task leading to the production of varied verb types (e.g., action, cognition, relational). Thus, the involvement of EFs in their verb-production results cannot be attributed to action verbs in particular. The same is true for the conclusions advanced by Colman et al. (2009). These were derived after analyzing action-verb production in sentential contexts. It is likely that WM was associated to sentence-specific processing demands. First, research with neurotypical samples reveals positive correlations between sentence processing and WM skills (James, Krishnan, & Aydelott, 2014; Pérez, Paolieri, Macizo, & Bajo, 2014). Second, the authors recognized that their patients made more verb production errors in subordinate clauses, which were longer than main clauses and thus involved greater WM demands. Third, our claim that the involvement of WM may reflect syntactic (as opposed to action-verb) processing demands aligns with evidence for WM impairments as a factor underlying sentence comprehension deficits in PD (Hochstadt et al., 2006). In sum, the involvement of EFs in these studies may have resulted from the demands of processing abstract verbs or syntactic constructions rather than action verbs proper.

Indeed, recent studies have reported findings compatible with our own. In an experiment with early PD patients, Ibáñez et al. (2013) found deficits in both action semantics and the capacity to integrate action verbs and motor information. Crucially, none of these were associated with EFs. In the same line, Fernandino et al. (2013) found that non-demented PD patients were more impaired at processing action verbs than abstract verbs, in the absence of executive influences. This evidence reinforces our claim that action-verb impairments in PD are independent of EFs. Moreover, our patients' deficits in action naming and action semantics occurred even in the absence of MCI, and this pattern was not explained by the group variable. Therefore, our results suggest that action-verb impairments constitute a *sui generis* deficit present since early stages of PD.

In sum, action-verb processing seems altered in PD at both the semantic and lexical levels. These results suggest that action verbs are critically subserved by a BG-cortical circuit and that they are selectively compromised in early PD, prior to MCI. Furthermore, action-verb impairment seems to constitute a primary deficit in PD, as it can occur independently of executive dysfunction.

5.3. *Object-semantic deficits in PD depend on EFs but not on MCI*

Object semantics, as tapped by the PPT, was impaired in our PD patients, including those without MCI. However, such deficits were greater in patients exhibiting cognitive impairment, under a partial influence of executive dysfunction. While evidence of object-semantic skills in PD is scant, a few studies have revealed congruent lexical-level impairments through tasks involving concrete nouns —which prototypically realize semantic representation of objects. Previous reports have revealed noun processing alterations in PD, although these are less marked than verb impairments (Cotelli et al., 2007; Crescentini et al., 2008). Note, in this sense, that lexical class effects likely depend on underlying semantic effects involving representation of objects (Vigliocco et al., 2011).

Notably, our data revealed that difficulties to associate pictures of objects are partly secondary to executive dysfunction. This finding is consistent with the results reported by Crescentini et al. (2008), who found that noun processing speed was lower for PD patients than controls and related with cognitive control and attentional skills. In addition, the patients had more difficulties in generating nouns when the association between stimulus and response was weak. According to the authors, these findings reflect deficits in supervisory processes rather than in automatic semantic access during lexical retrieval. In the same vein, the Huntington's disease patients tested by Lepron, Peran, Cardebat, and Demonet (2009) made more errors in noun than in verb production when the task involved a controlled, as opposed to automatic, process. This finding further suggests a distinctive relation between object-related information and executive processes. Suggestively, studies with PD-MCI groups revealing naming and fluency deficits on nouns documented concomitant executive dysfunctions (Biundo et al., 2014; Caviness et al., 2007; Pfeiffer, Løkkegaard, Zoetmulder, Friberg, & Werdelin, 2014). Taken together, these data indicate that aspects of the BG may be involved in the networks supporting object-relevant knowledge (at the lexical and semantic levels) and their association with EFs, although further research is required in this regard.

Note that understanding the meaning of objects and nouns requires both relevant conceptual knowledge and executive mechanisms to select and manipulate such information in a context-dependent manner (Jefferies, 2013). Such semantic control operations have been related to a network including inferior frontal and posterior temporal regions (Krieger-Redwood, Teige, Davey, Hymers, & Jefferies, 2015; Whitney, Kirk, O'Sullivan, Lambon Ralph, & Jefferies, 2012). In this sense, the apparently differential relation between object semantics and EFs in PD suggests that both domains may rely on partially shared neural substrates, with different fronto-striatal loops for object- and action-related meanings. However, further research is needed to determine the influence of semantic control in the processing of objects/nouns versus actions/verbs.

5.4. *Dissociability and progression of linguistic and semantic deficits subsequent to BG damage*

The above results provide hints on the dissociability and progression of linguistic and semantic deficits subsequent

to BG deterioration. Our patients exhibited abnormal performance in measures of syntax, action naming, action semantics, and object semantics even in the absence of cognitive impairment. However, these domains were not identically compromised. Notably, only difficulties in action naming and action semantics proved independent of executive skills. Therefore, while action verbs in PD are compromised in a primary, *sui generis* fashion, deficits in syntax and object semantics seem secondary to executive dysfunction. These findings indicate that varied linguistic and semantic domains are differentially related to the BG, contradicting popular approaches to neurolinguistics (see Section 5.5.2).

Although our study is cross-sectional rather than longitudinal, the difference between PD-nMCI and PD-MCI enables us to make indirect inferences about the progression of linguistic and semantic deficits and their relation to EFs. Studies on PD at different disease stages have reported a wide spectrum of cognitive dysfunction, ranging from normal general cognition (Aarsland et al., 2009; Hobson & Meara, 2015), going through MCI, (Aarsland et al., 2010; Caviness et al., 2007; Janvin et al., 2006; Litvan et al., 2011; Yu et al., 2012), to dementia (Aarsland & Kurz, 2010; Hely, Reid, Adena, Halliday, & Morris, 2008; Reid et al., 2011). These findings point to different states of cognitive impairment in the same disease. In addition, prospective studies suggest that nearly 50% of PD patients without cognitive impairment convert to PD-MCI even just a few years after diagnosis (Broeders et al., 2013; Hobson & Meara, 2015). Moreover, PD-MCI patients are at higher risk to develop dementia over time (Aarsland et al., 2003; Buter et al., 2008; Reid et al., 2011; Williams-Gray et al., 2013). Taken together, these findings support the idea that MCI represents a transition stage indexing disease progression in the PD population.

5.5. *Clinical and theoretical implications*

Our findings have significant clinical and theoretical implications regarding the role of the BG in language processing.

5.5.1. *Clinical implications*

For several decades, neuropsychological assessments of PD patients focused on memory, assuming that this population's cognitive profile should resemble that of Alzheimer's disease patients. Nevertheless, cognitive alterations in PD are now known to differ from those typical of neurodegenerative diseases of cortical predominance (Bronnick, Emre, Lane, Tekin, & Aarsland, 2007; Noe et al., 2004; Park et al., 2011). The current model for assessing PD also taps EFs, as these may be disrupted following fronto-striatal damage. Additionally, as shown elsewhere in this work, different linguistic domains are compromised early in PD patients without dementia or MCI. Additional linguistic evaluations may hone the efficacy of current assessment tools. As García and Ibáñez (2014) argue, effective diagnosis might be achieved through early detection of linguistic alterations even before other domains are affected, paving the way for timely application of cognitive stimulation programs. Also, in light of convergent results from other clinical populations (Bak et al., 2006; Cotelli et al., 2006; Daniele et al., 2013; Kargieman et al., 2014; Silveri & Ciccarelli, 2007), this prospective assessment model could be extended to other neurodegenerative diseases involving comparable language affectation (especially in the domain of action verbs) following BG damage (e.g., progressive supranuclear palsy, Huntington's disease, cortico-basal degeneration).

Another issue of clinical interest is establishing the level of cognitive impairment in PD patients. Most of the studies presently considered have focused on language impairments in *non-demented* PD patients. Nevertheless, cognitive deficits may occur even before dementia symptoms, as revealed by the construct of MCI (Petersen, 2011). MCI was initially intended to describe a pre-clinical stage of dementia in Alzheimer's disease (Petersen, 2004), but it was quickly extrapolated to other neurodegenerative diseases, such as PD (Litvan et al., 2012). Crucially, recent studies have shown that MCI may be part of the PD profile since early stages (Aarsland et al., 2010; Caviness et al., 2007; Litvan et al., 2011; Muslimovic, Post, Speelman, & Schmand, 2005). The evidence suggests that the cognitive profile of PD-MCI is predominantly non-amnesic and characterized mainly by executive dysfunction (Aarsland et al., 2010; Caviness et al., 2007; Janvin et al., 2006; Yu et al., 2012). In this sense, we have pooled our patients apart in terms of their level of cognitive impairment and thus provided indirect evidence of how linguistic and semantic deficits progress in PD before the onset of the dementia. Our findings highlight that cognitive deficits in non-amnesic patients may affect other domains, such as syntactic processing, action-verb production, and processing of object and action semantics. This approach may be fruitfully replicated in pursuit of further results with diagnostic and therapeutic implications.

5.5.2. *Theoretical implications*

The BG are currently acknowledged as a key substrate of high-order cognitive domains, such as EFs and language. In part, this role reflects their complex organization and multiple circuitries, including pathways from and toward the motor and premotor cortices through cortico-striatal and thalamo-cortical loops (Haber & Calzavara, 2009; Leh, Ptito, Chakravarty, & Strafella, 2007). More specifically, a network involving the BG, the thalamus, and Broca's area has been recently implicated in language processing (Ford et al., 2013; see also Crosson et al., 2003; Moro et al., 2001). Notwithstanding, it remains uncertain whether language impairments subsequent to BG damage are primary or epiphenomenal to other cognitive dysfunctions. The present results suggest that only action-verb deficits, at the lexical and semantic levels, are *sui generis* in PD.

Such a finding supports a recent model distinguishing two networks underlying action-language processing: a motor circuit and a semantic circuit, both crucially related to BG structures (Cardona et al., 2013; Ibáñez et al., 2013). The first circuit includes frontal areas and supports the processing of motor simulation and the selection of preexisting motor programs. The second circuit involves temporal areas and subserves processing of abstract conceptual knowledge. This model of action-language processing is in agreement with embodied cognition approaches (Barsalou, 1999; Gallese & Lakoff, 2005), which, as stated at the outset, propose that semantic and conceptual information is grounded in sensorimotor experience.

In terms of this model, during action naming, posterior and superior temporal portions of the second circuit, linked to a

BG-thalamic network, would be first engaged by lexical access mechanisms, leading to amodal semantic activations in the anterior temporal lobe. Word production would then be aided by simulation of congruent motor information through the first circuit, involving cortico-subcortical connections along frontobasal structures. The activation dynamics of this process would be significantly impaired subsequent to BG affectation, resulting in the observed deficits. Interestingly, the profusion of BG projections to areas implicated in lexical semantics but not in EFs (through the second circuit) might account for the *sui generis* nature of action-language disturbances in our samples. However, this possibility is only speculative at present and should be empirically tested in future research.

The critical role of the BG in grounding action verbs and action semantics has been corroborated by recent evidence from the embodied cognition framework. Notably, Cardona et al. (2014) explored action-language processing in three patient groups featuring motor symptoms. In one group, composed of PD patients, the symptoms were caused by damage to the frontobasal brain networks supporting motor action. Instead, motor impairments in the other two patient groups, diagnosed with acute traverse myelitis and neuromyelitis optica, resulted from musculoskeletal (non-cerebral) affectation of the motor system. Relative to matched controls, performance on both the KDT and action-sentence compatibility paradigm was impaired in the PD group but not in the other two. This demonstrates that the embodiment of action verbs and action semantics distinctively depend on the BG and its cortical projections, rather than on non-neural systems supporting bodily action.

In addition, our results agree with theoretical approaches suggesting that BG dysfunction may lead to non-linguistic deficits compromising syntactic skills (Grossman, Lee, et al., 2002; Lee et al., 2003). Grossman (1999) argued that executive limitations caused by BG damage may disturb comprehension of grammatically complex constructions. In a similar vein, Longworth et al. (2005) proposed that the role of the BG in language concerns the inhibition of competing alternatives in late integrational processes rather than automatic activation of linguistic routines. The present findings agree with both proposals in showing that syntactic impairments in patients with BG damage are secondary to executive dysfunction.

The two patterns of results discussed above question the descriptive and explanatory adequacy of modular neurolinguistic models, in general, and the declarative/procedural model (Ullman, 2001, 2004, 2008), in particular. Contrary to this model's predictions, our results and those of several other studies demonstrate that verbs and nouns, at both the semantic and lexical levels, are affected by damage beyond declarative memory circuits, such as BG structures. Moreover, the finding that syntactic deficits in frontobasal patients are subordinate to executive dysfunction undermines the model's claim that the BG subserve grammar-specific skills.

To summarize, the findings reported here and elsewhere in the literature may contribute to clinical practice by highlighting the need to consider language screening as a part of neuropsychological assessments of PD. Also, neurolinguistic models should acknowledge the importance of BG structures for word processing (both at the semantic and lexical levels) while revisiting claims of a language-specific role of the BG in syntactic processing. These clinical and theoretical implications may be extrapolated to other diseases that compromise the BG.

5.6. *Limitations*

This work has some limitations. First, the sample size of the subgroups (PD-nMCI, PD-MCI, and their respective controls) was relatively small, which may have affected statistical results. Yet, we found significant differences in the majority of the comparisons. Moreover, other studies (Boulenger et al., 2008; Colman et al., 2009; Crescentini et al., 2008; Friederici et al., 2003) have used similar or even smaller sample sizes without dividing them into subgroups according to cognitive state. Second, the tests used to evaluate syntactic processing and action naming included a low number of items and were designed to assess severe language disorders, such as aphasias. While this may have undermined their precision to detect subtle deficits in our target population, statistical analyses revealed significant group differences which mirrored previous reports in the literature. Third, we focused on a particular type of sentence structure; further studies should consider sentences with different syntactic organization and complexity.

Also, there is no theoretical consensus on how closely the semantic representations of pictures correspond to those evoked by their verbal labels. A previous study by Bak and Hodges (2003) suggests that performance on verb- versus noun-processing tasks is highly congruent with that of action-picture versus object picture tasks. This is consistent with the complete congruency between the results presently observed in the action-naming task and the KDT. However, our study did not include a task tapping noun processing *per se*, which prevented us from obtaining comparable observations considering object pictures and nouns. Future studies should also include tasks including both types of stimuli to more directly disentangle the influence of object semantics in noun processing in PD —for a relevant review, see Vigliocco et al. (2011). One final caveat concerns the lack of intra-task stimulus distinctions in the PPT test. Previous research indicates that the motor system is differentially recruited by graspable versus non-graspable nouns (Marino, Gallese, Buccino, & Riggio, 2012), with clear involvement for manipulable nouns (Marino, Gough, Gallese, Riggio, & Buccino, 2013) and no engagement for nouns lacking action associations (Aravena et al., 2014). Thus, the deficits observed in our patient groups on the PPT test may have been partly dragged by the dominant presence of manipulable objects. Indeed, 34 out of 52 triads in this task contain at least one manipulable object. Nevertheless, the very nature of the stimulus set in the PPT test precludes an informative analysis of this factor, as manipulable and non-manipulable objects are not homogeneously distributed across trials and such subcategories are not matched for critical variables (such as frequency, familiarity, and visual complexity). Further research is needed to investigate whether object-related (including noun-specific) deficits in PD are sensitive to degree of manipulability. Further studies should also consider complementing neuropsychological assessment with behavioral paradigms and neuroimaging. Finally, language studies in non-demented PD patients with genetic vulnerability could also shed light on early cognitive markers of disease.

6. Conclusions

To summarize, different linguistic and semantic domains are significantly impaired in PD, even in the absence of MCI. Our findings indicate that action-naming and action-semantic deficits in this population constitute a *sui generis* disturbance, whereas impairments of syntax and object semantics are secondary to executive dysfunction. Also, the present data support an embodied cognition model in which a BG-cortical network involving a motor circuit and a semantic circuit proves critical for action-verb processing and for the recruitment of executive resources underlying processing of syntax and object semantics. In addition to their relevance for neurolinguistic modeling, such conclusions entail important implications to foster progress in the diagnosis and treatment of PD and other neurodegenerative disorders.

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