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Parkinson's disease compromises the appraisal of action meanings evoked by naturalistic texts

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ABSTRACT

The linguistic profile of Parkinson's disease (PD) is characterized by difficulties in processing units which denote bodily movements. However, the available evidence has low ecological validity, as it stems from atomistic tasks which are never encountered in real life. Here, we assessed whether such deficits also occur for meanings evoked by context-rich narratives, considering patients with and without mild cognitive impairment (PD-MCI and PD-nMCI, respectively) and matched controls for each group. Participants read two naturalistic stories (an action text and a neutral text) and responded to questions tapping the appraisal of verb-related and circumstantial information. In PD-MCI, impairments in the appraisal of action meanings emerged alongside difficulties in other

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categories, but they were unique in their independence from general cognitive dysfunction. However, in PD-nMCI, deficits were observed only for action meanings, irrespective of the patients' domain-general skills (executive functions and general cognitive state). Also, using multiple group discriminant function analyses, we found that appraisal of action meanings was the only discourse-level variable that robustly contributed to classifying PD-MCI patients from controls (with an accuracy of 88% for all participants and for each sample separately). Moreover, this variable actually superseded a sensitive executive battery in discriminating between PD-nMCI and controls (with a combined accuracy of 83% for all participants, correctly classifying 79.2% of patients and 87.5% of controls). In sum, action appraisal deficits seem to constitute both a hallmark of naturalistic discourse processing in PD and a sensitive subject-level marker for patients with and without MCI. Such findings highlight the relevance of ecological measures of embodied cognitive functions in the assessment of this population.

1. Introduction

As predicted by embodied cognition theories (García & Ibáñez, 2016a; Pulvermüller, 2005), damage to motor brain networks distinctively impairs processing of linguistic units denoting bodily actions (for a review, see Bak, 2013). Such disturbances have been systematically reported in Parkinson's disease (PD), a highly prevalent neurodegenerative disorder characterized by movement abnormalities (Rodriguez-Oroz et al., 2009; Samii, Nutt, & Ransom, 2004). However, the available evidence has low ecological validity, as it stems from artificial tasks based on isolated, randomized words or sentences rather than context-rich, coherent and cohesive texts (for a review, see Cardona et al., 2013). Against this background, we assessed whether similar difficulties prove salient for meanings evoked by naturalistic narratives, considering patients with and without mild cognitive impairment (PD-MCI and PD-nMCI, respectively), a form of moderate cognitive decline which may emerge in early disease stages (Broeders et al., 2013; Hobson & Meara, 2015).

PD patients exhibit pervasive difficulties in processing action-related verbs (e.g., Abrevaya et al., 2017; Fernandino et al., 2013), sentences (e.g., Cardona et al., 2014; Ibáñez et al., 2013; Melloni et al., 2015), and images (e.g., Ibáñez et al., 2013) – for reviews, see Cardona et al. (2013), García and Ibáñez (2014). Though these impairments are not always selective (e.g., García, Sedeño et al., 2017), they do seem unique in their independence from domain-general disturbances, such as general cognitive alterations (overarching disruptions of visuospatial, attentional, and mnesic abilities) or executive deficits (difficulties in broad control functions, including inhibition or working memory). For example, whereas action and non-action words may be similarly affected in PD-MCI, the former are selectively compromised in PD-nMCI (Bocanegra et al., 2017). Moreover, unlike object-semantic difficulties, action-semantic deficits occur irrespective of executive dysfunctions in both PD-MCI and PD-nMCI samples (Bocanegra et al., 2015). Therefore, the impairment of action meanings may constitute a selectively *sui generis* marker of PD, even before cognitive dysfunction becomes widespread.

Despite its theoretical (Cardona et al., 2013) and clinical (Bocanegra et al., 2017) relevance, this empirical corpus is undermined by its poor ecological validity, that is, the degree to which tasks reflect the conditions of everyday functioning (Sbordone, 1996; Spooner & Pachana, 2006). Indeed, while the above studies involve randomized series of disconnected, decontextualized items, daily language processing is based on unfolding *texts*: when listening to the news or reading a story, people face context-rich pieces of discourse, characterized by cohesion (lexico-grammatical ties holding successive units together, via resources such as reference, ellipsis, repetition, and synonymy) and coherence (the functional–semantic relation between a text and its generic purpose) (Halliday & Matthiessen, 2004).

A crucial question thus arises: are the reported action-semantic deficits in PD patients indicative of their performance when dealing with full-blown texts? More precisely, do these impairments remain distinctive when patients have to *appraise* actions through ecological discourse-level processes subsuming multiple operations, such as word access, syntactic parsing, semantic integration, and memory retrieval? An affirmative answer cannot be assumed a *priori*, as contextual information modulates action-word processing (García & Ibáñez, 2016a; van Dam, Rueschemeyer, Lindemann, & Bekkering, 2010), facilitates linguistic performance by favoring maintenance of relevant information (Ledoux, Camblin, Swaab, & Gordon, 2006), and typically enhances cognitive outcomes in neuropsychiatric conditions (Aviezer et al., 2009; Ibáñez et al., 2016). So, if differential action-semantic deficits do not emerge for meanings evoked by naturalistic discourse, they may not reflect the patients' verbal skills in ecological settings. However, if they do, their potential as cognitive markers would be emphasized, as they would prove salient despite contextual support and the joint recruitment of multiple verbal and non-verbal processes.

To address this issue, we assessed the appraisal of action meanings in PD-MCI and PD-nMCI samples through a narrative reading task. Specifically, we created two naturalistic stories – an action text (AT) and a neutral text (NT) – and evaluated the patients' performance on both verb-related and circumstantial information. Moreover, we examined whether results from action and non-action categories were related to their general cognitive status.

Guided by extant findings (Bocanegra et al., 2015, 2017), we raised specific hypotheses for each group. We predicted that action appraisal difficulties in PD-MCI would also extend to non-action domains, but that they would prove uniquely independent from domain-general disturbances. However, in PD-nMCI, these deficits should prove selective and impervious to extralinguistic dysfunction. Also, we explored the relevance of such potential impairments for individual classification. This way, we sought to establish ecologically valid links between the embodied cognition framework and clinical approaches.

2. Materials and methods

2.1. Participants

The study included 40 PD patients and 40 healthy volunteers from an ongoing protocol (Bocanegra et al., 2015, 2017; García, Sedeño et al., 2017; Melloni et al., 2015) in Antioquia, Colombia. All participants had normal or corrected-to-normal vision. PD patients were diagnosed by an expert neurologist (ML) in accordance with the United Kingdom PD Society Brain Bank criteria (Hughes, Daniel, Kilford, & Lees, 1992). Their motor symptoms were evaluated through Section 3 of the Unified Parkinson's Disease Rating Scale (Fahn & Elton, 1987) and the Hoehn &Yahr scale (Hoehn & Yahr, 1967). The patients had no symptoms of Parkinson-plus and they lacked a history of other neurological or psychiatric disorders. None of them underwent deep brain stimulation. In all cases, assessment was conducted during the "on" phase of anti-parkinsonian medication, which was converted to Levodopa equivalent daily dose following Tomlinson et al.'s (2010) formula (see Table 1).

Depending on their degree of cognitive impairment, patients were classified as PD-MCI or PD-nMCI. Diagnosis of MCI was based on the Movement Disorder Society Task Force Level I criteria (Litvan et al., 2012), including an abbreviated assessment of the patients' general cognitive state via the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005). This instrument has been recommended to detect 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 it has been validated in the present population (Pereira-Manrique & Reyes, 2013). In addition, the patients' functional skills were assessed through the Barthel Index (Mahoney & Barthel, 1965) and the Lawton & Brody Index (Lawton & Brody, 1969). Patients with functional independence and a MoCA score below the cutoff suggested for the present population (Pereira-Manrique & Reyes, 2013) were diagnosed as PD-MCI ($n = 16$), whereas those with preserved functional skills and a normal MoCA score were classified as PD-nMCI ($n = 24$).

As in previous studies (Bocanegra et al., 2015, 2017), each patient group was matched for age, sex, and education level with its own control group (PD-MCI controls: $n = 16$; PD-nMCI controls: $n = 24$). Subjects in these samples had full functional independence, a normal MoCA score, and no history of neurological or psychiatric disease. For details, see Table 1.

All participants provided written informed consent in agreement with the Declaration of Helsinki. The study protocol was approved by the Institutional Ethics Committee.

2.2. Assessment of executive functions

Executive functions were assessed through the INECO Frontal Screening (IFS) battery (Torralva, Roca, Gleichgerrcht, Lopez, & Manes, 2009), a sensitive tool for PD patients with and without MCI (Bocanegra et al., 2015). The IFS 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 working memory: subjects are asked to repeat a progressively longer string of digits in the reverse order; (5) verbal working memory: subjects are asked to list the months of the year backwards, starting with December; (6) spatial working memory: 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. The maximum global score on the IFS is 30 points.

2.3. Discourse-based tasks

2.3.1. Text construction procedure

We composed two naturalistic stories, namely, an NT (with low action content) and an AT (with high action content). First, we created 22 grammatical patterns which were pseudorandomly distributed for each text and filled with selected lexical items. Each text included 32 verbs which satisfied the neutral versus action opposition following semantic, syntactic, and distributional criteria described in Halliday and Matthiessen (2014). For example, one of the patterns was "Complex sentence: adjunct of time + adjunct of time [embedded clause (prepositional phrase with infinitive verb)] + subject + transitive verb + direct object + adjunct of place". This pattern was filled as "*Como siempre, al decidirse, Elsa se olvidó la cartera en la silla*" ("*As usual, upon deciding, Elsa forgot her purse on the chair*") for the NT, and as "*Como siempre, al terminarlo, arrojó el envoltorio en el basurero*" ("*As usual, upon finishing, he threw the wrapping in the trash can*") for the AT. All sentences communicated mostly literal meanings and contained no jargon. Minor adjustments to the grammatical

Table 1 – Demographic and clinical data.

	PD-MCI	Controls	PD-MCI versus controls	PD-nMCI	Controls	PD-nMCI versus controls	PD-MCI	PD-nMCI	PD-MCI versus PD-nMCI
	$n = 16$	$n = 16$	*p*-value	$n = 24$	$n = 24$	*p*-value	$n = 16$	$n = 24$	*p*-value
Years of age	63.94 (8.66)	64.00 (6.91)	.92[a]	61.13 (9.67)	60.46 (7.38)	.74[a]	63.94 (8.66)	61.13 (9.67)	.45[a]
Years of education	12.44 (5.14)	13.44 (4.69)	.66[a]	12.08 (5.04)	12.29 (4.63)	.80[a]	12.44 (5.14)	12.08 (5.04)	.94[a]
Gender (F:M)	5:11	6:10	.71[b]	10:14	9:15	.77[b]	5:11	10:14	.50[b]
MoCA	21.63 (1.78)	25.94 (1.69)	**< .001**[a]	26.83 (1.34)	27.21 (1.41)	.39[a]	21.63 (1.78)	26.83 (1.34)	**< .001**[a]
Barthel Index	100 (0)	100 (0)	1.0[a]	100 (0)	100 (0)	1.0[a]	100 (0)	100 (0)	1.0[a]
L&B	8 (0)	8 (0)	1.0[a]	8 (0)	8 (0)	1.0[a]	8 (0)	8 (0)	1.0[a]
Years since Diagnosis							6.16 (4.34)	5.30 (3.31)	.67[a]
H&Y							2.16 (.35)	1.98 (.23)	.09[a]
UPDRS-III							36.31 (14.22)	27.46 (10.11)	.06[a]
LED							714.34 (353.06)	602.21 (396.94)	.26[a]

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; MoCA: Montreal Cognitive Assessment; L&B: Lawton & Brody Index; 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 Mann–Whitney *U* test.
[b] *p*-values were calculated using chi-square test (χ^2).

patterns were then applied to enhance cohesion and coherence in each text.

The texts were matched for multiple variables, namely: (i) character count; (ii) overall and content-word-type counts; (iii) mean content-word frequency, familiarity, syllabic length, number of letters, and imageability-based on data from the B-Pal software (Davis & Perea, 2005); (iv) sentence and sentence-type counts; (v) reading difficulty, as measured through the Szigrist Pazos (1993) scale; and (vi) readability rating, as established through the Inflezs scale (Barrio-Cantalejo et al., 2008). Moreover, a panel of 10 Spanish-speaking undergraduates judged the texts in terms of grammatical correctness, coherence, and comprehensibility (from 1 through 5). Both texts were similar in these three variables. In addition, a separate group comprising 17 native Spanish speakers rated the texts in terms of overall emotional content (positive, negative or neutral) and arousal level (intensity of the chosen emotion, from 1 through 7). No significant differences between the texts were found in either variable, and both texts were rated as emotionally positive. See Table 2 for full details.

2.3.2. *NT*

The NT describes the feelings, thoughts, and perceptions of Alberto, a young man who is relaxing at a bar in a disco. Emphasis is placed on Alberto's affective, mental, and sensory processes as he talks to his friend, Mario, and his girlfriend, Elsa. In particular, several sentences focus on his emotional responses to surrounding events [e.g., "*Alberto estaba eufórico*" ("*Alberto was euphoric*"), "*Alberto escuchó su canción favorita y se entusiasmó mucho*" ("*Alberto heard his favorite song and was very excited*")]. In addition, the text offers abundant circumstantial information depicting places, objects, and temporal features of Alberto's inner states. Crucially, 31 out of 32 verbs in the story denote non-motor processes. The NT can be found in Supplementary data 1A, and a communicative English translation is provided in Supplementary data 1C – note that this rendition does not replicate the strict control of variables present in the original.

2.3.3. *AT*

The AT narrates an afternoon in the life of Juancito, focusing on his bodily actions while he plays with his parents at a park. His activities include running on the grass, playing soccer, and interacting with both his parents and various objects. Also highlighted are the bodily actions of other characters, such as a clown who dances and children who applaud him. For example, one of the sentences reads "*Juancito corrió velozmente hacia el lugar donde el payaso saltaba y bailaba*" ("*Juancito ran quickly to the place where the clown was jumping and dancing*"). Also, the text includes rich details about the park, the objects in it, and the manner in which bodily actions were performed. Importantly, 24 out of 32 verbs in this text denote explicit motor actions. The AT can be found in Supplementary data 2A, and an English translation is provided in Supplementary data 2C – once again, this communicative rendition does not replicate the strict control of variables present in the Spanish original.

2.3.4. *Procedure*

Participants silently read each text on a separate printed page, at their own pace. They were further informed that, upon completing the first text, the page would be removed and they would be asked a few comprehension questions. The same procedure was followed for the second text. The order of presentation of the AT and the NT was counterbalanced between participants.

Appraisal of information in each text was assessed through a 22-question multiple-choice questionnaire. Half of the questions ($n = 11$) referred to verb-related information, and the other half ($n = 11$) pointed to circumstantial information explicitly realized by adverbial or prepositional phrases. For example, the question "*¿Qué hizo Juancito con la pelota?*" ("*What*

Table 2 – Linguistic features of the texts.

	Neutral text	Action text	Statistic	*p*-value[f]
Characters[a]	978	944	$\chi^2 = .60$	.44
Words	204	208	$\chi^2 = .04$	.84
Nouns	44	48	$\chi^2 = .17$	.68
Adjectives	9	7	$\chi^2 = .25$	.62
Adverbs	8	6	$\chi^2 = .29$	.59
Verbs	**32**	**32**	$\chi^2 = 0$	**1**
Action verbs	**1**	**24**	$\chi^2 = 21.16$	**<.001**
Non-action verbs	**31**	**8**	$\chi^2 = 13.56$	**<.001**
Mean content word frequency[b]	1.79	1.63	$t = 1.53$	.13
Mean content word familiarity[b]	6.24	6.15	$t = .74$	.46
Mean content word imageability[c]	4.97	5.25	$t = 1.39$	.17
Mean content word syllabic length[c]	2.49	2.52	$t = .25$	.80
Mean content word orthographic length[c]	6.26	6.16	$t = .36$	.72
Sentences	22	22	$\chi^2 = 0$	1
Minor sentences	3	3	$\chi^2 = 0$	1
Simple sentences	8	8	$\chi^2 = 0$	1
Compound sentences	3	4	$\chi^2 = .14$	.71
Complex/complex-compound sentences	8	7	$\chi^2 = .07$	.80
Grammatical correctness	4.29	4.52	$t = .66$	.51
Coherence	3.86	4.05	$t = .62$	.54
Comprehensibility	4.10	4.24	$t = 1.05$	.30
Szigriszt-Pazos Index[d]	77.3	79.92	$\chi^2 = .04$	.83
Inflezs scale rating[e]	Fairly easy	Fairly easy	–	–
Emotional valence	33.29	33.25	$F = 1.0$	.33
Arousal	4.24	4.81	$F = 2.7$	.20

[a] Character count was performed without counting spaces.
[b] Data was extracted from the LEXESP database, through B-Pal (Davis & Perea, 2005).
[c] Data extracted from B-Pal (Davis & Perea, 2005).
[d] Formula applied as described in (Szigrist Pazos, 1993).
[e] Formula applied as described in (Barrio-Cantalejo et al., 2008).
[f] Alpha level set at $p < .05$.

did Juancito do to the ball?") pointed to verb-related information, whereas the question "*¿Cuándo fue Juancito a la plazoleta?*" ("*When did Juancito go to the park?*") pointed to circumstantial information realized by a prepositional phrase. All verb-related questions in the NT questionnaire referred to non-action processes, and all of those in the AT questionnaire pointed to action processes. Crucially, verbs in the AT questionnaire implied significantly higher levels of motility than those in the NT questionnaire [$t(20) = 6.6804$, $p < .001$] – see Supplementary data 3.

All questions in the questionnaires were of the *wh*-type. In both instruments, verb-related questions were mostly based on the form "*¿Qué hizo [un personaje] cuando…?*" ("*What did [a character] do when…?*, while circumstantial questions pointed to locative, temporal, causal, or modal features signaled by the words *Dónde*, *Cuándo*, *Por qué*, or *Cómo* [*Where*, *When*, *Why*, or *How*]. These questions were evenly distributed across both questionnaires, which were also similar in the number of items pointing to the main character ($n = 15$) and to secondary characters or objects ($n = 7$).

Questions were presented following the order of the corresponding events in the texts, with a strict alternation between verb-related and circumstantial items. Successive questions were fully independent from each other, as they did not include information that would reveal the answer to subsequent items and whatever response they elicited could not bias upcoming responses. Each question was accompanied by five options, namely: (i) a correct response (i.e., the exact word used in the text), (ii) a subtly incorrect response (partially overlapping in meaning with the correct response, due to a coincidence in their modality, valence, or denotation, among other features), (iii) a grossly incorrect response (a plausible but contextually incompatible word, typically standing in antonymic relation to the correct response), (iv) a ridiculous response (an implausible scenario), and (v) an 'I don't remember' option. Sequencing of these options was randomized across questions, except for the 'I don't remember' option, which was always presented last. For example, the question "*What did Juancito do to the ball?*" featured these options: "He grabbed it (grossly incorrect)/He pushed it (subtly incorrect)/He threw it (correct)/He stirred it (ridiculous)/I don't remember". Correct responses were given one point, while incorrect answers or the "I don't remember" option were given zero points. Therefore, each questionnaire had a maximum score of 22 points (11 for verb-related questions and 11 for questions about circumstantial information). The questionnaires accompanying the NT and the AT can be found in Supplementary data 1B and 2B, respectively; English translations are offered in Supplementary data 1D and 2D.

2.4. *Data analysis*

Demographic and neuropsychological data were compared between groups using Mann–Whitney's *U* tests or chi-squared tests, as needed. Following previous studies on language embodiment in PD (Bocanegra et al., 2015, 2017; García, Sedeño et al., 2017), action and non-action tasks were subjected to separate analyses – 2 × 2 repeated-measures ANOVAs comprising the factors of group (patients, controls) and information type (circumstantial, verb-related). Interaction effects were further scrutinized with one-way ANOVAs. Moreover, to determine whether potential discourse-level deficits in PD-MCI and PD-nMCI patients were related to general cognitive impairments, we reanalyzed results from both the NT and the AT using the total MoCA and IFS scores as covariates. Alpha levels were set at $p < .05$. Effect sizes were calculated through partial eta squared (η^2) tests. As in previous studies (Bocanegra et al., 2015, 2017), all statistical analyses compared (a) PD-MCI patients versus controls, (b) PD-nMCI patients versus controls, and (c) PD-MCI versus PD-nMCI patients.

Also, using Pearson's correlations, we analyzed the relation between each group's performance and the motility implied by verbs targeted by verb-related questions in each questionnaire (see Supplementary data 3). In addition, we explored whether the patients' performance was associated with their motor symptoms. To this end, we conducted Pearson's correlations between individual scores on each discourse-level variable (appraisal of circumstantial and verb-related information, for NTs and ATs) and UPDRS-III scores.

Finally, we performed multiple group discriminant function analyses (MDAs) (Porebski, 1966; Stevens, 1996) to identify the measures that best discriminated between (a) PD-MCI patients and controls, (b) PD-nMCI patients and controls, and (c) PD-MCI and PD-nMCI patients. All neuropsychological measures (total MoCA and IFS scores) and discourse-level variables (appraisal of circumstantial and verb-related information, for NTs and ATs) were included as predictors. For every significant discriminant function, the variables' level of prediction in every group was tested via the MDA case classification module on the Statistical Package for Social Sciences (SPSS) software, version 22.0. Stepwise discriminant analysis was used for entering independent variables one at a time on the basis of their discriminating power. Wilks' Lambda was used as the criterion for selecting the discriminant functions and to evaluate the individual discriminant coefficients, with an F value for entry of 3.85 and an F value for removal of 2.71. For details, see Supplementary data 4.

In addition, we conducted receiver-operating characteristic (ROC) curve analyses, which are useful to assess the effectiveness of a given test in *classifying* individuals as belonging within one group or the other (Faraggi & Reiser, 2002), and allow comparing the discrimination accuracy of two or more tests (Tripepi, Jager, Dekker, & Zoccali, 2009). Specifically, we employed these analyses to determine which of the measures selected by the MDA proved most accurate to distinguish between each group pair. Given the results of MDAs, ROC curve analyses were conducted on the following variables: (a) total MoCA score and appraisal of verb-related information for PD-MCI patients versus controls; (b) total IFS score and appraisal of verb-related information for PD-nMCI patients versus controls; and (c) total MoCA score for PD-MCI versus PD-nMCI patients. The areas under the ROC curves, compared via Mann–Whitney tests, were used as a measure of discriminatory accuracy.

3. Results

3.1. *PD-MCI patients versus controls*

3.1.1. *General cognitive state*

Relative to controls, PD-MCI patients showed lower total scores on both the MoCA [$F(1, 30) = 49.21$, $p < .01$, $\eta^2 = .62$] and the IFS [$F(1, 30) = 1.19$, $p < .01$, $\eta^2 = .37$] – Fig. 1, panels a1 and a2).

3.1.2. *Appraisal of discourse-level information*

3.1.2.1. NT. Analysis of NT results revealed a main effect of group [$F(1, 30) = 24.68$, $p < .01$, $\eta^2 = .45$], with poorer performance for patients than controls. Moreover, a main effect of information type [$F(1, 30) = 5.75$, $p < .05$, $\eta^2 = .16$] showed that participants appraised verb-related information better than circumstantial information. No significant interaction was found between group and information type [$F(1, 30) = .43$, $p = .51$, $\eta^2 = .01$]. Despite the lack of interactions, we also performed separate one-way ANOVAs for each information type to individualize their visualization; results showed that the patients were impaired in the appraisal of both circumstantial and verb-related information (see Supplementary data 5.1, and Fig. 1, panels b1 and b2).

Additionally, ANCOVA results revealed that significant between-group differences in the appraisal of circumstantial information disappeared after adjusting for the patients' general cognitive state [$F(1, 28) = 3.90$, $p = .06$, $\eta^2 = .10$] (Fig. 1, panel b1). The same was true of differences in the appraisal of verb-related information [$F(1, 28) = 2.32$, $p = .13$, $\eta^2 = .07$] (Fig. 1, panel b2).

The performance of PD-MCI patients did not correlate with the verbs' implied motility ($r = -.02$, $p = .94$). Neither did the patients' appraisal of circumstantial ($r = -.16$, $p = .54$) or verb-related ($r = -.41$, $p = .11$) information in the NT correlate with severity of motor symptoms.

In sum, results from the NT task showed that PD-MCI patients were impaired in the appraisal of both circumstantial and verb-related information, and that these deficits were related to their overall cognitive dysfunctions.

3.1.2.2. AT. Results from the AT showed a main effect of group [$F(1, 30) = 34.44$, $p < .01$, $\eta^2 = .53$], indicating lower scores in PD-MCI patients than in controls. Moreover, a main effect of information type [$F(1, 30) = 78.72$, $p < .01$, $\eta^2 = .72$] revealed better appraisal of circumstantial than verb-related information. No significant interaction emerged between group and information type [$F(1, 30) = 1.15$, $p = .29$, $\eta^2 = .03$]. Despite the latter result, we also performed separate one-way ANOVAs for each information type to individualize their visualization; the patients' difficulties emerged separately for both circumstantial and verb-related information (see Supplementary data 5.4, and Fig. 1, panels c1 and c2).

Additionally, ANCOVA results revealed that significant between-group differences in the appraisal of circumstantial information disappeared after adjusting for the participants' general cognitive state [$F(1, 28) = 3.97$, $p = .06$, $\eta^2 = .10$] (Fig. 1, panel c1). Conversely, between-group differences in verb-related information were preserved after covariation [$F(1, 28) = 6.51$, $p < .05$, $\eta^2 = .20$] (Fig. 1, panel c2).

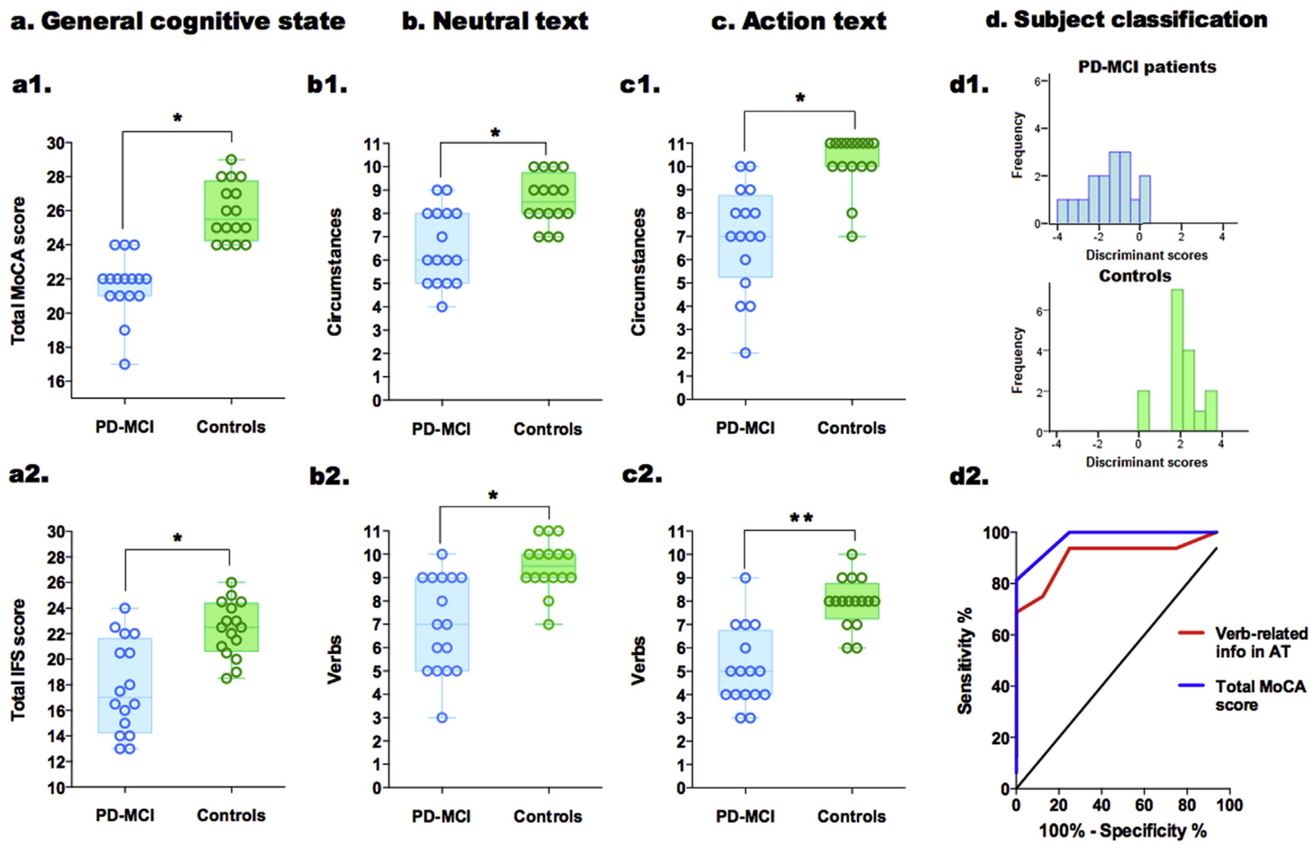

Fig. 1 – Comparisons between PD-MCI patients and controls. (a) General cognitive state: (a1) total MoCA score; (a2) total IFS score. (b) NT comprehension (see Supplementary data 5.1): (b1) circumstantial information; (b2) verb-related information. (c) AT comprehension (see Supplementary data 5.2): (c1) circumstantial information; (c2) verb-related information. Boxes represent median and interquartile range values, and whiskers indicate minimum and maximum values. Differences that were statistically significant only before adjusting for general cognitive state are identified with a single asterisk (*), while those that remained significant after covariation are marked with a double asterisk (**). (d) Subject classification: (d1) histograms showing the distribution of discriminant scores for PD-MCI patients and controls; (d2) ROC curves for total MoCA score and appraisal of verb-related information.

The patients' performance was not associated with the verbs' implied motility ($r = .06$, $p = .85$). Also, no significant correlation emerged between the patients' severity of motor symptoms and their appraisal of circumstantial ($r = -.28$, $p = .28$) or verb-related ($r = -.33$, $p = .20$) information in the AT.

In sum, results from the AT task indicated that PD-MCI patients were impaired in both circumstantial and verb-related information, but only the latter proved independent of domain-general disturbances.

3.1.3. *MDA between PD-MCI patients and controls*

To identify the variables that best contribute to classifying between groups, we performed an MDA including all neuropsychological and discourse-level measures. The two variables offering the best contribution to differentiate the groups were total MoCA score and appraisal of verb-related information in the AT. One discriminant function was calculated from the predictors with a Wilkis's $\lambda = .30$, X^2 (2) $= 34.40$, $p < .01$. This function accounted for 100% of the total variance. Importantly, although total MoCA score was the measure that most reliably discriminated between PD-MCI patients (standardized coefficient = .74), the only discourse-level variable that robustly contributed to between-group classification was appraisal of verb-related information in the AT (standardized coefficient = .54). This model successfully classified 88% of participants (88% of PD-MCI patients and 88% of control subjects) (see Fig. 1, panel d1).

3.1.4. *ROC curve analysis*

ROC curves were calculated to establish which of the measures selected by the MDA yielded the best discrimination accuracy. Both variables (total MoCA score and appraisal of verb-related information in the AT) afforded good discrimination accuracy. At a cut-off of 23 on the total MoCA score, sensitivity and specificity were .81 and .100, respectively (area under the curve: .97, CI: .93–1.01; $p < .01$) (see Fig. 1, panel d2). Appraisal of verb-related information showed a sensitivity of .93 and a specificity of .75, with a 7.5-point cut-off. The area under the ROC curve was .90 (CI: .79–1.02; $p < .01$) (Fig. 1, panel d2). A statistical comparison between the area under the ROC curves for total MoCA score and appraisal of verb-related information in the AT revealed that the former offered better discrimination accuracy ($z = 2.06$, $p = .01$).

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3.2. PD-nMCI patients versus controls

3.2.1. General cognitive state

Comparison of total MoCA scores between PD-nMCI and controls yielded no significant differences [$F(1, 46) = .88$, $p = .35$, $\eta^2 = .01$] (Fig. 2, panel a1). However, analysis of total IFS scores showed impaired performance for the patients [$F(1, 46) = 10.33$, $p < .01$, $\eta^2 = .18$] (Fig. 2, panel a2).

3.2.2. Appraisal of discourse-level information

3.2.2.1. NT. Analysis of NT results showed a null effect of group [$F(1, 46) = 3.03$, $p = .08$, $\eta^2 = .05$] (Fig. 2, panel b). Also, a main effect of information type [$F(1, 46) = 17.53$, $p < .01$, $\eta^2 = .27$] indicated that participants appraised verb-related information better than circumstantial information. No significant interaction was observed between group and information type [$F(1, 46) = .10$, $p = .74$, $\eta^2 = .002$].

The patients' performance was not associated with the verbs' implied motility ($r = .03$, $p = .91$). Neither was there a significant correlation between the patients' severity of motor symptoms and their appraisal of circumstantial ($r = -.11$, $p = .59$) or verb-related ($r = -.05$, $p = .78$) information.

3.2.2.2. AT. AT results showed a main effect of group [$F(1, 46) = 25.46$, $p < .01$, $\eta^2 = .35$], with lower scores for PD-nMCI patients than controls. There was also a main effect of information type [$F(1, 46) = 104.3$, $p < .01$, $\eta^2 = .69$], showing that participants appraised circumstantial information better than verb-related information. Moreover, a significant interaction emerged between group and information type [$F(1, 46) = 7.75$, $p < .01$, $\eta^2 = .14$]. To further interpret this interaction, we performed separate between-group analyses for each information type. Appraisal of circumstantial information was similar between groups [$F(1, 46) = 2.62$, $p = .11$, $\eta^2 = .05$] (Fig. 2, panel c1), whereas appraisal of verb-related information was significantly poorer in PD-nMCI patients [$F(1, 46) = 29.59$, $p < .01$, $\eta^2 = .39$] (Fig. 2, panel c2). Moreover, the latter difference remained significant after adjusting for the participants' general cognitive state [$F(1, 44) = 25.37$, $p < .01$, $\eta^2 = .36$] (Fig. 2, panel c2).

The patients' performance did not correlate with the verbs' implied motility ($r = -.28$, $p = .39$). Also, the patients' appraisal of circumstantial ($r = -.09$, $p = .65$) and verb-related ($r = -.11$, $p = .59$) information in the AT did not correlate with their severity of motor symptoms.

In brief, compared to controls, PD-nMCI patients were selectively impaired in appraising verb-related information in the AT, and this deficit was not dependent on their general cognitive dysfunction.

3.2.3. MDA between PD-nMCI patients and controls

To identify the variables that best contribute to classifying between groups, we performed an MDA including all neuropsychological and discourse-level measures. Two variables were selected by the stepwise discriminant procedure, namely, total IFS score and appraisal of verb-related information in the AT. One discriminant function was calculated with a Wilkis's $\lambda = .52$, X^2 (2) $= 26.68$, $p < .01$. This function accounted for 100% of the total variance. Appraisal of verb-related information in the AT was the only discourse-level measure that discriminated between PD-nMCI patients and controls. This variable, indeed, showed the best discrimination accuracy of them all (standardized coefficient = .86), followed by total IFS score (standardized coefficient = .52). With this model, 83% of participants were correctly classified (79.2% of PD-nMCI patients and 87.5% of control subjects) (see Fig. 2, panel d1).

3.2.4. ROC curve analysis

Once again, we performed ROC curve analyses to determine which of the measures selected by the MDA yielded the best discrimination accuracy. The best discrimination between groups was afforded by appraisal of verb-related information in the AT (area under the curve: .87, CI: .78–.97; $p < .01$). At a cut-off of 7.5, sensitivity and specificity were .71 and .88, respectively (Fig. 2, panel d2). Relative to this variable, total IFS score showed a lower discrimination accuracy (area under the curve: .74, CI: .60–.88; $p < .01$). At a cut-off of 23, sensitivity was .75 and specificity reached .59 (Fig. 2, panel d2). A statistical comparison between the area under the ROC curves for appraisal of verb-related information in the AT and total IFS score revealed better discrimination accuracy in the former ($z = 2.07$, $p = .01$).

3.3. PD-MCI versus PD-nMCI patients

3.3.1. General cognitive state

As expected, total MoCA scores were lower for PD-MCI than PD-nMCI patients [$F(1, 38) = 111.09$, $p < .01$, $\eta^2 = .74$] (Fig. 3, panel a1). The same was true of total IFS scores [$F(1, 38) = 8.65$, $p < .01$, $\eta^2 = .18$] (Fig. 3, panel a2).

3.3.2. Appraisal of discourse-level information

3.3.2.1. NT. Results from the NT revealed a main effect of group [$F(1, 38) = 30.22$, $p < .01$, $\eta^2 = .44$], with poorer performance for PD-MCI than PD-nMCI patients. There was also a main effect of information type [$F(1, 38) = 5.12$, $p < .05$, $\eta^2 = .11$], showing better appraisal of verb-related information than circumstantial information. No significant interaction was found between group and information type [$F(1, 38) = .35$, $p = .55$, $\eta^2 = .009$]. Despite the lack of interactions, we also performed separate one-way ANOVAs for each information type to individualize their visualization; relative to PD-nMCI patients, PD-MCI patients had poorer performance on both circumstantial and verb-related information (see Supplementary data 5.2.3, and Fig. 3, panels b1 and b2).

After adjusting for general cognitive state, between-group differences disappeared for both appraisal of circumstantial [$F(1, 36) = .73$, $p = .39$, $\eta^2 = .02$] and verb-related [$F(1, 36) = .17$, $p = .67$, $\eta^2 = .004$] information (Fig. 3, panels b1 and b2).

In sum, in the NT task, PD-MCI patients had greater difficulties than PD-nMCI patients in processing circumstantial and verb-related information. However, all significant differences disappeared after adjusting for the patients' general cognitive state.

3.3.2.2. AT. Analysis of AT results revealed a main effect of group [$F(1, 38) = 12.0$, $p < .01$, $\eta^2 = .24$], indicating that PD-MCI patients had greater impairments than PD-nMCI patients.

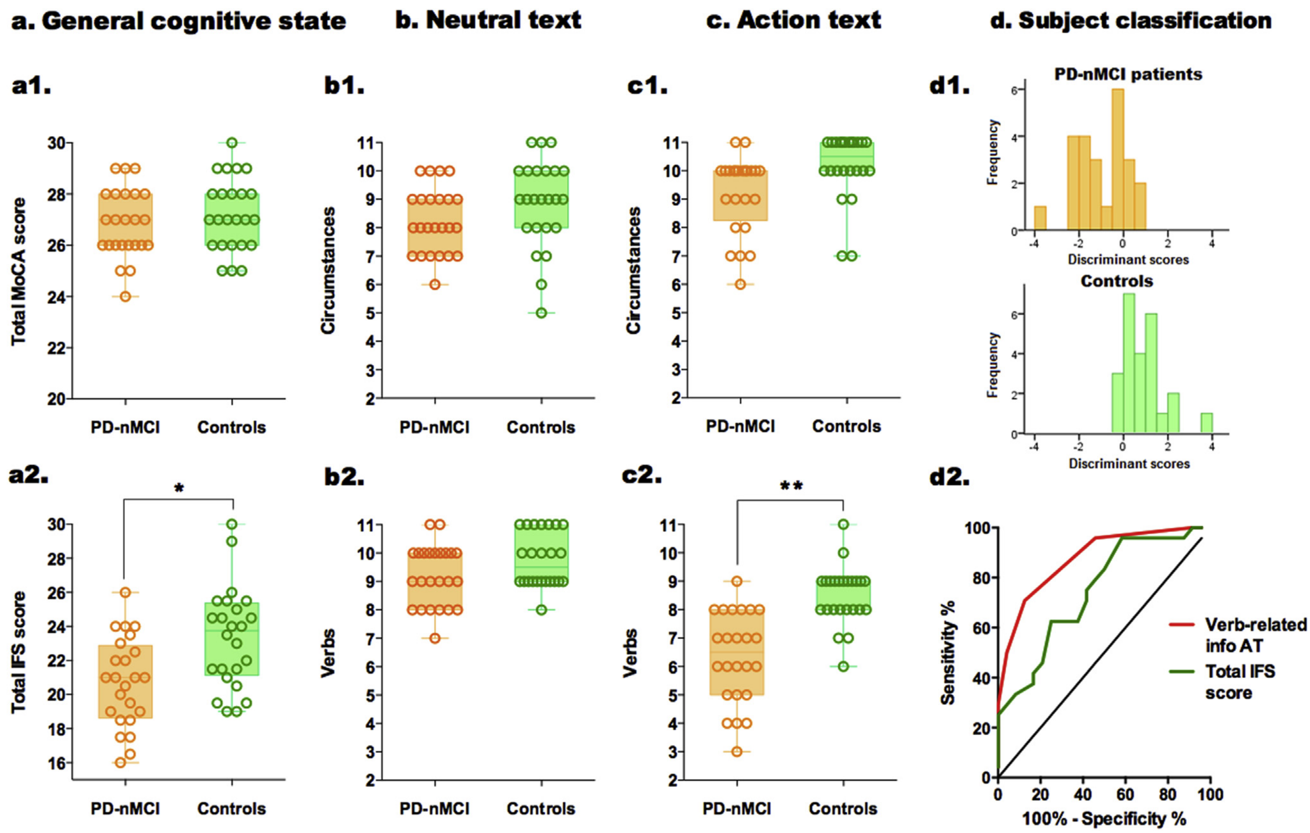

Fig. 2 – Comparisons between PD-nMCI patients and controls. (a) General cognitive state: (a1) total MoCA score; (a2) total IFS score. (b) NT comprehension: (b1) circumstantial information; (b2) verb-related information. (c) AT comprehension: (c1) circumstantial information; (c2) verb-related information. Boxes represent median and interquartile range values, and whiskers indicate minimum and maximum values. Differences that were statistically significant only before adjusting for general cognitive state are identified with a single asterisk (*), while those that remained significant after covariation are marked with a double asterisk (**). (d) Subject classification: (d1) histograms showing the distribution of discriminant scores for PD-nMCI patients and controls; (d2) ROC curves for appraisal of verb-related information and total IFS score.

There was also a main effect of information type [$F(1, 38) = 83.0$, $p < .01$, $\eta^2 = .68$], showing that both PD-MCI and PD-nMCI patients appraised circumstantial information better than verb-related information. Also, we found a significant interaction between group and information type [$F(1, 38) = 4.52$, $p < .05$, $\eta^2 = .10$].

To further interpret this interaction, we performed separate between-group analyses for each information type. Appraisal of circumstantial information was poorer in PD-MCI than in PD-nMCI [$F(1, 38) = 27.65$, $p < .01$, $\eta^2 = .42$] (Fig. 3, panel c1). However, no significant between-group differences were observed for verb-related information [$F(1, 38) = 2.10$, $p = .15$, $\eta^2 = .05$] (Fig. 3, panel c2). Also, differences in the appraisal of circumstantial information disappeared after adjusting for the patients' general cognitive state [$F(1, 36) = .09$, $p = .76$, $\eta^2 = .002$] (Fig. 3, panel c1).

In short, results from the AT task showed that PD-MCI and PD-nMCI patients only differed in the appraisal of circumstantial information. This pattern was dependent on the patients' general cognitive state. However, both groups evinced similar deficits in the appraisal of verb-related information.

3.3.3. *MDA between PD-MCI versus PD-nMCI patients*

To identify the variables that best contribute to classifying between groups, we performed an MDA including all neuropsychological and discourse-level measures. The only variable selected by the model in terms of its contribution to between-group differentiation was total MoCA score. One discriminant function was calculated from the predictors with a Wilks's $\lambda = .25$, X^2 (1) $= 51.26$, $p < .01$. This function accounted for 100% of the total variance (standardized coefficient = 1.00). Based on this model, 97.5% of participants were correctly classified (100% of PD-MCI patients and 96% of PD-nMCI patients) (see Fig. 3, panel d1).

3.3.4. *ROC curve analysis*

A ROC curve analysis was conducted to determine the discrimination accuracy of the total MoCA score, the only measure selected by the MDA. As expected, this variable perfectly discriminated between both groups of patients (area under the curve: 1.0, CI: 1.0–1.0; $p < .01$). At a cut-off of 24.5, sensitivity and specificity were .10 and .10, respectively (Fig. 3, panel d2).

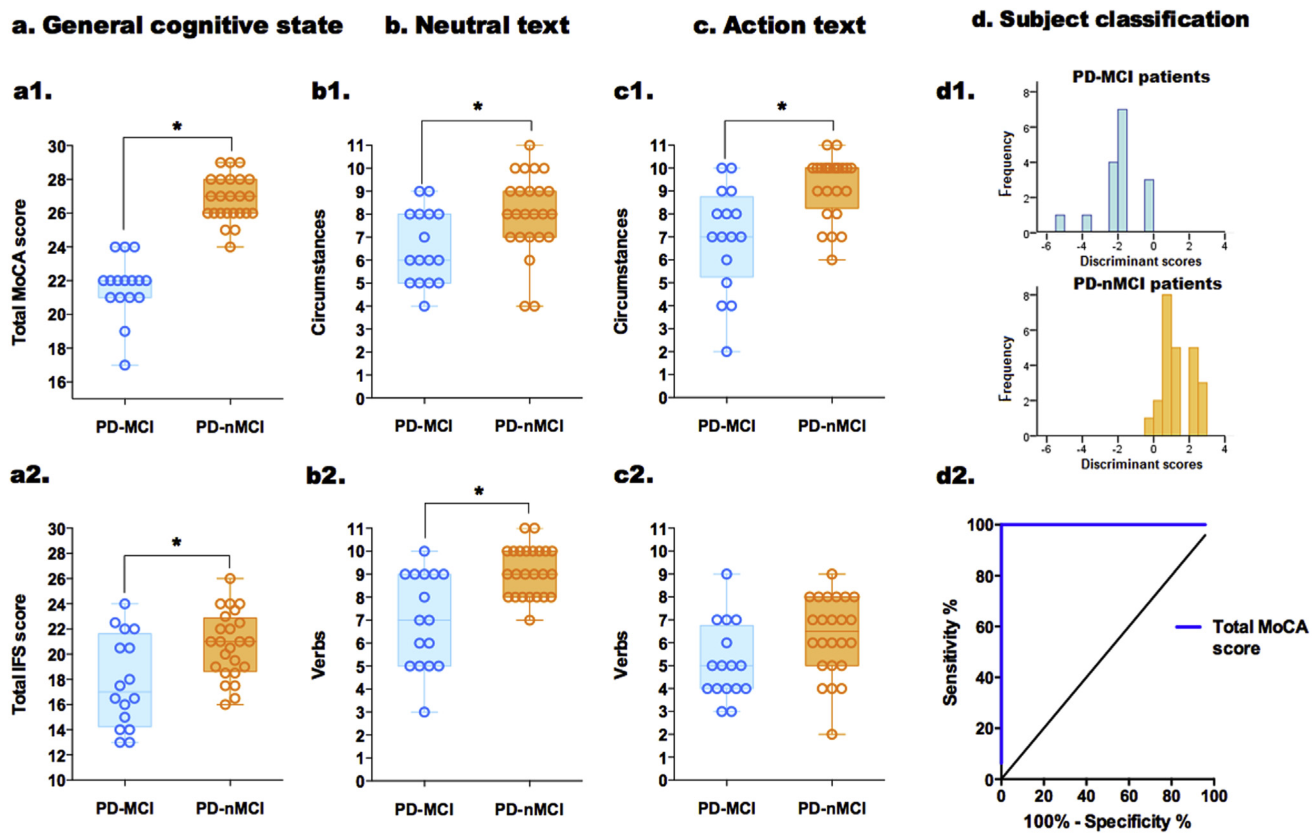

Fig. 3 – Comparisons between PD-MCI and PD-nMCI patients. (a) General cognitive state: (a1) total MoCA score; (a2) total IFS score. (b) NT comprehension (see Supplementary data 5.3): (b1) circumstantial information; (b2) verb-related information. (c) AT comprehension: (c1) circumstantial information; (c2) verb-related information. Boxes represent median and interquartile range values, and whiskers indicate minimum and maximum values. Differences that were statistically significant only before adjusting for general cognitive state are identified with a single asterisk (*), while those that remained significant after covariation are marked with a double asterisk (**). (d) Subject classification: (d1) histograms showing the distribution of discriminant scores for PD-MCI and PD-nMCI patients; (d2) ROC curve for total MoCA score.

4. Discussion

This is the first study on PD assessing the appraisal of action meanings evoked by naturalistic texts. Crucially, deficits in such a category proved uniquely *sui generis* in patients with and without MCI, and they emerged selectively in the latter. Moreover, action appraisal was the only discourse-level variable that robustly classified PD-MCI patients from controls, and it even superseded a sensitive executive battery in discriminating between PD-nMCI and controls. The detection of these patterns via narrative-based tasks is all the more noteworthy because contextual support typically improves cognitive performance in neurological disorders. Therefore, difficulties in appraising actions during discourse processing may constitute a robust early marker of PD. Below we discuss our findings, addressing their theoretical and clinical implications.

4.1. *Discourse-level action meanings in PD*

PD-MCI patients showed difficulties in appraising action, non-action, and circumstantial information. This corroborates that action meanings in PD may be compromised alongside other categories when overall cognitive skills are affected (García, Sedeño et al., 2017). However, action-semantic deficits did prove unique in their independence from domain-general skills, as tapped through the MoCA and the IFS battery. The same result has been reported in other PD-MCI samples via picture association (Bocanegra et al., 2015) and word production (Bocanegra et al., 2017) tasks, and it has been replicated in other movement disorders, such as Huntington's disease (García, Bocanegra et al., 2017). Our results extend such findings, showing that impairments of action categories in PD remain distinctively primary even for meanings evoked through naturalistic tasks.

Of note, verb-related information deficits in the NT (involving mental, sensory, and affective verbs) did depend on extralinguistic dysfunctions. Thus, the above pattern seems driven by the semantic specificity of action verbs rather than morphosyntactic features of verbs as a whole. Indeed, functional subdomains within the linguistic system seem to be organized in terms of fine-grained conceptual categories (Huth, de Heer, Griffiths, Theunissen, & Gallant, 2016), as opposed to broad grammatical distinctions (Vigliocco, Vinson,

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Druks, Barber, & Cappa, 2011). Conceivably, such specifically primary deficit in PD-MCI could reflect disturbances in one particular subprocess (e.g., lexical access, comprehension, or memory retrieval), although our ecological design is neither suitable nor intended to test that possibility. Notwithstanding, the key finding is that action-semantic difficulties in PD remain distinctive despite being embedded in the multiple operations which underlie naturalistic text processing.

This claim is reinforced by results from PD-nMCI patients. Whereas their appraisal of non-action and circumstantial information was comparable to that of controls, they exhibited significant action-semantic deficits irrespective of overall cognitive dysfunction. A similar pattern was observed in a picture-naming study (Bocanegra et al., 2015), showing that PD-nMCI patients were impaired in processing high-motion action verbs, with no concomitant difficulties in nouns and low-motion action verbs. Compatibly, selective action-verb deficits despite normal MoCA scores have been reported in cerebellar ataxia, another condition characterized by movement disorders and motor network damage (García, Abrevaya et al., 2016). Moreover, in the latter study as well as in the present one, processing of abstract verbs was preserved, although these are typically more cognitively demanding in neurotypicals (Dalla Volta, Fabbri-Destro, Gentilucci, & Avanzini, 2014; García & Ibáñez, 2016b). Therefore, it seems that if the extent of atrophy is not sufficient to compromise the patients' overall cognitive state, their semantic profile may be mainly characterized by impairments of action categories.

More strikingly, this seems to be so even when action verbs are seamlessly embedded in naturalistic narratives featuring hosts of other information. In particular, PD-nMCI patients successfully retrieved circumstantial details from the very story in which they evinced *sui generis* action appraisal deficits (i.e., the AT). In linguistic terms, the elements which typically realize circumstances (e.g., adverbial or prepositional phrases) are semantically and structurally autonomous from action verbs (Halliday & Matthiessen, 2014). Such a dissociation may be mirrored in the neural organization of language. Specifically, frontostriatal integrity seems so crucial to ground action semantics that even discourse-level deficits may be circumscribed to such a category in the absence of domain-general deficiencies. Note, also, that this pattern was not associated with the verbs' implied motility, as shown by correlation results. It seems, then, that the patients' action appraisal deficits did not worsen in proportion to the level of movement implied by target words, but rather reflected the accumulation of action information in the AT relative to the NT.

Our claim that the action appraisal difficulties in PD are distinctively independent from the patients' cognitive state is underscored by the lack of association between individual performance and other critical factors, such as the degree of motor impairment. Indeed, motor disability, as captured by the UPDRS-III subscale, did not correlate with performance in any discourse-level variable in either patient group. Previous studies on PD have also reported non-significant associations between UPDRS-III scores and action-language processing in fluency (Signorini & Volpato, 2006), verb-generation (Crescentini, Mondolo, Biasutti, & Shallice, 2008; Peran et al., 2003), picture-naming (Bocanegra et al., 2017), and lexical decision (Boulenger et al., 2008) tasks. Yet, since the UPDRS-III subscale exclusively assesses gross aspects of motor function (e.g., gait, rigidity, postural stability), a significant relationship cannot be ruled out between action semantic disturbances and fine-grained motor anomalies (e.g., alterations in motion acceleration, strength, amplitude or precision). Such possible associations should be explored in future studies via paradigms combining action semantics with fine-grained measures of motion – for examples, see García and Ibáñez (2016b). Be that as it may, the present findings further highlight the intimate connection between action appraisal impairments and the patients' higher-order cognitive profile, irrespective of gross motoric abilities.

A cross-sectional comparison between both patient groups supports this conjecture. Although PD-nMCI and PD-MCI subjects had similar levels of motor compromise (see Table 1), the latter showed lower scores not only on the MoCA, but also on an executive function test (the IFS battery). At the same time, their discourse-level impairments were greater for all categories but one: action information. This further highlights the highly specific role of frontostriatal networks in the embodiment of action meanings. Beyond basal ganglia degeneration, PD-nMCI patients are mainly characterized by frontal cortical thinning (Mak et al., 2015). Conversely, cortical atrophy in PD-MCI typically reaches temporo-parietal cortices (Mak et al., 2015) and other posterior regions (Danti et al., 2015; Pereira et al., 2014, 2015), which are crucially implicated in multimodal semantics (Pulvermüller, 2013) even during natural speech processing (Huth et al., 2016). In line with our claim, direct comparisons between both populations show greater deficits in the latter on general naming and semantic fluency tasks (Biundo et al., 2014; Caviness et al., 2007; Hobson & Meara, 2015). Spared appraisal of non-action information in PD-nMCI patients might thus reflect not only their greater cognitive preservation, but potentially their less extended atrophy pattern.

While the above neurological claims remain conjectural, deficits in action meanings evoked by naturalistic texts could well represent a touchstone to classify *individual* PD patients from controls. In PD-MCI, only two variables were successful to this end. Unsurprisingly, the first one was total MoCA score – i.e., the very neuropsychological measure which was manipulated by design between groups. The second one, however, was appraisal of action information. Notably, this was the only discourse-level variable contributing to classification, even though controls also outperformed patients in every other text-related measure. Compatibly, semantic analysis of spontaneous monologues showed that moderate classification success (65%) between PD patients and controls was dominated by differential reliance on action concepts (García, Carrillo et al., 2016). Here, we found that performance on an action-loaded narrative contributed to a classification rate of 88%, which stresses the relevance of constrained action-semantic tasks for patient identification.

Moreover, in PD-nMCI, action appraisal emerged as the *best* classifier between patients and controls, leading to a classification rate of 83%. In fact, such a variable proved more robust for patient identification than a highly sensitive executive function test – the IFS battery (Torralva et al., 2009). This is noteworthy because previous studies point to dysexecutive syndrome as a cognitive hallmark of PD (Muslimovic, Post, Speelman, & Schmand, 2005; Rodriguez-Oroz et al., 2009), even when measured through this very tool (Bocanegra et al., 2015; García, Sedeño et al., 2017; Ibáñez et al., 2013). Thus, our findings suggest that a short, theoretically driven, naturalistic task may afford sensitive markers for cognitive screening in the assessment of PD patients.

4.2. Clinical implications

Evidence on action-semantic deficits in PD and other motor disorders has motivated both theoretical and clinical proposals (Bak, 2013; Cardona et al., 2013; García & Ibáñez, 2014). However, virtually all relevant studies fail to meet the requisite of ecological validity (Sbordone, 1996; Spooner & Pachana, 2006). Specifically, they rank low in "representativeness" and "generalizability": as they fail to match situations encountered in daily life, their results may not be good predictors of performance beyond typical experimental settings (Burgess et al., 2006). Conversely, our approach involves ecological texts together with typical multiple-choice questionnaires. Moreover, the brevity of our task may reduce the fatigue and frustration often induced by artificial paradigms (Kurzban, Duckworth, Kable, & Myers, 2013). Accordingly, discourse-level tasks tapping action appraisal may be fruitfully incorporated into the current toolkit used for language assessment in PD.

Moreover, other verbal skills, such as semantic and phonological fluency, are similarly impaired in PD (Ellfolk et al., 2014; Obeso, Casabona, Bringas, Alvarez, & Jahanshahi, 2012) and radically different conditions, such as Alzheimer's disease (Henry, Crawford, & Phillips, 2004) and posterior cortical atrophy (Crutch, Lehmann, Warren, & Rohrer, 2013). In contrast, action-semantic tasks have revealed marked deficits in PD (Cardona et al., 2013) and other neurodegenerative motor diseases (Bak, 2013), but not in patients with semantic dementia (Bak & Hodges, 2003) or musculoskeletal motor compromise (Cardona et al., 2014). Thus, tasks targeting action semantics could prove particularly sensitive for PD and other movement disorders. Indeed, our study shows that these deficits prevail even though sensible discourse contexts typically facilitate maintenance of linguistic information, in general (Ledoux et al., 2006), and modulate action-language processing, in particular (García & Ibáñez, 2016b; van Dam et al., 2010). More promisingly, given that action-semantic deficits have been reported in several other movement disorders, such as Huntington's disease, corticobasal degeneration, motor neuron disease, and cerebellar ataxia (Bak & Chandran, 2012; Bak, 2013; Cotelli et al., 2006; García, Bocanegra et al., 2017; García, Abrevaya et al., 2016), the present task should be tested as a potential transdiagnostic marker of motor network compromise. Indeed, such category-specific alterations have been proposed as markers of atrophy in any neural region subserving motor functions (García, Abrevaya et al., 2016).

Finally, our results align with those reported by Bocanegra et al. (2017) to suggest that selective action-semantic deficits in PD patients may be indicative of a preserved cognitive status, while transcategorical lexico-semantic impairments could be indicative of MCI. In this sense, note that diagnosis of non-demented PD is moot on whether patients present MCI (Aarsland et al., 2009; Broeders et al., 2013). Moreover, subtests of traditional tools to detect MCI, like the MoCA, may not offer a robust picture of their hypothesized target domains (Coen, Robertson, Kenny, & King-Kallimanis, 2016). Thus, ecological fine-grained tasks rooted in embodied hypotheses may be a useful complement to cognitive screening in the neuropsychological assessment of PD. However, replication and normative studies are needed to directly test this possibility.

4.3. Limitations and avenues for further research

Our work features some limitations. First, our sample size was modest. However, it was certainly not smaller than those of other informative studies on the topic (Boulenger et al., 2008; Kemmerer, Rudrauf, Manzel, & Tranel, 2012), and the high rates of accuracy in classifying individual participants speak to the robustness of the results. Second, we lacked neuroimaging data to complement our clinical and behavioral observations. Future replications or adaptations of our study could be complemented with data from structural or functional magnetic resonance imaging, event-related potentials, and ongoing EEG-connectivity data to fully exploit the potential of the lesion method (Rorden & Karnath, 2004) in its neurodegeneration version (Baez, Kanske, et al., 2016; Melloni et al., 2015). Third, in the absence of a contrastive pathology, the specificity of our findings remains uncertain. Direct comparisons with different patient groups, including other motor conditions, could be critical to ascertain the broader clinical value of our approach, especially if complemented with neuroimaging data – for examples targeting other cognitive domains, see Melloni et al. (2016). In addition, further research is required to compare the classification power of naturalistic and atomistic language tasks in PD, so as to better gauge the need for reformulations of extant protocols.

Also, note that the patients performed the tasks during the "on" phase of medication. Importantly, this created more stringent testing conditions for our hypothesis, given that levodopa has been observed to differentially improve action-verb processing in PD (Boulenger et al., 2008; Herrera & Cuetos, 2012). Although this circumstance further attests to the robustness of our findings, it would be useful to assess how full-text processing in PD is affected by manipulations of medication dosage, especially considering that similar facilitatory effects are not systematically obtained through other forms of intervention, such as deep brain stimulation (Tomasino et al., 2014).

Furthermore, despite the strict matching of variables between both texts and questionnaires, subtle difficulty differences cannot be fully ruled out between conditions, and these may have partially influenced the results. However, since the NT and the AT were subjected to individual analyses, task difficulty in each condition was kept constant between patients and controls. Moreover, performance on the AT was independent from the patients' general cognitive state, which could hardly have been the case if deficits in this category were driven by increased overall demands. In this sense, it is worth stressing that, although the AT takes place in a disco with a dance floor, its characters engage almost exclusively in non-physical processes and all the verbs targeted in the corresponding questionnaire denote non-motor processes. Still, new applications of our paradigm could be further improved by incorporating additional controls of difficulty-related variables.

Finally, a key caveat must be recognized in the present approach: the convergence of multiple verbal and non-verbal operations during discourse processing prevents us from ascertaining the specific contribution of lexico-semantic, pragmatic, mnemonic, or executive operations. In other words, we cannot establish whether the observed deficits emerged due to disruptions in one or many of those dimensions. This is the typical tradeoff to contemplate when increasing the ecological validity of the assessment. However, relevant insights could be gained with specific methodological maneuvers. For example, to assess the role of short-term memory skills, questionnaires could be administered in an immediate and a delayed condition: if performance remains similar in both, deficits in that executive domain could be justifiably ruled out. Alternatively, this and other domains (e.g., lexical access, discourse integration) could be directly assessed with specific instruments and ensuing results could be entered as covariates or regressors in complementary analyses.

5. Conclusion

This study offers unprecedented evidence that PD triggers deficits in the appraisal of action meanings evoked by naturalistic texts. Moreover, these impairments seem to constitute a sensitive marker individual patients with and without MCI. Such findings highlight the relevance of ecological measures of embodied cognitive functions in the assessment of this population. Future applications of our approach could promote theoretical and applied breakthroughs in various branches of neuropsychology and clinical neuroscience.

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Conflict of interest

None to declare.

Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.cortex.2017.07.003.

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