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Cognitive Impairment in Parkinson's Disease: More than a Frontostriatal Dysfunction

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Abstract. Cognitive deficit in Parkinson's disease has been traditionally considered as being mainly related to executive dysfunction secondary to frontostriatal affectation. However, this traditional consideration has recently been challenged. Forty-three nondemented PD patients (mean age = 59.19; *SD* = 9.64) and twenty control group subjects (mean age = 60.85; *SD* = 12.26) were studied. They were assessed on a wide range of cognitive functions. Patients showed motor slowing ($p = .012$), along with alterations in visuoperceptive ($p = .001$), visuospatial ($p = .007$) and visuoconstructive functions ($p = .017$), as well as in visual span (direct: $p = .008$; inverse: $p = .037$). Regarding executive functions, differences were not observed in classical measures for verbal fluency (phonetic: $p = .28$; semantic: $p = .27$) or in response inhibition (Stroop test: $p = .30$), while execution was altered in other prefrontal tasks (Wisconsin Test: $p = .003$; action fluency: $p = .039$). Patients showed altered performance in verbal learning processes ($p = .005$) and delayed memory (free: $p = .032$; cued: $p = .006$), visuospatial learning ($p = .016$) and linguistic functions (naming: $p < .001$; comprehension: $p = .007$). Poor performance in visuospatial memory is predicted by deficits in working memory and visuospatial perception. Taken together, the observed alterations not only suggest prefrontal affectation, but also temporal and parietal systems impairment. Thus, cognitive dysfunction in nondemented PD patients cannot be exclusively explained by frontostriatal circuit affectation and the resulting executive dysfunction.

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Parkinson's disease (PD) is a neurodegenerative disorder, mainly defined as the degeneration of pigmented cells in the substantia nigra and the consequent dysfunction of the nigrostriatal system. Cognitive deficits have traditionally been seen as an executive dysfunction secondary to frontostriatal system affectation. In this schema, this executive dysfunction is responsible for other cognitive disturbances such as deficits in memory or linguistic functions. Although this type of description is frequent, recent evidence has questioned this interpretation (Barone et al., 2011).

As regards declarative memory, alterations in learning and free delayed recall without deficits in cued recall have been reported. This pattern of affectation has been related to a deficit in the use of self-elaborated encoding and recall strategies. Thus, the aforementioned deficit has been considered as being indicative of frontal dysfunction due to frontostriatal circuitry impairment (Stefanova, Kostic, Ziropadja, Ocic, & Markovic, 2001; Tröster & Fields, 1995). However, some recent findings indicate that declarative memory deficits are not confined to poor learning strategies or impaired free recall. In fact, patients can continue to show altered execution even after the use of external cues (semantic keys, recognition) (Beyer et al., 2013; Higginson, Wheelock, Carroll, & Sigvardt, 2005; Whittington, Podd, & Stewart-Williams, 2006). On the other hand, a poor performance in WCST is well documented, which is one of the most commonly used instruments to assess executive function (Lees & Smith, 1983; Liozidou, Potagas, Papageorgiou, & Zolonis, 2012; Muslimovic, Post, Speelman, & Schmand, 2007; Witt, Nuhsman, & Deuschl, 2002), but none of the other tests used to measure these functions has yielded conclusive evidence. This is particularly relevant in the case of verbal fluency tests as, despite being one of the measures most strongly linked to prefrontal activity, there are as many studies showing altered performance in patients (Muslimovic et al., 2007; Obeso, Casabona, Bringas, Alvarez, & Jahanshahi, 2012; Signorini & Volpato, 2006; Uc et al., 2005) as those in which no differences are observed (Brand et al., 2004; Piatt, Fields, Paolo, Koller, & Troster, 1999; Schneider, 2007). With regard to language, some authors have reported that deficits in comprehension may occur in complex sentences and that they are mainly due to limitations in executive resources such as working memory (Grossman, 1999; Grossman, Carvell, Stern, Gollomp, & Hurtig, 1992; Hochstadt, Nakano, Lieberman, & Friedman, 2006).

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However, other results have questioned this assumption: alterations in sentence comprehension are not limited to those of greater complexity, but they are also found in simple sentences. In addition, these deficits are present in patients without alteration of working memory (Skeel et al., 2001).

Contributions from neuroimaging studies also suggest that cognitive deficits in PD are not explained by frontostriatal system affectation alone. These findings demonstrate that, even in nondemented cases, patients may present hippocampal, frontal and parietal atrophy related to alterations in different cognitive functions (Beyer et al., 2013; Jokinen et al., 2009; Pereira et al., 2009). Furthermore, the development of dementia in PD involves structural changes in limbic areas and extensive atrophy of different cortical regions (Ibarretxe-Bilbao, Tolosa, Junque, & Marti, 2009).

Many of the findings obtained so far are based on studies of isolated cognitive functions which do not allow in-depth study of the relationships among these different functions or their components and do not provide a holistic impression of these deficits. Taking this situation into account, the aim of this work is to study cognitive functioning in PD patients over a wide range of cognitive domains and the main components of these.

Method

Participants

The study included 63 participants: 43 patients with idiopathic PD and 20 healthy and neurologically normal controls. Patients were recruited from the Hospital Universitario Ntra. Sra. Candelaria (HUNSC, Tenerife), where they were evaluated at the movement disorder unit using the Hoehn and Yahr Scale (Hoehn & Yahr, 1967) and UPDRS (Fahn & Elton, 1987). All the patients met the clinical criteria for the diagnosis of PD (Hughes, Daniel, Kilford, & Lees, 1992). Those who met the criteria of the Movement Disorder Society (MDS) for the diagnosis of dementia associated with PD (PD-D) were excluded (Emre et al., 2007). The diagnostic criteria for PD-D were operationalized according to the level 1 algorithm proposed by the MDS Task Force (Dubois et al., 2007). Patients and controls were matched in age, years of study, gender, manual preference and estimated IQ (information WAIS-III) (Wechsler, 1997a). The Beck Depression Inventory was administered for the assessment of mood state (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961).

Both groups of participants were informed about the aims of the investigation and participated voluntarily. All gave their informed consent. The data was obtained in accordance with the regulations of the Ethics Committees of the Universidad de La Laguna and in compliance with the Helsinki Declaration for Human Research.

Procedure

An extensive assessment protocol was designed in order to assess a wide range of cognitive domains and their main components. Tests were selected in such a way that no or only limited movements had to be carried out by the patient. The neuropsychological tests which were administered are described below:

Processing speed, attention and working memory

-Reaction Time test: This system permits the dissociation of decision and motor times. Decision time (DT) is

Table 1. *Demographic data and clinical characteristics*

	Patients (*n* = 43)		**Controls (*n* = 20)**		ANOVA test	
Variable	*M*	*SD*	*M*	*SD*	*F*	*p*
Age (years)	59.19	9.64	60.85	12.26	0.341	NS
Gender (men/women)*	24/19	–	9/11	–	–	–
Education (years)	7.88	2.75	8.55	2.72	0.808	NS
MMSE**	27.58	1.80	28.40	1.50	3.113	NS
Information (WAIS-III)	12.50	5.78	14.30	5.32	1.380	NS
Beck Depression Inventory	13.33	9.37	7.88	4.94	5.138	.027
Hoehn & Yahr stage	2.28	0.77	–	–	–	–
Hoehn & Yahr stage (range)	1–4	–	–	–	–	–
UPDRS-Motor score	28.46	13.96	–	–	–	–
Age at onset	50.88	9.26	–	–	–	–
Disease duration (years since diagnosis)	8.30	6.33	–	–	–	–

Note: M: mean. *SD*: standard deviation. NS: not significant. *number of men and women; **correction by age and educational level (Blesa et al., 2001).

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a cognitive measure of information processing speed. Motor time (MT) reflects motor and coordination deficits (Schuhfried, 1992).

-Paced Auditory Serial Addition Test (PASAT): adaptation of original version (Gronwall, 1977). Stimuli are presented with a temporal interval of 3 seconds. The subject must say if every number heard is higher or lower than the previous one.

-Digit Span and Spatial Span (WMS-III) (Wechsler, 1997b).

Visuospatial, visuoperceptive and visuoconstructive functions

-Judgment of Line Orientation Test (JLOT, 15 items simplified version) (Benton, Hamsher, Varney, & Spreen, 1983).

-Facial Recognition Test (FRT, simplified version) (Benton et al., 1983).

-Block design subtest: Three designs of four cubes (5, 7, 9 designs) and three designs of nine cubes (10, 11, 12 designs) were selected, measured according to standard procedure, except for time bonuses (Wechsler, 1997a).

Executive functions

-Stroop Color and Word Test (Golden, 1978): This Stroop Test version includes an index to assess the interference related to the word–color conflict by comparing the subject's performance in the third sheet (Word–Color), with the same subject's performance in the other two neutral conditions (Word and Color sheets).

-Wisconsin Card Sorting Test (Heaton, 1981).

-Verbal fluency tasks: These tasks consist of asking the participants to rapidly generate words beginning by a given letter (phonemic fluency —FAS), to generate only animals (semantic fluency) (Benton & Hamsher, 1989), and to rapidly generate verbs (action fluency) (Piatt, Fields, Paolo, & Troster, 1999).

Learning and memory

-California Verbal Learning Test (CVLT) (Delis, Kramer, Kaplan, & Ober, 1987). The test includes learning over a five-trial presentation of a 16-word list, free and cued delayed recall and recognition.

-8/30 Spatial Recall Test (8/30 SRT): 7/24 SRT adaptation (Barbizet & Cany, 1968). Subjects must learn the spatial location of eight black circles displayed in a matrix from 6 x 5 boxes. When the sheet is removed the subject must place eight circles in the corresponding locations on an empty matrix. The test includes five trials of learning and two trials of delayed recall (short and long term).

Linguistic functions

-Actions and Noun Naming Test: a naming task of pictorial visual stimuli. The Noun Naming test consists of 40 stimuli taken from the work of Cuetos and colleagues (Cuetos, Ellis, & Álvarez, 1999). The Action Naming task consists of 20 stimuli (Druks & Masterson, 2000).

-Sentence Comprehension Test: based on studies by Grossman and colleagues (1992, 1999) and Skeel and colleagues (2001). The test consists of auditory stimuli-20 sentences presented on a PC, each followed by a question to assess their understanding. The level of syntactic complexity was manipulated as follows: 10 were simple sentences *(The bellboy greeted the slim receptionist. Who greeted? or Who was greeted?)* and 10 complex sentences with subordinate clause, in which the subject of the main clause is in turn the subject of the relative clause (The girl who pinched her cousin was naughty. *Who pinched? or Who was pinched?*

Data Analysis

Statistical comparisons were conducted using one-way analyses of variance (ANOVA). Correlational analyses were performed using Pearson´s correlation coefficient and linear regression analysis in order to examine the relation between cognitive functions. The level of statistical significance was established as $p < .05$. All the analyses were performed with SPSS-PC software version 15.0 for Windows.

Results

Processing speed, attention and working memory

In terms of reaction times, patients showed poorer performance in Motor Time, compared to controls, $F(1, 60) = 6.68$, $p = .012$. No difference was found in Decision Time, $F(1, 60) = 1.52$, $p = .22$. The PD group had significantly lower scores than controls in both the direct and inverse subtest in Spatial Span (direct: $F(1, 61) = 7.61$, $p = .008$; inverse: $F(1, 61) = 4.57$, $p = .037$). There were no differences between controls and patients in PASAT, $F(1, 61) = 0.01$, $p = .94$, and Digit Span (direct: $F(1, 61) = 0.08$, $p = .78$; inverse: $F(1, 61) = 1.88$, $p = .18$).

Visuospatial, visuoperceptive and visuoconstructive functions

The PD group performed significantly worse than the control group in the JLOT, $F(1, 60) = 7.69$, $p = .007$, on the FRT, $F(1, 60) = 12.47$, $p = .001$, and Block Design subtest, $F(1, 59) = 6.07$, $p = .017$.

Executive functions

The patients showed a poorer performance compared to controls in the Wisconsin categories and Action

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Fluency tests. No differences between groups were found in either Stroop interference or in Phonetic and Semantic Fluency (Table 2).

Learning and memory

As for verbal memory, patients showed a lower performance in learning as well as in free and cued short-term memory. A marginally significant difference was obtained between groups in free long-term memory. In addition, patients performed significantly worse than the control group in cued recall. In terms of visual memory, the PD group performed significantly worse in visuospatial learning compared to the control group. However, patients and controls did not differ in any of the visual recall measures (Table 3).

In order to control for the possible effects of executive functioning on memory performance participant`s scores on WCST and Action fluency were included as covariates and reanalyzed group differences. The ANCOVA showed that WCST performance only had a significant effect as a covariate on the free verbal short-term memory, $F(1, 59) = 5.247$, $p = .026$, and visuospatial learning, $F(1, 59) = 4.333$, $p = .042$. Nonetheless, WCST performance did not account for all the variance in these measures and significant between-groups differences remained (free verbal short-term memory, $F(1, 59) = 4.691$, $p = .005$, visuospatial learning, $F(1, 59) = 4.744$, $p = .005$).

Visual memory performance can be conditioned by spatial perception (JLOT) and spatial working memory (Spatial Span). A linear regression analysis was performed to determine the nature of these relationships. The results showed that JLOT and Spatial Span accounted for 32% of visuospatial learning variance in the PD group, $F(2, 40) = 8.80$, $p = .001$. In the controls, 37% of visuospatial learning variance was explained by JLOT, $F(1, 18) = 9.99$, $p = .001$ (Table 4).

Linguistic functions

Correct responses in the naming task were analyzed using repeated measures, with one within-subject factor (task, 2 levels) and one between-subject factor (group, 2 levels). There was a significant main effect of group, $F(1, 60) = 9.02$, $p < .001$, and task, $F(1, 60) = 17.59$,

Table 2. *Performance in executive functions*

	Patients (n = 43)		**Controls (n = 20)**		ANOVA test	
Variable	*M*	*SD*	*M*	*SD*	*F*	*p*
Stroop (Interference)	–2.60	6.73	–4.68	8.21	1.112	NS
Wisconsin (categories)	2.16	1.93	3.88	1.97	9.601	.003
Phonetic fluency (FAS)	22.58	9.54	25.47	9.55	1.211	NS
Semantic fluency (animals)	15.72	3.61	17.00	5.24	1.243	NS
Action fluency (verbs)	9.35	3.93	11.79	4.79	4.439	.039

Note: M: mean. *SD*: standard deviation. NS: not significant.

Table 3. *Performance in verbal memory and visuospatial memory*

	Patients (n = 43)		**Controls (n = 20)**		ANOVA test	
Variable	*M*	*SD*	*M*	*SD*	*F*	*p*
Verbal memory						
Learning (trial 5)	11.00	2.42	12.95	2.61	8.378	.005
Short term	9.10	3.41	11.25	3.99	4.843	.032
Short term- Semantic cued	10.12	2.70	12.35	3.22	8.174	.006
Long term	9.93	3.23	11.80	3.92	3.965	*.051*
Long term- Semantic cued	10.45	2.93	12.80	3.05	8.459	.005
Recognition	14.43	1.53	14.65	1.93	0.239	NS
Visuospatial memory						
Learning (trial 5)	5.57	2.12	6.89	1.37	6.198	.016
Short term	4.45	2.16	5.58	1.87	3.871	*.054*
Long term	4.76	2.05	5.74	1.97	3.040	NS

Note: M: mean. *SD*: standard deviation. NS: not significant.

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Table 4. *Regression analysis for memory and linguistic functions*

		Patients				Controls			
Visuospatial memory		R^2	β	pr^2	sr^2	R^2	β	pr^2	sr^2
	Global	.317*				.370*			
Learning	JLOT		.392*	.181	.151		.608*	.370	.370
	Spatial Span		.348*	.147	.118		.369	–	–
		Patients				**Controls**			
Linguistic functions		R^2	β	pr^2	sr^2	R^2	β	pr^2	sr^2
	Global	.220*				.214*			
Simple sentences	Digit Span		.469*	.220	.220		.462*	.214	.214
	PASAT		.145	–	–		.023	–	–
	Global	.121*				.397*			
Complex sentences	Digit Span		.348*	.121	.121		.630*	.397	.397
	PASAT		–.040	–	–		.259	–	–

Note: *$p < .05$.

$p < .001$, but no significant interaction between the two factors, $F(1,60) = 0.60$, $p = .44$. Patients performed poorly compared to controls in naming nouns and actions. Both patients and the control group subjects performed worse in the naming of actions (Figure 1). Analysis of errors showed that patients made more mistakes in all types of errors (perceptive, $F(1, 60) = 12.36$, $p = .001$, semantic, $F(1, 60) = 10.19$, $p = .002$, and mixed errors, $F(1, 60) = 5{,}71$, $p = .02$).

Performance in sentence comprehension was analyzed using repeated measures, with one within-subject factor (complexity, 2 levels) and one between-subject factor (group, 2 levels). There was a significant main effect of group, $F(1, 60) = 7.77$, $p = .007$, but no significant main effect of complexity, $F(1, 60) = 2.89$, $p = .09$, or significant interaction between the two factors, $F(1, 60) = 0.35$, $p = .56$. The PD group performed poorly on simple and complex sentences (Figure 2).

An ANCOVA was performed in order to statistically control for the possible effects of executive functions on linguistic functions. Group differences

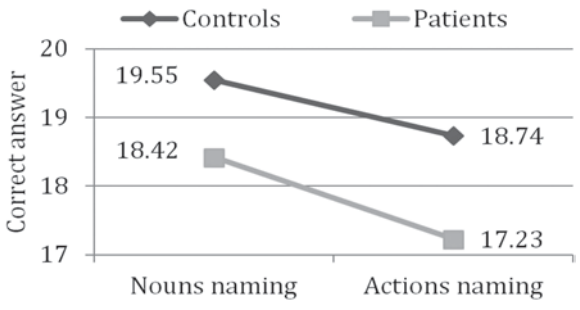


Figure 1. Performance in Actions and Nouns Naming Test.

in the linguistic tests were reanalyzed with participant's scores on the WCST and Action Fluency tests included as covariates. WCST performance had a significant effect as a covariate on Naming Nouns, $F(1, 60) = 8.623$, $p = .005$, Naming Actions, $F(1, 60) = 8.639$, $p = .005$, Simple Sentences, $F(1, 60) = 5.927$, $p = .018$, and Complex Sentences, $F(1, 60) = 7.206$, $p = .01$. Nonetheless, significant between-group differences remained in all cases (Naming Nouns, $F(1, 60) = 9.682$, $p < .001$, Naming Actions, $F(1, 60) = 7.837$, $p < .001$, Simple Sentences, $F(1, 60) = 5.625$, $p = .002$, and Complex Sentences, $F(1, 60) = 6.686$, $p = .001$).

Performance in sentence comprehension can be conditioned by attention (PASAT) and verbal working memory (Verbal Span). A linear regression analysis was carried out to determine the nature of these relationships. Results in the PD group showed that Verbal Span explained 22% of variance in Simple Sentences and 12.1% of the variance in Complex Sentences, $F(1, 41) = 11.56$, $p = .002$ and $F(1, 41) = 5.65$, $p = .022$ respectively. In the control group, Verbal Span accounted for 21% of the variance in Simple Sentences whereas PASAT explained 40% of the variance in Complex Sentences, $F(1, 18) = 4.62$, $p = .046$ and $F(1, 18) = 11.19$, $p = .004$ respectively (Table 4).

Cognitive performance and depression

Significantly higher scores on the BDI were obtained in patients than in controls (table 1). BDI was considered as a covariate in statistical analyses in order to control for the possible effects of depression on cognitive functions. Depression was not associated with any of the analyzed variables, with the exception of

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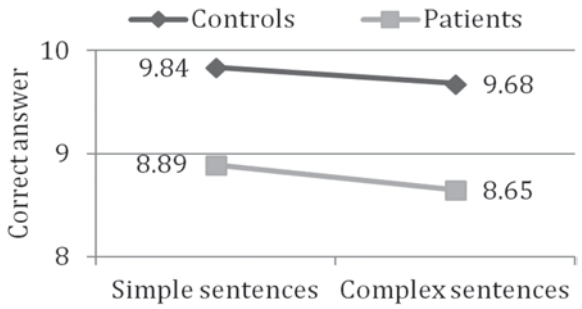


Figure 2. Performance in Sentences Comprehension Test.

Noun Naming (r = –.31; p = .04). Although depression had a significant effect as a covariate, $F(1, 60) = 6.01$, p = .017, between-group differences remained significant, $F(1, 60) = 7.22$, p = .009.

Discussion

The aim of this study was to examine the nature of the cognitive deficits associated with PD in depth. The results confirm the presence of motor slowing, along with alterations in visuospatial perception, visuoperceptive processing, visuoconstructive functions and spatial working memory.

In terms of executive functions, patients presented poor performance in the concept formation, set shifting and verb retrieval (WCST, Action Fluency), a result which coincides with those observed in other studies (Lees & Smith, 1983; Signorini & Volpato, 2006). However, performance was normal in usual measures of verbal fluency (Phonetic and Semantic) and in response inhibition. Consequently, generalized impairment of prefrontal functions was not observed. It is worth mentioning that there was normal achievement in one of the most studied tests -Phonetic Fluency- which has been strongly associated with executive functioning.

With regard to verbal declarative memory, patients showed a deficient performance in learning and delayed recall, both in free and cued tests (semantic cues). Verbal memory alterations in PD have traditionally been interpreted as deficits in the use of self-elaborated encoding strategies and information recovery (Caballol, Marti, & Tolosa, 2007; Pillon, Deweer, Agid, & Dubois, 1993). However, the results here do not support this hypothesis but agree with the findings of some recent investigations in which memory deficits persist even when external cues facilitating memory are provided (Higginson et al., 2005).

As regards visual declarative memory, patients presented deficits in visuospatial learning, although no alteration in delayed memory was observed. The extent to which alterations in spatial working memory and visuospatial perception could predict visuospatial learning performance was analyzed to examine these visual memory deficits more closely. These variables had considerable predictive power (patients: 32%; control group subjects: 37%), so it can be assumed that they play a relevant role in explaining visuospatial learning impairment. These results reinforce previous findings (Galtier, Nieto, Barroso, & Lorenzo, 2009).

In relation to linguistic functions, we assessed production through a visual Noun and Action Naming test which indicated deficient performance among patients was assessed. No differences have been reported in previous studies between naming nouns and actions in the control group and the lower performance for naming of actions in the patients. This finding has been interpreted as evidence for frontal impairment in PD (Cotelli et al., 2007; Rodriguez-Ferreiro, Menendez, Ribacoba, & Cuetos, 2009). In the present study, however, both the patients and control group performed worse in Action Naming, which brings into question whether this naming deficit is related to frontal dysfunction. On the other hand, it has been suggested that visuosperceptive deficit is a relevant factor in explaining alterations in the naming of pictorial material (Bertella et al., 2002). In the particular case of this study, the lack of predominance of perceptive errors would indicate that naming deficits among patients cannot be attributed to perceptive dysfunction.

Language comprehension was assessed with a Simple and Complex Sentence test, with patients' performance being altered in both types of sentence. The results of this study are consistent with those obtained by Skeel and colleagues (2001), where deficits are not limited to the comprehension of more complex sentences. Alterations in comprehension have been related to attentional difficulties, processing speed and working memory, and have been considered a consequence of executive resource limitations (Grossman et al., 1992; Hochstadt et al., 2006). Nevertheless, in the present study, patients did not show deficits in either attentional functions or in verbal working memory. Moreover, these variables did not have a greater predictive power in patients (12–22%) compared to the control group (21–40%), or a greater weight in complex sentences (12%), compared to simple ones (22%). If alterations in comprehension were a consequence of executive resource limitation, a greater involvement of working memory would be expected and the predictive power of working memory would be related to the level of sentence complexity. Thus, the results here do not indicate that comprehension deficits can be interpreted as a result of executive dysfunction.

In sum, the results of this work shed more light on the nature of cognitive deficits in PD questioning the

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idea that the neuropsychological profile associated with PD is exclusively a consequence of frontostriatal connection impairment. A generalized impairment of executive functions is not observed in the present study and the deficits observed in memory and language domains cannot be attributed to predominantly frontal impairment. The cognitive deficits observed are indicative of frontal dysfunction, but also of alterations in temporal and parietal functions and so one could consider that they cannot be reduced to an effect of dysfunction of frontostriatal circuits. In this sense, the findings of the present study are coherent with those from neuroimaging studies (Apostolova et al., 2012; Ibarretxe-Bilbao et al., 2009) and the contributions of Braak and colleagues (Braak, Rüb, & Del Tredici, 2006), which demonstrate that PD progression involves structural and metabolic changes that, after basal ganglia impairment, progressively affect medial temporal structures, limbic areas and other regions of the cerebral cortex. Further studies are needed to understand the cognitive heterogeneity of PD examining a wide range of cognitive domains and their relationship with neuroimaging data.

References

Apostolova L., Alves G., Hwang K. S., Babakchanian S., Bronnick K. S., Larsen J. P., ... M. K Beyer. (2012). Hippocampal and ventricular changes in Parkinson's disease mild cognitive impairment. *Neurobiology of Aging*, *33*, 2113–2124. http://dx.doi.org/10.1016/j.neurobiolaging.2011.06.014

Barbizet J., & Cany E. (1968). Clinical and psychometrical study of a patient with memory disturbances. *International Journal of Neurology*, *7*, 44–54.

Barone P., Aarsland D., Burn D., Emre M., Kulisevsky J., & Weintraub D. (2011). Cognitive impairment in nondemented Parkinson's disease. *Movement Disorders*, *26*, 2483–2495. http://dx.doi.org/10.1002/mds.23919.

Beck A. T., Ward C. H., Mendelson M., Mock J., & Erbaugh J. (1961). An inventory for measuring depression. *Archives of General Psychiatry*, *4*, 561–571. http://dx.doi.org/10.1001/archpsyc.1961.01710120031004 .

Benton A. L., & Hamsher K. (1989). *Multilingual aphasia examination* (2nd Ed.). Iowa City, IA: Department of Neurology and Psychology. The University of Iowa.

Benton A. L., Hamsher K. S., Varney N. R., & Spreen O. (1983). *Contributions of the neuropsychological assessment: A clinical manual*. New York: Oxford University Press.

Bertella L., Albani G., Greco E., Priano L., Mauro A., Marchi S., … Semenza C. (2002). Noun verb dissociation in Parkinson's disease. *Brain and Cognition*, *48*, 277–280.

Beyer M. K., Bronnick K. S., Hwang K. S., Bergsland N., Tysnes O. B., Larsen J. P., ... Apostolova L. G. (2013). Verbal memory is associated with structural hippocampal changes in newly diagnosed Parkinson's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, *84*, 23–28. http://dx.doi.org/10.1136/jnnp-2012-303054.

Blesa R., Pujol M., Aguilar M., Santacruz P., Bertran-Serra I., Hernández G., … NORMACODEM Group (2001). Clinical validity of the mini-mental state for Spanish speaking communities. *Neuropsychologica*, *39*, 1150–1157. http://dx.doi.org/10.1016/S0028-3932(01)00055-0

Braak H., Rüb U., & Del Tredici K. (2006). Cognitive decline correlates with neuropathological stage in Parkinson's disease. *Journal of the Neurological Sciences*, *248*, 255–258. http://dx.doi.org/10.1016/j.jns.2006.05.011 .

Brand M., Labudda K., Kalbe E., Hilker R., Emmans D., Fuchs G., ... Markowitscha H. J. (2004). Decision-making impairments in patients with Parkinson's disease. *Behavioral Neurology*, *15*, 77–85. http://dx.doi.org/10.1155/2004/578354

Caballol N., Marti M. J., & Tolosa E. (2007). Cognitive dysfunction and dementia in Parkinson disease. *Movement Disorders*, *22*, 358–366. http://dx.doi.org/10.1002/mds.21677.

Cotelli M., Borroni B., Manenti R., Zanetti M., Arevalo A., Cappa S. F., … Padovani A. (2007). Action and object naming in Parkinson's disease without dementia. *European Journal of Neurology*, *14*, 632–637. http://dx.doi.org/10.1111/j.1468-1331.2007.01797.x

Cuetos F., Ellis A., & Álvarez B. (1999). Naming times for the Snodgrass and Vanderwart pictures in Spanish. *Behavior, Research, Methods, Instruments, & Computers*, *31*, 650–658. http://dx.doi.org/10.3758/BF03200741

Delis D. C., Kramer J. H., Kaplan E., & Ober B. A. (1987). *California Verbal Learning Test. Research edition manual*. New York, NY: Psychological Corporation.

Druks J., & Masterson J. (2000). *Object and action naming batter*. Hove, UK: Psychology Press.

Dubois B., Burn D., Goetz C., Aarsland D., Brown R. G., Broe G. A., … Emre M. (2007). Diagnostic procedures for Parkinson's disease dementia: recommendations from the movement disorder society task force. *Movement disorders*, *22*, 2314–2324. http://dx.doi.org/10.1002/mds.21844

Emre M., Aarsland D., Brown R., Burn D. J., Duyckaerts C., Mizuno Y., ... Dubois B. (2007) Clinical diagnostic criteria for dementia associated with Parkinson's Disease. *Movement Disorders*, *22*, 1689–1707. http://dx.doi.org/10.1002/mds.21507.

Fahn S., & Elton R. L. (1987). Unified Parkinson's Disease Rating Scale. In: S. Fahn, C. D. Marsden, M. Goldstein, & D. B. Calne (Eds.), *Recent developments in Parkinson's disease*. (pp. 153–163). New York, NY: Macmillan.

Galtier I., Nieto A., Barroso J., & Lorenzo J. N. (2009). Visuospatial learning impairment in Parkinson disease. *Psicothema*, *21*, 21–26.

Golden C. J. (1978*). Stroop color and word test. A manual for clinical and experimental uses*. Illinois, IL: Stoelting Company.

Gronwall D. M. (1977). Paced auditory serial-addition task: A measure of recovery from concussion. Perceptual & Motor Skills, *44*, 367–373. http://dx.doi.org/10.2466/pms.1977.44.2.367

Grossman M. (1999). Sentence processing in Parkinson's disease. *Brain and Cognition*, *40*, 387–413. http://dx.doi.org/10.1006/brcg.1999.1087

https://doi.org/10.1017/sjp.2014.69 Published online by Cambridge University Press

Grossman M., Carvell S., Stern M. B., Gollomp S., & Hurtig H. I. (1992). Sentence comprehension in Parkinson's disease: The role of attention and memory. *Brain and Language*, *42*, 347–384. http://dx.doi.org/10.1016/0093-934X(92)90074-O

Heaton R. K. (1981). *Wisconsin Card Sorting Test manual*. Odessa: FL: Psychological assessment resources.

Higginson C. I., Wheelock V. L., Carroll K. E., & Sigvardt K. A. (2005). Recognition memory in Parkinson's disease with and without dementia: Evidence inconsistent with the retrieval deficit hypothesis. *Journal of Clinical and Experimental Neuropsychology*, *27*, 516–528. http://dx.doi.org/10.1080/13803390490515469

Hochstadt J., Nakano H., Lieberman P., & Friedman J. (2006). The roles of sequencing and verbal working memory in sentence comprehension deficits in Parkinson's disease. *Brain and Language*, *97*, 243–257. http://dx.doi.org/10.1016/j.bandl.2005.10.011

Hoehn M. M., & Yahr M. D. (1967). Parkinsonism: Onset, progression and mortality. *Neurology*, *17*, 427–442. http://dx.doi.org/10.1212/WNL.17.5.427

Hughes A. J., Daniel S. E., Kilford L., & Lees A. J. (1992). Accuracy of clinical diagnosis of idiopathic Parkinson's disease: A clinico-pathological study of 100 cases. *Journal of Neurology, Neurosurgery, and Psychiatry*, *55*, 181–184. http://dx.doi.org/10.1136/jnnp.55.3.181

Ibarretxe-Bilbao N., Tolosa E., Junque C., & Marti M. J. (2009). MRI and cognitive impairment in Parkinson's disease. *Movement Disorders*, *24*, 748–753. http://dx.doi.org/10.1002/mds.22670.

Jokinen P., Bruck A., Aalto S., Forsback S., Parkkola R., & Rinne J. O. (2009). Impaired cognitive performance in Parkinson's disease is related to caudate dopaminergic hypofunction and hippocampal atrophy. *Parkinsonism & Related Disorders*, *15*, 88–93. http://dx.doi.org/10.1016/j.parkreldis.2008.03.005.

Lees A. J., & Smith E. (1983). Cognitive deficits in the early stages of Parkinson's disease. *Brain*, *106*, 257–270. http://dx.doi.org/10.1093/brain/106.2.257

Liozidou A., Potagas C., Papageorgiou S. G., & Zalonis I. (2012). The role of working memory and information processing speed on Wisconsin Card Sorting Test performance in Parkinson disease without dementia. *Journal of Geriatric Psychiatry and Neurology*, *25*, 215–221. http://dx.doi.org/10.1177/0891988712466456

Muslimovic D., Post B., Speelman J. D., & Schmand B. (2007). Motor procedural learning in Parkinson's disease. *Brain*, *130*, 2887–2897. http://dx.doi.org/10.1093/brain/awm211

Obeso I., Casabona E., Bringas M. L., Alvarez L., & Jahanshahi M. (2012). Semantic and phonemic verbal fluency in Parkinson's disease: Influence of clinical and demographic variables. *Behavioural Neurology*, *25*, 111–118. http://dx.doi.org/10.1155/2012/673610

Pereira J. B., Junque C., Marti M. J., Ramirez-Ruiz B., Bargallo N., & Tolosa E. (2009). Neuroanatomical substrate of visuospatial and visuoperceptual impairment in Parkinson's disease. *Movement Disorders*, *24*, 1193–1199. http://dx.doi.org/10.1002/mds.22560

Piatt A. L., Fields J. A., Paolo A. M., Koller W. C., & Troster A. I. (1999) Lexical, semantic, and action verbal fluency in Parkinson's disease with and without dementia. *Journal of Clinical and Experimental Neuropsychology*, *21*, 435–443. http://dx.doi.org/10.5555/jcen.21.4.435.885

Piatt A. L., Fields J. A., Paolo A. M., & Troster A. I. (1999). Action (verb naming) fluency as an executive function measure: Convergent and divergent evidence of validity. *Neuropsychologia*, *37*, 1499–1503. http://dx.doi.org/10.1016/S0028-3932(99)00066-4

Pillon B., Deweer B., Agid Y., & Dubois B. (1993). Explicit memory in Alzheimer's, Huntington's, and Parkinson's diseases. *Archives of Neurology*, *50*, 374–379. http://dx.doi.org/10.1001/archneur.1993.00540040036010

Rodriguez-Ferreiro J., Menendez M., Ribacoba R., & Cuetos F. (2009). Action naming is impaired in Parkinson disease patients. *Neuropsychologia*, *47*, 3271–3274. http://dx.doi.org/10.1016/j.neuropsychologia.2009.07.007

Schneider J. S. (2007). Behavioral persistence deficit in Parkinson's disease patients. *European Journal of Neurology*, *14*, 300–304. http://dx.doi.org/10.1111/j.1468-1331.2006.01647.x

Schuhfried G. (1992). *Vienna reaction unit (manual)*. Vienna, Austria: Schuhfried Ges.m.b.H.

Signorini M., & Volpato C. (2006). Action fluency in Parkinson's disease: A follow-up study. *Movement Disorders*, *21*, 467–472. http://dx.doi.org/10.1002/mds.20718.

Skeel R. L., Crosson B., Nadeau S. E., Algina J., Bauer R. M., & Fennell E. B. (2001). Basal ganglia dysfunction, working memory, and sentence comprehension in patients with Parkinson's disease. *Neuropsychologia*, *39*, 962–971. http://dx.doi.org/10.1016/S0028-3932(01)00026-4

Stefanova E. D., Kostic V. S., Ziropadja L. J., Ocic G. G., & Markovic M. (2001). Declarative memory in early Parkinson's disease: Serial position learning effects. *Journal of Clinical and Experimental Neuropsychology*, *23*, 581–591. http://dx.doi.org/10.1076/jcen.23.5.581.1239

Tröster A. I., & Fields J. A. (2005). Frontal cognitive function and memory in Parkinson's disease: Toward a distinction between prospective and declarative memory impairments. *Behavioral Neurology*, *8*, 59–74. http://dx.doi.org/10.3233/BEN-1995-8201

Uc E. Y., Rizzo M., Anderson S. W., Qian S., Rodnitzky R. L., & Dawson J. D. (2005). Visual dysfunction in Parkinson disease without dementia. *Neurology*, *65*, 1907–1913. http://dx.doi.org/10.1212/01.wnl.0000191565.11065.11.

Wechsler D. (1997a). *Wechsler Adult Intelligence Scale (3rd Ed.). Administration and scoring manual*. San Antonio, TX: The Psychological Corporation.

Wechsler D. (1997b). *Wechsler Memory Scale (3rd Ed.). Technical manual*. San Antonio, TX: The Psychological Corporation.

Whittington C. J., Podd J., & Stewart-Williams S. (2006). Memory deficits in Parkinson's disease. *Journal of Clinical and Experimental Neuropsychology*, *28*, 738–754. http://dx.doi.org/10.1080/13803390590954236.

Witt K., Nuhsman A., & Deuschl G. (2002). Dissociation of habit-learning in Parkinson's and cerebellar disease. *Journal of cognitive neuroscience*, *14*, 493–499. http://dx.doi.org/10.1162/089892902317362001.

https://doi.org/10.1017/sjp.2014.69 Published online by Cambridge University Press