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Unspeakable motion: Selective action-verb impairments in Parkinson's disease patients without mild cognitive impairment

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ABSTRACT

Parkinson's disease (PD) patients show marked impairments in processing action verbs, and to a lesser extent, concrete (specially, manipulable) nouns. However, it is still unclear to what extent deficits in each of these categories are influenced by more general cognitive dysfunctions, and whether they are modulated by the words' implied motility. To examine these issues, we evaluated 49 non-demented PD patients and 49 healthy volunteers in an oral production task. The patients were divided into two groups depending on the presence or absence of mild cognitive impairment (PD-MCI and PD-nMCI, respectively). Participants named pictures of actions varying in motion content (low and high) and of objects varying in manipulability (low and high). The PD-MCI group showed deficits across all four categories. However, PD-nMCI patients exhibited a selective difficulty for high-motion action verbs. This finding corroborates and refines previous results suggesting that disturbances of action-related lexico-semantic information in PD constitute a *sui generis* alteration manifested early in the course of the disease's physiopathology. Moreover, it suggests that the grounding of action verbs on motor circuits could depend on fine-grained intracategorical semantic distinctions.

1. Introduction

Abundant research couched in the embodied cognition framework indicates that high-order domains, including lexical semantics, are grounded in lower-level sensorimotor mechanisms (Barsalou, 2008; Gallese & Lakoff, 2005). For instance, in healthy subjects, motor and premotor brain areas are differentially recruited during processing of action verbs – i.e., verbs denoting bodily actions (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Boulenger, Hauk, & Pulvermüller, 2009; Hauk, Johnsrude, & Pulvermüller, 2004; Romero Lauro, Mattavelli, Papagno, & Tettamanti, 2013; Tettamanti et al., 2005). In the same vein, processing of manipulable nouns – i.e., nouns involving manual motor affordances– engages viso-motor circuits (Chao, Haxby, & Martin, 1999; Chao & Martin, 2000; Gerlach, Law, & Paulson, 2002; Grafton, Fadiga, Arbib, & Rizzolatti, 1997; Kellenbach, Brett, & Patterson, 2003; Króliczak & Frey, 2009; Martin, Wiggs, Ungerleider, & Haxby, 1996; Noppeney, Price, Penny, & Friston, 2006). Interestingly, while both action verbs and manipulable nouns involve distinct motor network activity, the latter do so to a lesser extent (Grabowski, Damasio, & Damasio, 1998; Grafton

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et al., 1997), as explicitly captured by a recent model of dynamic crossmodal language embodiment mechanisms (García & Ibáñez, 2016b).

In line with such findings, damage to motor networks has been proposed to differentially compromise processing of action-related language (Abrevaya et al., 2017; Bak, 2013; García, Abrevaya et al., 2016; García, Carrillo et al., 2016; García & Ibáñez, 2014). A crucial model to test this hypothesis is afforded by Parkinson's disease (PD), a neurodegenerative condition in which motor skills are progressively compromised by continuous loss of dopaminergic striatal innervation (Kalia & Lang, 2015). Several studies on non-demented PD patients have reported difficulties in both action verbs and nouns, with more pronounced deficits in the former (Cotelli et al., 2007; Crescentini, Mondolo, Biasutti, & Shallice, 2008). However, abundant research has shown that lexico-semantic deficits in PD can manifest as a selective impairment of action verbs with relative preservation of nouns (Boulenger et al., 2008; Peran et al., 2003; Rodrigues, Ferreira, Coelho, Rosa, & Castro-Caldas, 2015; Rodriguez-Ferreiro, Menendez, Ribacoba, & Cuetos, 2009; Signorini & Volpato, 2006).

Against this background, recent evidence (Bocanegra et al., 2015) suggests that impairments in either category may differentially depend on the integrity of non-linguistic mechanisms: in PD, only action verbs and action concepts would be altered irrespective of general cognitive impairment and executive dysfunction. Moreover, action-verb deficits in PD have been reported to worsen in proportion to their implied motility (Herrera & Cuetos, 2012; Herrera, Rodríguez-Ferreiro, & Cuetos, 2012). However, no study has assessed whether this pattern is related to the patients' overall cognitive profile.

To address these issues, we recruited PD patients with and without mild cognitive impairment (PD-MCI and PD-nMCI, respectively), alongside matched controls, and asked them to name pictures of actions varying in motion content (low and high) and objects varying in manipulability (low and high). Following Bocanegra et al. (2015), we predicted that, even if both action verbs and nouns are grounded in motor networks, only the former should be compromised when damage to those networks has not yet triggered domain-general cognitive disturbances. More specifically, we expected PD-MCI patients to be impaired across all categories, while perhaps showing greater difficulties for action-verb than noun processing. Conversely, PD-nMCI patients were expected to evince a selective deficit in at least one category of action verbs. Confirmation of these hypotheses would further highlight the neurofunctional specificity of the grounding of action verbs in motor (and, particularly, basal ganglia) networks.

2. Materials and methods

2.1. Participants

Forty-nine PD patients and 49 healthy volunteers participated in this study. All of them were Spanish native speakers from Colombia. PD patients were diagnosed by expert neurologists (B. O., M.L., P.D., and L.F.) according to the criteria of the United Kingdom PD Society Brain Bank (Hughes, Daniel, Kilford, & Lees, 1992). Disease stage was established with the Hoehn & Yahr scale (H&Y) (Hoehn & Yahr, 1967), and motor disability was evaluated with section III of the Unified Parkinson's Disease Rating Scale (UPDRS-III) (Fahn & Elton, 1987). All the patients were taking antiparkinsonian medication and were evaluated during the "on" phase. The Levodopa equivalent daily dose was computed according to standard conversion factors of individual anti-parkinsonian drugs (Tomlinson et al., 2010). Patients with Parkinson-plus symptomatology, other neurological disorders, or major psychiatric conditions were excluded. The patients' cognitive screening was performed with the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005), an instrument with reliable psychometric properties which has been recommended to identify MCI in PD (Dalrymple-Alford et al., 2010; Gill, Freshman, Blender, & Ravina, 2008; Hoops et al., 2009; Kandiah et al., 2014; Nazem et al., 2009) and which has been validated in the Colombian population (Gil, Ruiz de Sánchez, Gil, Romero, & Pretelt Burgos, 2015). Finally, the patients' functional skills were rated with the Barthel Index (Mahoney & Barthel, 1965) and the Lawton & Brody Index (Lawton & Brody, 1969).

After a clinical interview and the functional and cognitive screening, patients were classified as PD-MCI ($N = 15$) and PD-nMCI ($N = 34$). These subgroups were similar in age, education level, and clinical features such as years since diagnosis, UPDRS-III score, H&Y rating, and Levodopa equivalent doses (for details about the demographical and clinical variables, see Table 1). MCI diagnosis was made according to the Movement Disorder Society (MSD) Task Force Level I criteria (Litvan et al., 2012). Patients were classified as PD-MCI if they had preserved functional independence and a MoCA score below 23 – the cutoff score suggested for the Colombian population (Gil et al., 2015). Inclusion criteria for the PD-nMCI group were spared functional independence and a MoCA score of 23 or above. None of the patients gave signs of dementia.

The patients' cognitive performance was compared to that of 49 sociodemograhically matched healthy controls with no history of neurological or psychiatric disease. All controls had a score of 23 or above on the MoCA and they had functional independence. These participants were separated into two groups, each matched for age, gender, and years of education with its corresponding PD subgroup (PD-MCI controls: $N = 15$; PD-nMCI controls: $N = 34$). See Table 1 for full demographic and clinical data, including statistical comparisons between the patients' subgroups and their respective controls.

The study was approved by the Ethics Research Committee of Antioquia University and performed according to the Declaration of Helsinki. All participants provided written informed consent.

2.2. Picture-naming task

2.2.1. Stimuli

We pre-selected 100 pictures of objects and 100 pictures of actions. Object pictures were taken from the Center for Research in Language International Picture-Naming Project corpus (Bates et al., 2003) – these have been tested across various languages, including Spanish. Action pictures were selected from Druks and Masterson (2000). All images were monochromatic drawings on a white background.

To classify the object pictures in terms of manipulability (low vs. high), and the action pictures in terms of motion content (low vs. high), we carried out two norming action-semantics rating studies with 34 university students. Prior to each study, participants viewed four illustrative trials with pre-rated items implying low, intermediate, and high degrees of manipulability and motion content. These practice trials provided a common point of reference that helped minimize inter-subjective variability in the ratings. For the object pictures, participants were asked to rate the extent to which each depicted item could be grasped and employed in a manual action. For the action pictures, they were requested to rate how much movement of the limbs and torso was needed to perform the action represented by each item. In both cases, ratings were made on a scale from 1 to 100, with those extremes values indicating minimal and maximal manipulability/motility, respectively. Items rated below 30 points were considered as featuring low manipulability/motility, whereas items rated above 60 points were classified as involving high

Table 1
Demographic and clinical data.

	PD-MCI $N = 15$	Controls $N = 15$	PD-MCI versus controls p-value	PD-nMCI $N = 34$	Controls $N = 34$	PD-nMCI versus controls p-value	PD-MCI $N = 15$	PD-nMCI $N = 34$	PD-MCI versus PD-nMCI p-value
Demographic data									
Age (years)	66.4 (7.27)	65.6 (5.49)	0.74[a]	61.29 (8.08)	60.29 (7.6)	0.6[a]	66.4 (7.27)	61.29 (8.08)	0.06[b]
Education (years)	12.13 (5.54)	12.87 (5.3)	0.71[a]	12.82 (5.2)	13.41 (4.5)	0.62[a]	12.13 (5.54)	12.82 (5.2)	0.68[a]
Gender (F:M)	5:10	5:10	1[c]	13:21	13:21	1[c]	5:10	13:21	0.74[c]
Clinical variables									
Years since diagnosis							6.2 (3.34)	5.18 (3.59)	0.35[a]
H&Y							2.07 (0.26)	2.03 (0.3)	0.68[b]
UPDRS III							34.27 (10.03)	28.94 (11.75)	0.13[a]
LED							743.63 (382.9)	616.5 (378.43)	0.27[b]

Data presented 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; LED: Levodopa equivalent dose.
[a] p values were calculated using t test for independent samples.
[b] p values were calculated using Mann-Whitney U test.
[c] p values were calculated using chi-square test (χ^2).

manipulability/motility. To maximize comparability between our final picture sets, we only retained object and action stimuli that were matched for picture-name agreement and key lexical properties of the pictures' names –namely, frequency, age of acquisition, imageability, number of phonemes, and number of syllables. Moreover, while visual complexity was predictably higher for action than object pictures, "high" and "low" items within each category were matched for such property. These variables were also matched between the subsets (low vs. high) of each category. Crucially, low and high stimuli within each category were statistically different in terms of action-semantics ratings, which attests to the validity of our classification procedure. The final set used in the experiment comprised 40 object pictures – 20 with low manipulability (e.g., *muro* [*wall*]), 20 with high manipulability (e.g., *llave* [*key*]) – and 40 action pictures – 20 with low motion content (e.g., *leer* [*to read*]), 20 with high motion content (e.g., *nadar* [*to swim*]). For details of the stimuli's features, see Table 2. The full list of target words and their English translations can be found in Appendix A.

2.2.2. Procedure

All participants performed the naming task sitting individually in a quiet, dimly illuminated room. The pictures were presented one at a time on a computer screen; participants were requested to produce the most concise and precise word that described the object or action in each case; for the action pictures, participants were asked to use the infinitive form of the verb. Previous to the task, three practice stimuli for each category were presented to ensure that the instructions had been properly understood. The examiner kept a record of every response. Only first responses were considered. Correct responses were given one point, and incorrect responses were given zero points.

2.3. Statistical analysis

Normal distribution of the data was confirmed via the Shapiro-Wilk test. Between-group comparisons of demographic and clinical variables were conducted with two-tailed student's t tests, Mann-Whitney tests, or Chi-square tests, as necessary. Naming measures were compared between groups through Mann-Whitney tests and effect sizes were calculated with Cohen's d. Additionally, non-parametric analyses were used to evaluate the correlation between the UPDRS-III and naming scores. Alpha values were set at $p < 0.05$. All statistical analyses were carried out on SPSS 20.0 statistical software.

3. Results

Results of the naming task and their correlation with UPDRS-III scores are summarized in Tables 3 and 4, respectively.

3.1. Picture naming in PD-MCI

Naming performance was significantly impaired for PD-MCI patients relative to their controls. Deficits emerged for noun processing as a whole [$U = 51.5$, $p = 0.01$], and they were also separately observed for nouns denoting objects with low [$U = 61.5$, $p = 0.03$] and high [$U = 44.5$, $p < 0.005$] manipulability. Similarly, PD-MCI patients were outperformed by controls in action naming [$U = 37$, $p < 0.005$]. Their deficits were significant both for action verbs involving low [$U = 51.5$, $p = 0.01$] and high [$U = 38.5$, $p < 0.005$] motion content. In sum, when PD patients were cognitively impaired, they showed overall deficits in both object and action naming, independently of the stimuli's degree of motor content.

Table 2
Summary of stimuli's characteristics.

	Naming			Objects			Actions		
	Objects *N* = 40	Actions *N* = 40	*p*-value	High[a] *N* = 20	Low[a] *N* = 20	*p*-value	High[b] *N* = 20	Low[b] *N* = 20	*p*-value
Picture features									
Name agreement[c]	93.90 (7.06)	93.38 (8.37)	0.89	91.32 (7.78)	96.47 (5.28)	0.06	92.65 (8.35)	94.12 (8.54)	0.41
Visual complexity[d]	18346.13 (12155.87)	27132.63 (7756.51)	<0.**001**[*]	19884.60 (14337.98)	16807.65 (9630.52)	0.62	25914.85 (6998.30)	28350.40 (8449.56)	0.53
Action semantics rating	–	–		13.70 (6.15)	77.80 (9.60)	<0.**001**[*]	18.15 (6.95)	76.51 (14.65)	<0.**001**[*]
Word features									
Word frequency[e]	26.43 (23.88)	20.23 (24.94)	0.06	27.63 (15.23)	25.23 (30.58)	0.15	19.19 (21.69)	21.27 (28.36)	0.88
Age of acquisition[f]	2.16 (0.97)	1.91 (1.01)	0.30	2.33 (0.97)	2.00 (0.97)	0.35	2.29 (0.99)	1.56 (0.92)	0.06
Imageability[g]	6.18 (0.53)	6.08 (0.46)	0.09	6.13 (0.74)	6.24 (0.22)	0.55	6.01 (0.59)	6.15 (0.28)	0.43
Phonemes[e]	6.08 (1.62)	6.53 (1.65)	0.20	5.65 (1.69)	6.50 (1.47)	0.06	6.40 (1.70)	6.65 (1.63)	0.51
Syllables[e]	2.50 (0.78)	2.48 (0.68)	0.98	2.40 (0.82)	2.60 (0.75)	0.41	2.45 (0.69)	2.50 (0.69)	0.82

Significant differences ($p < 0.001$) are indicated in bold.
Data presented as mean (*SD*).
p values were calculated using Mann-Whitney *U* test.
[a] In terms of manipulability.
[b] In terms of motion content.
[c] Values were taken from a pilot study of 34 university students.
[d] Values were calculated using the JEPG compression rate as suggested by Bates et al. (2003).
[e] Values were taken from LEXESP database (Sebastián-Gallés, Carreiras, & Martí, 2000).
[f] Values were taken from Center for Research in Language International Picture-Naming Project corpus (IPNP).
[g] Values were taken from Valle-Arrollo (1999). When data was missing for specific stimuli, the values were obtained from a new group of 30 healthy volunteers.
[*] Alpha level set at 0.05.

Table 3
Performance of each group on the picture-naming test.

	PD-MCI *N* = 15		Controls *N* = 15		PD-MCI versus controls *p*-value	Cohen's *d*
OBJECTS	35	(2.93)	37.47	(2.17)	0.01[*]	**0.99**
Low manipulability	16.2	(2.11)	17.73	(1.91)	0.03[*]	0.79
High manipulability	18.8	(0.94)	19.73	(0.46)	<0.**005**[*]	**1.3**
ACTIONS	31.27	(3.99)	35.93	(2.81)	<0.**005**[*]	**1.4**
Low motion content	16.13	(2.1)	17.93	(1.49)	0.01[*]	**1.02**
High motion content	15.13	(2.45)	18	(1.81)	<0.**005**[*]	**1.38**
	PD-nMCI *N* = 34		Controls *N* = 34		PD-nMCI versus controls *p*-value	Cohen's *d*
OBJECTS	37.12	(1.77)	37.29	(2.05)	0.62	0.09
Low manipulability	17.74	(1.4)	17.56	(1.88)	0.88	0.11
High manipulability	19.38	(0.89)	19.74	(0.45)	0.11	0.52
ACTIONS	34.5	(2.97)	36.26	(2.83)	0.02[*]	0.62
Low motion content	17.5	(2.12)	17.76	(1.99)	0.63	0.13
High motion content	17	(1.76)	18.5	(1.26)	<0.**001**[*]	**0.99**
	PD-MCI *N* = 15		PD-nMCI *N* = 34		PD-nMCI versus PD-MCI *p*-value	Cohen's *d*
OBJECTS	35	(2.93)	37.12	(1.77)	0.01[*]	**0.99**
Low manipulability	16.2	(2.11)	17.74	(1.4)	0.02[*]	**0.96**
High manipulability	18.8	(0.94)	19.38	(0.89)	0.02[*]	0.65
ACTIONS	31.27	(3.99)	34.5	(2.97)	0.01[*]	**1**
Low motion content	16.13	(2.1)	17.5	(2.12)	0.03[*]	0.66
High motion content	15.13	(2.45)	17	(1.76)	0.01[*]	**0.96**

Significant differences ($p < 0.005$ and $p < 0.001$) and large effect sizes (0.80) are indicated in bold.
Data presented as mean (*SD*).
PD = Parkinson's disease; PD-nMCI = Parkinson's disease without mild cognitive impairment; PD-MCI = Parkinson's disease with mild cognitive impairment.
p values were calculated using Mann-Whitney *U* test.
d = Cohen's effect size.
[*] Alpha level set at 0.05.

Table 4
Correlation between motor impairment and naming performance in PD patients.

	PD-MCI *N* = 15 UPDRS-III *R*	*p*-value	PD-nMCI *N* = 34 UPDRS-III *R*	*p*-value
Objects				
Low manipulability	−0.050	0.86	.100	0.57
High manipulability	−0.269	0.34	−0.105	0.56
Actions				
Low motion content	−0.467	0.08	−0.170	0.35
High motion content	−0.483	0.07	−0.077	0.67

R = Spearman's Rank Correlation.
UPDRS III = Unified Parkinson's Disease Rating Scale, part III.

3.2. Picture naming in PD-nMCI

Object-naming performance was similar between PD-nMCI patients and their controls [$U = 538$, $p = 0.62$]. Between-group differences were not significant for nouns denoting objects with either low [$U = 566$, $p = 0.88$] or high [$U = 470.5$, $p = 0.11$] manipulability. On the contrary, these patients obtained significantly a lower score in the action-naming task [$U = 385.5$, $p = 0.02$]. This result was driven by a selective deficit in high-motion verbs [$U = 283$, $p < 0.001$], as processing of action verbs involving low motion content was preserved [$U = 539.5$, $p = 0.63$]. In sum, PD-nMCI patients showed no difficulties in processing manipulable nouns, but they exhibited a selective disturbance for naming action verbs with high motion content.

3.3. PD-MCI versus PD-nMCI

As expected, naming performance was altogether worse for PD-MCI than for PD-nMCI. Relative to PD-nMCI, PD-MCI patients showed greater deficits in object naming [$U = 139.5$, $p = 0.01$], including objects with low [$U = 145.5$, $p = 0.02$] and high [$U = 157$, $p = 0.02$] manipulability. Likewise, PD-MCI exhibited more pronounced action-naming impairments [$U = 129$, $p = 0.01$], which were present for actions with both high [$U = 156$, $p = 0.03$] and low [$U = 142.5$, $p = 0.01$] motion content. In brief, this cross-sectional comparison between the patient groups suggests two distinct patterns of lexico-semantic alterations in PD: while cognitively impaired patients present widespread lexico-semantic deficits, those with a preserved overall cognitive profile feature selective deficits in (high-motion) action verbs.

3.4. Correlations between motor impairment and naming performance

We performed Spearman's rank correlations between UPDRS-III scores and naming scores. No significant correlations emerged in either of the PD subgroups; also, although there was a trend towards significance in the associations between UPDRS-III scores and both action-naming categories in the PD-MCI group, the correlation coefficients were low ($r = -0.483$ and -0.467).

4. Discussion

This study examined the processing of nouns and action verbs implying different levels of motility in PD patients with and without mild cognitive impairment (PD-MCI and PD-nMCI). In particular, through a picture-naming task, we tested the hypothesis that only the latter word type would be compromised in PD-nMCI. Moreover, we explored the role of manipulability (for nouns) and motion content (for verbs) in the groups' lexico-semantic performance. Our results showed that PD-MCI patients exhibited deficits in all noun and action-verb categories. However, PD-nMCI patients were selectively impaired in processing action verbs implying high levels of motion. Below we discuss these findings and their implications.

4.1. Action-verb deficits as a selective sui generis disturbance in Parkinson's disease

PD-MCI patients were impaired in processing both nouns and action-verbs. These results replicate previous reports in PD (Cotelli et al., 2007; Crescentini et al., 2008) and other neurodegenerative motor diseases (Daniele et al., 2013), showing that not only action-verbs, but also nouns, may be impaired subsequent to motor-network compromise. However, while these studies considered patients with some degree of cognitive impairment, they failed to assess the influence of general cognitive profile on such transcategorical pattern. Here, we found that only PD-MCI patients were impaired in processing both word types, suggesting that the pervasiveness of lexico-semantic alterations following early deterioration of basal-ganglia and frontostriatal loops is related to the integrity of extralinguistic mechanisms. Indeed, while differential action-verb impairments have been repeatedly documented in PD (Cardona et al., 2013; García & Ibáñez, 2014), noun-processing deficits have also been revealed in PD samples featuring other cognitive alterations (Biundo et al., 2014; Caviness et al., 2007; Pfeiffer, Løkkegaard, Zoetmulder, Friberg, & Werdelin, 2013).

More crucially, previous research on PD considering action-verb and noun processing has shown that both categories can be compromised in the presence of domain-general disturbances – e.g., executive, attentional, or memory skills (Cotelli et al., 2007; Crescentini et al., 2008). In line with these results, studies of patients with other motor disorders who exhibit mild executive deficits (Daniele et al., 2013) have also shown significant difficulties in processing both word types.

Moreover, we found that these transcategorical deficits in PD-MCI held regardless of the level of manipulability and motion content implied by nouns and action-verbs, respectively. To our knowledge, this specific and fine-grained semantic contrast had not been hitherto directly explored. However, the result is in line with previous research on PD. For instance, using a semantic similarity judgments task, Kemmerer, Rudrauf, Manzel, and Tranel (2012) found that non-demented PD patients (some of them showing mild executive and attentional impairments) had comparable deficits in processing of action verbs which imply different effectors (and, presumably, different levels of motion content). In fact, their results showed similar performance on both action verbs and verbs which did not evoke bodily movement. In the same line, Cotelli et al. (2007) found that non-demented PD patients with mild cognitive deficits were impaired in action-verb naming, but

they did not find a difference on action verbs implying different levels of manual motility.

Instead, a different pattern emerged in PD-nMCI patients. This group showed complete sparing of noun processing, with a selective deficit for action verbs with high motion content. This finding is broadly consistent with previous results (Bocanegra et al., 2015) showing that only action-verb and action-semantic deficits in PD occurred independently of the integrity of domain-general cognitive skills (in this case, executive abilities).[2] By the same token, previous studies on PD patients with a relatively preserved overall cognitive profile have also shown selective deficits for action verbs with relative preservation of nouns. This has been observed, for instance, on lexical-decision (Boulenger et al., 2008) and picture-naming (Rodriguez-Ferreiro et al., 2009) tasks. Yet, above and beyond those findings, which refer to action verbs in general, the selective deficit we observed in PD-nMCI concerned only action verbs with high motion content. It seems, therefore, that the level of reliance of action verbs on motor circuitry and overall cognitive profile may vary as a function of their implied motility.

Most previous research on the topic has failed to consider fine-grained distinctions within the categories of action verbs and manipulable nouns. Given our results, the words' implied motility in preceding studies may have constituted a confounding factor. In fact, the few studies which did operationalize such distinctions have yielded findings compatible with our own. For instance, Herrera et al. (2012) found that non-demented PD patients were more impaired in naming high- than low-motion action verbs. Moreover, as shown by Herrera and Cuetos (2012), PD patients off medication evinced longer reaction times in naming high-motion action verbs relative to both controls and PD patients on medication. Taken together, these findings highlight the value of considering fine-grained distinctions within action-semantics models (García & Ibáñez, 2016b), and suggest that partially independent subnetworks may be specialized for specific motility-based subcategories within the action-language domain. This could inspire further research which goes beyond the exploration of inter-categorical lexical dissociations to focus on disease-specific alterations within the action-language domain. This would represent an innovation for research into category-specific deficits (Capitani, Laiacona, Mahon, & Caramazza, 2003), while honing our understanding of action-language disruptions in neurodegenerative diseases – for a review, see Bak (2013).

Additionally, a cross-sectional comparison between the patient groups revealed two differential patterns of lexico-semantic disturbances in PD. These deficits can become pervasive when the underlying physiopathology leads to cognitive impairment, but they manifest selectively in the domain of (high-motion) action verbs when the patients' overall cognitive skills are preserved. In this sense, neuropsychological studies comparing PD-MCI with PD-nMCI patients have consistently reported greater deficits for the former groups on language abilities such as naming and semantic fluency – alongside impairments of attention, recent memory, and executive function (Biundo et al., 2014; Caviness et al., 2007; Hobson & Meara, 2015). Moreover, semantic deficits can be predictors of the development of multidomain MCI (Hobson & Meara, 2015) and dementia (Williams-Gray et al., 2009, 2013). Our results extend these findings by showing that, whereas lexico-semantic alterations in PD can become transcategorical in the context of overall cognitive impairment, they are characterized by a selective deficit for (high-motion) action verbs when domain-general mechanisms are still functional.

While we were at present unable to obtain imaging data from the patients, our data leads us to speculate that specific deficits in high-motion action verbs could be specifically related to damage focused on basal ganglia and frontostriatal circuits. Indeed, the selective recruitment of non-canonical, extra-motor pathways for action-verb processing in PD correlates with the patients' degree of basal ganglia atrophy (Abrevaya et al., 2017). Instead, generalized lexico-semantic impairments could result from more extensive neurodegeneration, perhaps reaching temporal and parietal structures. Indeed, it has been proposed that PD-nMCI patients are characterized by frontal cortical thinning, whereas in PD-MCI such atrophy becomes greater and extends to temporo-parietal cortices (Mak et al., 2015). In a similar vein, other studies have also found a posterior pattern of atrophy in PD-MCI (Danti et al., 2015; Pereira et al., 2014, 2015). The speculation that this contrastive pattern could be reflected in the extent and location of neurodegeneration should be tested in future studies.

Our cross-sectional design and the absence of an intermediate stage between PD-MCI and PD-nMCI do not allow us to conclude whether the selective deficits in the latter group were mainly grammatical or semantic in nature. If a progression in their deficits first compromised low-motion verbs, the pattern could be surmised to be driven by a grammatical factor (namely, the word class 'action verb', or verbs in general). Conversely, if the second compromised category were that of high-manipulability nouns, the pattern would seem semantic in nature. While no study seems to have assessed this issue, a number of findings seem to support the second possibility. First, research on other motor diseases has shown a dissociation between *non-verbal* tasks tapping semantic association of objects and actions, with greater deficits in the latter category (Taylor et al., 2013). Second, evidence from lexical and semantic decision tasks shows that PD patients can be impaired in action-verb processing without comparable deficits in other verb categories (e.g., abstract verbs) (Fernandino et al., 2013). Third, joint assessment of abundant behavioral, neuropsychological, and imaging data indicates that the neural separability between nouns and verbs is driven by semantic/pragmatic rather than grammatical distinctions (Vigliocco, Vinson, Druks, Barber, & Cappa, 2011). Thus, the selective deficit observed in PD-nMCI may be speculated to reflect the role of the basal ganglia in grounding semantic rather than form-level features of action verbs. Nevertheless, this conjecture should be systematically tested in further research, ideally via longitudinal assessments.

Finally, motor impairment did not correlate with naming performance in any condition in either patient group. This reinforces our claim that the extent of lexico-semantic impairments in PD is distinctively related to the patients' general cognitive state as opposed to other factors, such as the degree of motor impairment. In this sense, previous studies also found no association between UPDRS-III scores and action-language processing in several tasks, including action fluency (Signorini & Volpato, 2006), verb-generation (Crescentini et al., 2008; Peran et al., 2003), and lexical decision (Boulenger et al., 2008). Also, note that motor impairment is not necessarily related to the degree of neuropsychological alterations, as these may appear only a few years after diagnosis in the absence of significant motor impairments (Kalia & Lang, 2015). However, this does not rule out a relationship between fine-grained dimensions of movement and specific disturbances of action semantics. Indeed, the UPDRS-III scale exclusively taps gross aspects of motor function (e.g., rigidity, articulation, postural stability, gait, finger tapping), and it proves blind to more subtle dimensions (e.g., goal-directed movements). Moreover, we observed a trend towards significance in the association between motor function and action-verb naming for the PD-MCI group,

[2] Note that while the *sui generis* action-verb impairments reported by Bocanegra et al. (2015) were observed for both PD-nMCI and PD-MCI patients, the cut-off used to ascertain MCI was more stringent (26 points) than the one used here based on population-specific norms (23 points). Also, such study lacked a noun-processing task. These two reasons preclude more specific comparisons with our present results.

which suggests that both domains may become subtly related once the neuropathological process has surpassed a given threshold (namely, the one leading to cognitive impairment). However, our data do not warrant any firm conclusions on this issue, which should thus be more directly explored in future studies. In sum, then, while broad motoric abilities do not seem to account for the degree of categorical specificity of lexico-semantic deficits in PD, these could be related to finer aspects of movement dysfunction or to subtle (perhaps marginally significant) interactions between the patients' neurocognitive profile and their motor skills.

Taken together, this evidence supports the hypothesis that action-verb difficulties in PD would selectively constitute a *sui generis* lexico-semantic impairment – i.e., one that is not contingent on the preservation of more general cognitive functions. Moreover, our study suggests that such a pattern is specifically driven by verbs implying high levels of motion. This indicates that the grounding of action verbs on motor circuits, rather than a broad embodiment phenomenon operating in a category-general fashion, is actually sensitive to fine-grained semantic factors (García & Ibáñez, 2016b,a). Finally, our findings also indicate that once cognitive impairment surpasses a critical threshold in PD, word-processing deficits become less selective and extend to various lexical categories.

4.2. Theoretical and clinical implications

From a theoretical perspective, our findings highlight the crucial role of frontobasal networks in lexico-semantic processing. In particular, they support the model proposed by Cardona et al. (2013) and Ibáñez et al. (2013), which posits that action-language deficits are associated to a striatal-cortical network which is compromised early in the course of PD. Moreover, these results underline the importance of considering fine-grained distinctions within broad categories of embodied semantics. Specifically, they suggest that the grounding of action verbs on motor circuits depends on intracategorical semantic variables –in particular, the level of implied motility. More generally, our study indicates that action-language processing, including action verbs and manipulable nouns, involves a *dynamic* relation with domain-general cognitive mechanisms. In other words, the processing of at least some lexical categories could be associated with the integrity of overall cognitive skills. This assertion underscores the need to propose dynamic neurolinguistic models that conceive of language mechanisms as interactively embedded in broader cognitive systems.

As previously proposed by Bocanegra et al. (2015), from of clinical stance, it is important to consider the level of cognitive impairment of PD patients. Clinical studies have clearly demonstrated that non-demented PD patients may have MCI (Aarsland et al., 2010; Caviness et al., 2007; Janvin, Larsen, Aarsland, & Hugdahl, 2006; Litvan et al., 2011), even since early disease stages (Aarsland et al., 2009; Broeders et al., 2013). Nevertheless, given that most studies assessing language in PD have been carried out with non-demented samples, it remains unclear whether the observed verbal impairments could have been related to more general cognitive factors. This background stresses the relevance and potential importance of the between-group differences reported in the present study. Further research on how the linguistic performance of PD patients relates to their MCI status could help to disentangle the role of overall cognitive profile in the observed deficits. Moreover, additional insights could thus be gained into the evolution of language deficits as the disease progresses. Finally, our results also highlight the need to include language skills as part of the neuropsychological batteries to assess non-demented PD patients. Traditionally, language impairment has been considered as a predictor of dementia (Hobson & Meara, 2015; Williams-Gray et al., 2009, 2013), and it has been associated with late stages of the disease. However, our results and others cited elsewhere in this manuscript indicate that specific language disorders may become manifest even before the onset of more widespread cognitive disturbances. On account of the tasks yielding such insights, we propose that category-specific linguistic tasks (e.g., action naming) should be incorporated as a complement to more traditional measures (e.g., semantic fluency) in order to timely detect high-order alterations in PD and, potentially, in other neurodegenerative motor diseases.

4.3. Limitations and avenues for further research

Some limitations must be acknowledged in this study. First, the sample size of the patient subgroups, especially that of the PD-MCI group, was moderately small – though certainly similar to that of other insightful studies in the literature (Boulenger et al., 2008; Kemmerer et al., 2012). Even so, we found significant differences with a satisfactory effect size (see Table 3). Second, further research could contemplate Level-II criteria, including a comprehensive neuropsychological evaluation (Litvan et al., 2012), to look for specific characterizations of the interaction between the subtypes of MCI and the linguistic profile of PD patients. In addition, further studies should also evaluate the relationship between the patients' linguistic performance and neuroanatomical changes as the disease progresses. Critical data on early cognitive markers of PD could also be garnered by exploring language processing in samples with genetic vulnerability to the disease (García et al., accepted for publication). Finally, to better grasp the role of specific motor structures in action-language processing, further studies should compare motor conditions involving contrastive patterns of brain damage (e.g., PD vs. amyotrophic lateral sclerosis).

4.4. Conclusion

This study offers new insights into the nature of lexico-semantic deficits in PD. When patients manifest mild cognitive impairment, they show difficulties in processing action verbs and manipulable nouns, irrespective of the stimuli's level of motor content or manipulability, respectively. However, when they present a relatively preserved overall cognitive profile, their lexico-semantic impairments affect only action verbs with high motion content, arguably driven by semantic rather than grammatical factors. This pattern supports the view that action-verb impairments constitute a selectively *sui generis* alteration in PD, which underscores the relevance of studying fine-grained, intracategorical semantic distinctions to understand the neurofunctional organization of this lexical class. Overall, our findings fit well within embodied conceptions of language organization and open new avenues to examine fine-grained linguistic dissociations in motor diseases.

Conflict of interest

None to declare.

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Appendix A. List of experimental stimuli used in the picture-naming task and their approximate English translation

Objects		Actions	
Low manipulability	High manipulability	Low motion content	High motion content
Avión [airplane]*	Bombillo [bulb]*	Soplar [to blow]*	Gatear [to crawl]*
Montaña [mountain]*	Destornillador [screwdriver]*	Acariciar [to stroke]*	Cabalgar [to ride]*
Árbol [tree]	Bastón [cane]	Arrodillarse [to kneel]	Bailar [to dance]
Cactus [cactus]	Cámara [camera]	Besar [to kiss]	Caminar [to walk]
Carretera [road]	Cepillo [toothbrush]	Bostezar [to yawn]	Cavar [to dig]
Cerca [fence]	Escalera [ladder]	Dormir [to sleep]	Cocinar [to cook]
Columna [pillar]	Gafas [glasses]	Flotar [to float]	Columpiarse [to swing]
Cruz [cross]	Guitarra [guitar]	Fumar [to smoke]	Comer [to eat]
Esqueleto [skeleton]	Hacha [ax]	Gotear [to drip]	Correr [to run]
Fantasma [ghost]	Llanta [tire]	Leer [to read]	Cortar [to cut]
Humo [smoke]	Llave [key]	Llorar [to cry]	Deslizarse [to slide]
Luna [moon]	Martillo [hammer]	Pedir [to beg]	Doblar [to fold]
Muro [wall]	Piano [piano]	Pellizcar [to pinch]	Empujar [to push]
Nariz [nose]	Coche [stroller]	Pesarse [to weigh]	Escribir [to write]
Nube [cloud]	Plancha [iron]	Pescar [to fish]	Jugar [to play]
Oreja [ear]	Regla [ruler]	Recostarse [to lean]	Marchar [to March]
Puente [bridge]	Serrucho [saw]	Rezar [to pray]	Nadar [to swim]
Rayo [lightning]	Silla de ruedas [wheelchair]	Sangrar [to bleed]	Patinar [to skate]
Semáforo [traffic light]	Tambor [drum]	Sentarse [to sit]	Pintar [to paint]
Techo [roof]	Teléfono [telephone]	Señalar [to point]	Saltar [to skip]
Tumba [grave]	Tijeras [scissors]	Sonreír [to smile]	Taladrar [to drill]
Volcán [volcano]	Ventilador [fan]	Tocar [to touch]	Tejer [to knit]

* Practice items.

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