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ORIGINAL COMMUNICATION

Characterization of cognitive and motor performance during dual-tasking in healthy older adults and patients with Parkinson's disease

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Abstract The primary purpose of this study was to investigate the effect of dual-tasking on cognitive performance and gait parameters in patients with idiopathic Parkinson's disease (PD) without dementia. The impact of cognitive task complexity on cognition and walking was also examined. Eighteen patients with PD (ages 53–88, 10 women; Hoehn and Yahr stage I-II) and 18 older adults (ages 61–84; 10 women) completed two neuropsychological measures of executive function/attention (the Stroop Test and Wisconsin Card Sorting Test). Cognitive performance and gait parameters related to functional mobility of stride were measured under single (cognitive task only) and dual-task (cognitive task during walking) conditions with different levels of difficulty and different types of stimuli. In addition, dual-task cognitive costs were calculated. Although cognitive performance showed no significant difference between controls and PD patients during single or dual-tasking conditions, only the patients had a decrease in cognitive performance during walking. Gait parameters of patients differed significantly from controls at single and dual-task conditions, indicating that patients gave priority to gait while cognitive performance suffered. Dual-task cognitive costs of patients increased with task complexity, reaching significantly higher values then controls in the arithmetic task, which was correlated with scores on executive function/attention (Stroop Color-Word Page). Baseline motor functioning and task executive/attentional load affect the performance of cognitive tasks of PD patients while walking. These findings provide insight into the functional strategies used by PD patients in the initial phases of the disease to manage dual-task interference.

Keywords Parkinson's disease · Dual-task · Cognition · Gait

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Introduction

In addition to classical motor symptoms, Parkinson's disease (PD) is associated with a variety of cognitive deficits that begin to appear in the earliest stages of the disease. These deficits encompass executive function, attention, memory, language, and visuospatial aspects [1–3] which can significantly interfere with occupational and social functioning. Tasks that require the simultaneous performance of two or more cognitive functions along with motor activities (e.g., walking and talking on the phone or walking while rehearsing a shopping list) can be particularly affected. Specific cognitive features, such as set shifting, divided or alternating attention and executive function have been specifically associated with impairments in "dual-tasking" ability in PD patients [4–6]. While dual-tasking deficits do not independently predict the likelihood of falls, they are linked to gait parameters associated with falling [7]. Deficits in performing a cognitive task while walking may uncover problems not apparent under single-task conditions, and may be a more sensitive assessment of everyday cognitive impairments in patients in the initial stages of PD, with mild symptom severity and discrete neuropsychological deficits.

The ability to walk while performing another task can have a significant influence on cognition, gait and mobility. Dual-task impairments in PD patients have been observed during standing [8, 9] and gait tasks. Both PD patients and elderly controls demonstrate shorter strides, less time in the swing phase, and lower functional ambulation values than healthy younger controls [10]. Decrements in performance from single-task to dual-task cognitive scores have been related to "prioritization" of gait in a system that has limited processing capacity [11]. However, the majority of previous studies on motor–cognition dual-task performance were primarily designed to investigated dual-task interference on gait parameters, resulting in a scanty characterization of dual-task interference on cognition in PD.

The current study characterized changes in cognitive performance under single- and dual-task conditions with different levels of task difficulty and different types of stimuli (i.e., text comprehension, phoneme monitoring and mathematical subtractions) in PD patients in the initial phases of the disease and in elderly healthy controls. In addition, motor performance of participants was determined by means of stride-related measures (speed, average swing time and relative stance time). Associations between two specific neuropsychological measures (executive function and divided attention) previously demonstrated to be related to dual-task performance were also tested. It was hypothesized that PD patients would not only alter gait parameters to a greater extent, but would also perform worse on cognitive tasks during dual-task conditions, and that such dual-task interference would be greater for tasks demanding greater attention. Additionally, whether cognitive–motor performance during dual-task conditions was affected to a greater extent in PD patients than in controls was investigated.

Methods

Participants

Participants in this study included 18 older adults diagnosed with idiopathic PD (ages 53–88; 10 women) from the Movement Disorders Clinic at the Hospital de Clínicas de Porto Alegre (Porto Alegre, Brazil) and 18 adult controls (ages 61–84; 10 women) recruited from the community. Inclusion criteria for patients comprised a clinical diagnosis of PD according to the UK Parkinson's Disease Society Brain Bank [12] and the absence of balance alterations (indicated by scores below 3 in Hoehn and Yahr's classification system [13]). Thus, advanced PD patients were not included.

All patients were taking dopamine precursors either alone (levodopa + carbidopa, $n = 8$ or Levodopa + benserazide chloridrate, $n = 5$), or in combination with amantadine alone (levodopa + carbidopa plus amantadine $n = 1$, Levodopa + benserazide chloridrate plus amantadine, $n = 1$), amantadine and dopaminergic agonists (levodopa + carbidopa plus amantadine plus bromocriptine, $n = 1$; levodopa + carbidopa plus amantadine plus pramipexole dihydrochloride, $n = 1$) or amantadine and anticholinergic drugs (levodopa + carbidopa plus amantadine plus trihexyphenidyl hydrochloride, $n = 1$). Patients were not required to abstain from medication prior to testing.

Exclusion criteria for PD patients and controls included the use of psychotropic medication (except for treatment of PD complications), neurological disorders (other than PD) and injuries with known significant effects on cognitive functioning (e.g., traumatic brain injury, multiple sclerosis, stroke), major unstable medical illnesses (e.g., metastatic cancer), history of neurosurgical procedure, inability to ambulate independently, past history of disorders affecting gait or posture (except PD), cognitive deficits as evidenced by the Mini Mental Status Examination (cut-off adjusted for education) [14], scores on the Beck Depression Inventory (BDI) [15] indicating severe depressive symptoms and visual and hearing impairment incompatible with the neuropsychological tests.

Motor functioning of PD patients was rated with the Unified Parkinson's Disease Rating Scale part III (UPDRS III) [16]. Neuropsychological and gait assessments were made only during the "on" medication phase.

The current study was approved by the Research Ethics Committee of the Hospital de Clínicas de Porto Alegre (Porto Alegre, Brazil) and have therefore been performed in accordance with the ethical standards of the 1964 Declaration of Helsinki. All participants gave informed consent.

Neuropsychological assessment

Participants completed neuropsychological tests to compare cognitive ability across experimental groups. Tests included the Wisconsin Card Sorting Test-64 card computer version (WCST) [17] and the Golden version of the Stroop Color and Word Test [18] for executive function assessment. Previous studies have demonstrated that executive functioning (e.g., inhibition processes, the capacity to divide attention and shift between two concurrent tasks) [19] is involved in dual-task performance [20].

The Wisconsin Card Sorting Test requires participants to use trial and feedback to determine how to sort a deck of cards on the basis of four stimulus cards that vary on such parameters as number, colour and shape of symbol [17]. Scores were tallied along several dimensions. In this study the number of categories performed correctly, the number of perseverative errors and a global score were reported. The number of categories (ranging from 0 to 6) is one of the most commonly reported measures [21] and is a good general measure of executive function [22]. Together the completed categories and perseverative errors are among the most sensitive parameters to identify PD impairment relative to healthy older adults [23]. Additionally, a global score that allows capturing, in a single measure, the combined information of number of categories completed, number of trials administered, percent conceptual level responses and total number of errors, was calculated as follows: Global score = [no of trials−(no of achieved categories × 10)] [24].

The Stroop Color and Word Test measures the ability to shift perceptual set to conform to changing demands and to suppress a habitual response in favor of an unusual one [25]. In brief, the test consists of a Word Page with color words (e.g., “pink”, “green”, “blue”) printed in black ink, a Color Page with Xs printed in either pink, green, or blue ink, and a Color-Word Page with words from the first page (“pink”, “green”, “blue”) printed in colors from the second page such that the color and the word do not match. For example, the word “pink” may be printed in blue ink. The test yields three scores based on the number of correct responses on each of the three stimulus sheets [18].

Dual-task assessment

Three cognitive tasks adapted from the protocol developed by Yogev et al. [20] were performed: (1) text comprehension: the subject listened to a story through earphones; (2) phoneme counting: the subject listened to a different story through earphones and counted the number of times a predetermined phoneme was heard; (3) arithmetic task: subjects were asked to perform serial 7 subtractions aloud. Text comprehension was scored as a percent of correct responses on a multiple-choice questionnaire. Phoneme counting performance was measured as the percent of total phonemes in the text counted by the subject. Performance on the arithmetic task was measured by the total correct serial subtractions. Each of the cognitive tasks was performed while sitting (baseline cognition) and while walking (dual-task cognition), as described below.

The effects of dual-tasking (performing a cognitive task during walking) on cognition were analyzed under three walking conditions: (1) text comprehension during walking; (2) phoneme counting during walking, and (3) arithmetic task during walking. The only instruction participants received was to walk at a comfortable rhythm while performing the cognitive tasks. The texts presented at baseline and dual-task conditions were different and the serial subtractions were initiated with different numbers in the two conditions (300 while sitting and 234 while walking).

The ability of controls and PD patients to execute two tasks concurrently was further analyzed to investigate the effect of gait on cognitive performance. For this purpose dual task cost (DTC) was calculated for each subject and condition as follows: DTC (%) = 100 × (single-task cognitive score−dual-task cognitive score)/single-task cognitive score [26].

Gait assessment

Gait was assessed under baseline conditions (walking only) and dual-tasking conditions (walking while performing each of the cognitive tasks) in order to identify possible relationships between cognitive performance during dual-tasking and gait parameters (stride length and frequency, average swing time, average support phase, speed and relative stance time). Participants walked down a nine-meter corridor and gait parameters were obtained by kinemetry with a fixed camera (JVC GR-DVL 9800—JVC Company of America, Wayne, NJ, USA—50 Hz) positioned laterally to the corridor at a distance of 4 m from where the individual passed, a spotlight and a two-dimensional gauge. Reflective markers were placed on the following anatomical landmarks: fifth metatarsal, calcaneus, lateral malleolus, lateral femoral epicondyle, greater trochanter.

The movement analysis system Dvideow (Digital Video for Biomechanics, developed by Instrumentation Laboratory for Biomechanics, Faculty of Physical Education, UNICAMP, Campinas, Brazil, Version 5.0) was used for two-dimensional analysis (2D) of a stride cycle (first touch from the right foot on the ground until the next touch of the same foot on the ground). Coordinate evaluation was made point by point on the digitalized images and the movement analysis system calculated and monitored the bidimensional positions of the reflective markers. The data processing was carried out with Labview 85 software.

For simplicity, only average swing time, gait speed (stride length multiplied by the stride frequency) and relative stance time (support time divided by stride time) are reported and discussed. These parameters were chosen due to their prior proven validity as predictors of gait automaticity, stability and protective adjustments during dual-tasks [27–30].

Statistical analysis

Independent Student's *t*-tests and chi-square tests were used to compare demographic and neuropsychological characteristics of the PD patients and control subjects. Between-group performance on cognitive tasks was analyzed with independent Student's *t*-tests and comparisons of dual-tasking effects on cognitive performances of controls and PD patients were analyzed with dependent sample *t*-tests. Between-group differences in performance on cognitive tasks at baseline and during each of the dual-tasking conditions (text comprehension, phoneme monitoring and mathematical subtractions) were examined by independent *t*-tests. Repeated measures analysis of variance (ANOVA) was used to examine differences between groups (healthy older adults versus PD patients) and type of task (baseline walking, walking + text comprehension, walking + phoneme monitoring, walking + mathematical subtractions) on stride parameters (relative stance time, speed, average swing time). Multiple comparisons among group mean differences were checked with Tukey post hoc tests. Independent and paired samples *t*-tests were used whenever appropriate (confidence interval adjustments with Bonferroni corrections). Raw data of the arithmetic task were submitted to mathematical transformation (square root) to meet the assumptions of parametric tests. Results are expressed as mean ± standard error, and $P < 0.05$ was considered statistically significant.

Results

Table 1 summarizes the demographic and neuropsychological characteristics of all participants. Groups did not significantly differ in age ($t = -0.037$, $df = 25.940$, $p = 0.971$), gender (Pearson chi-Square = 0, $p = 1.00$), years of education ($t = -0.522$, $df = 34$ $p = 0.605$), as well as on the BDI score ($t = 1.596$, $df = 34$, $p = 0.120$) and MMSE ($t = -1.195$, $df = 34$, $p = 0.240$) scores. Overall, PD patients performed worst than controls on the WCST parameters. However, only scores for completed categories differed significantly between groups ($t = -2.043$, $df = 34$, $p = 0.049$). PD patients also scored significantly lower than controls on the Stroop Color-Word Page ($t = -2.365$, $df = 34$, $p = 0.024$). However, groups did not significantly differ in performance on the Stroop Word ($t = -0.433$, $df = 34$, $p = 0.688$) or Color ($t = -1.157$, $df = 34$, $p = 0.255$) pages.

Performance on cognitive tasks during baseline (sitting) and dual-tasking (during walking) is displayed in Table 2. There were no significant differences between PD patients and controls in baseline text comprehension ($t = 0.887$, $df = 34$, $p = 0.381$), phoneme counting ($t = 0.856$, $df = 34$, $p = 0.398$) and arithmetic task ($t = 0.277$, $df = 34$, $p = 0.783$). Controls and PD patients also showed similar cognitive performances during dual tasking, since no significant differences were found between groups during walking in text comprehension ($t = -1.204$, $df = 34$, $p = 0.234$), phoneme counting ($t = -0.891$, $df = 34$, $p = 0.379$) and arithmetic task ($t = -0.825$, $df = 34$, $p = 0.415$). However, performance on text comprehension ($t = 2.997$, $df = 17$, $p = 0.008$), phoneme counting ($t = 2.870$, $df = 17$, $p = 0.011$) and the arithmetic task ($t = 2.596$, $df = 17$, $p = 0.019$) was significantly decreased in the dual-tasking condition compared to the baseline condition in PD patients, although the effect sizes were small. Control participants, on the other hand, showed no significant alterations in cognitive performance during dual-tasking as compared to baseline. While there were no significant differences in cognitive performance between controls and PD patients during baseline or dual-tasking conditions, these results indicate a greater difficulty for PD patients to perform dual-tasks, since cognitive performance decreased with walking (all p values <0.05). PD is associated with gait alterations [31, 32] and a growing body of evidence suggests that gait requires attention resources during dual-tasking [33–35] and therefore this issue was further investigated.

Gait parameters during baseline (walking only) and dual-tasking (walking while performing cognitive tasks) are displayed in Table 3. There were significant differences between PD patients and controls in relative stance time [$F(1,34) = 14.74$, $p = 0.01$) and gait speed [$F(1,34) = 10.39$, $p = 0.03$]. Independent sample t-tests found PD patients to have a longer relative stance time and slower speed than controls during both baseline and all dual-task conditions (all p values <0.05). PD patients and controls did not significantly differ in swing time [$F(1,34) = 0.45$, $p = 0.5$], indicating the absence of differences in this gait parameter between controls and PD patients at the different walking conditions, as confirmed with independent t tests (all p values >0.05).

Table 1 Demographic and neuropsychological measures for healthy controls and PD patients

	Controls ($n = 18$)	PD ($n = 18$)	*P* value
Age (years)	69.44 ± 1.41	69.33 ± 2.65	0.971
Gender (female/male)	10/8	10/8	1.00
Education (years)	6.72 ± 0.68	6.22 ± 0.67	0.605
BDI	3.72 ± 0.83	6.94 ± 1.86	0.122
MMSE	27.06 ± 0.31	26.39 ± 0.46	0.242
Hoehn and Yahr stage	–	1.97 ± 0.36	–
Disease duration (years)	–	8.39 ± 2.85	–
UPDRS (part III)	–	16.22 ± 7.88	–
WCST (categories completed)	1.22 ± 0.25	0.61 ± 0.16	0.049
WCST (perseverative errors)	13.56 ± 1.14	15.95 ± 2.2	0.34
WCST (global score)	19.17 ± 7.50	38.83 ± 6.77	0.06
Stroop Word Page	69.28 ± 3.56	67.00 ± 3.87	0.668
Stroop Color Page	50.89 ± 1.98	46.89 ± 2.83	0.255
Stroop Color-Word Page	27.94 ± 2.1	21.83 ± 1.51	0.024

Results are expressed as mean ± standard error (SEM), except for sex (female/male proportion)

MMSE Mini Mental Status Examination, *UPDRS* Unified Parkinson's Disease Rating Scale, *BDI* Beck Depression Inventory, *WCST* Wisconsin Card Sorting Test

Table 2 Subjects performance for cognitive tasks in baseline (sitting) and dual tasking (during walking) conditions

Tasks performance	Patients	Controls	Patients × controls (P value)	Single × dual task	
				Patients (*P* value)	Controls (*P* value)
Text comprehension (single-task)	78.33 ± 3.63	73.88 ± 3.44	0.38	0.008	0.82
Text comprehension (dual-task)	65.55 ± 4.21	72.77 ± 4.26	0.23	0.008	0.82
Phoneme counting (single-task)	47.99 ± 6.05	40.94 ± 5.57	0.39	0.011	0.49
Phoneme counting (dual-task)	30.94 ± 3.87	36.50 ± 4.89	0.37	0.011	0.49
Arithmetic task (single-task)	3.94 ± 0.72	3.50 ± 0.58	0.78	0.019	0.47
Arithmetic task (dual-task)	2.77 ± 0.69	3.72 ± 0.93	0.41	0.019	0.47

Comparison between patients and control were performed with independent Student's *t*-test. Comparisons between single and dual task conditions for each cognitive task and group were performed with dependent Student's *t*-test. Results are expressed as mean ± standard error

Table 3 Gait parameters at baseline and dual tasking conditions in controls and PD patients

	Relative stance time	*P*	Speed	*P*	Average swing time	*P*
Baseline gait						
Control	0.61 ± 0.005	<0.01	4.36 ± 0.175	<0.01	0.44 ± 0.007	0.97
Parkinson	0.64 ± 0.006		3.22 ± 0.191		0.44 ± 0.015	
Gait/text comprehension						
Control	0.62 ± 0.006	<0.01	3.91 ± 0,20	0.01	0.46 ± 0.01	0.32
Parkinson	0.65 ± 0.005		3.13 ± 0.21		0.44 ± 0.01	
Gait/phoneme counting						
Control	0.63 ± 0.005	0.01	3.81 ± 0.20	0.03	0.44 ± 0.01	0.26
Parkinson	0.66 ± 0.010		3.10 ± 0.23		0.42 ± 0.02	
Gait/arithmetic task						
Control	0.64 ± 0.010	0.02	3.31 ± 0.30	0.01	0.48 ± 0.014	0.85
Parkinson	0.67 ± 0.011		2.25 ± 0.20		0.48 ± 0.025	

Results are expressed as mean ± standard error

Relative stance time [$F(3,102) = 12.57$, $p < 0.01$], speed [$F(3,102) = 46.02$, $p = 0.003$] and average swing time [$F(3,102) = 8.64$, $p < 0.01$] were all significantly affected by condition. Bonferroni confidence interval adjustments of paired *t*-tests confirm the greatest dual-task gait alteration in the control group relative to baseline values occurred under the arithmetic task condition, in which the relative stance time ($p = 0.012$) and average swing time ($p = 0.009$) significantly increased and the gait speed significantly decreased ($p < 0.001$) Fig. 1a). A

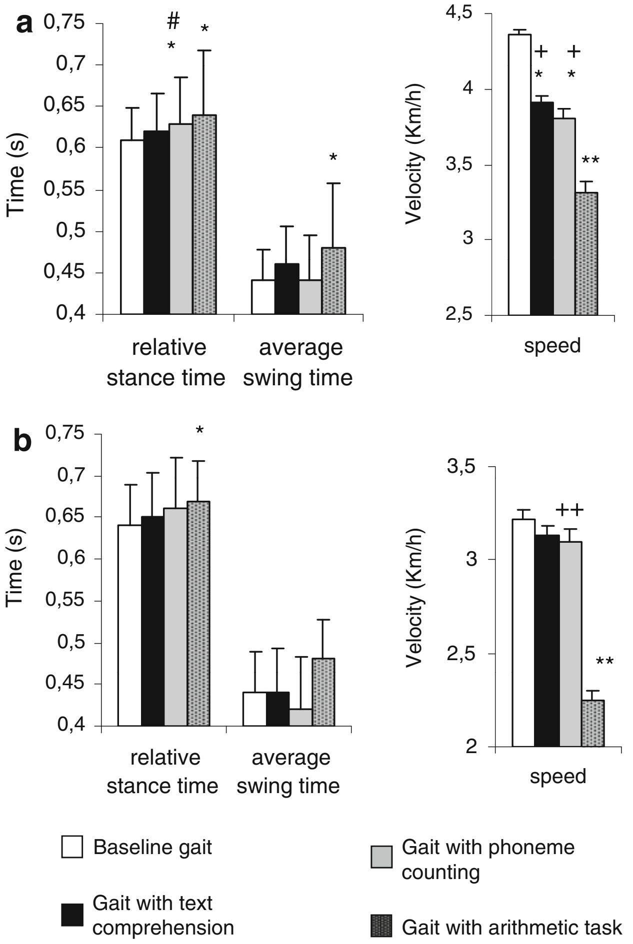

Fig. 1 Effect of simultaneous activities on relative stance time (s), average swing time (s) and speed (km/h) of controls (**a**) and patients (**b**). Results are expressed as mean ± standard error. $*p < 0.05$ and $**p < 0.001$ in relation to the baseline gait. $^{+}p < 0.05$, $^{++}p < 0.001$ and $^{\#}p = 1$ in relation to arithmetic task condition

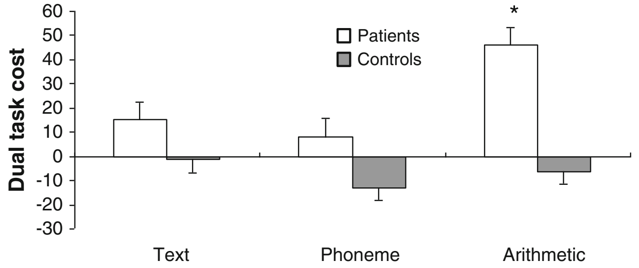

Fig. 2 Dual task cost. DTC values ranged from negative values in controls (indicating that gait did not impose any additional cost to cognitive performance) to positive values in PD patients (suggesting that walking can impair concurrent cognitive tasks). Although PD patients showed larger DTCs than control participants, only arithmetic DTC reached statistical significance. Results are expressed as mean ± standard error. $*p = 0.031$ compare arithmetic DTC in patients and controls

similar increase of relative stance time also occurred in the phoneme counting condition ($p = 0.03$ in relation to baseline and $p = 1$ in relation to the arithmetic task condition) and smaller speed alterations were found in the text comprehension task ($p = 0.005$ in relation to baseline and $p = 0.027$ in relation to arithmetic task conditions) and the phoneme counting conditions ($p = 0.003$ in relation to the baseline condition and $p = 0.036$ in relation to arithmetic task conditions). PD patients showed gait adjustments only in the arithmetic task condition, in which a decrease in speed ($p < 0.001$) and an increase in relative stance time ($p = 0.014$) were found, as shown by Bonferroni confidence interval adjustments (Fig. 1b).

Parkinson's disease patients significantly differed from controls in gait at baseline and throughout the different dual-task conditions. To further investigate the effect of gait on PD patient cognitive performance the ability to execute two tasks concurrently was quantified. Thus, the dual task cost (DTC) was calculated. Overall, PD patients had larger DTCs than control participants. However, only the arithmetic DTC differed significantly between the groups ($p = 0.031$) (Fig. 2). We next analyzed whether DTCs and the decrease in cognitive performance of PD patients during the dual-task conditions were related to executive and attention dysfunctions (since PD patients scored lower on the completed categories of WCST and Stroop Color-Word Page relative to controls) and/or to gait alterations (PD patients demonstrated greater effort than controls in maintaining stability in all experimental conditions). We thus performed correlation analyses exploring relationships between performance on different cognitive tasks during walking and neuropsychological test scores (WCST completed categories and Stroop Color-Word Page) and gait parameters. A correlation analysis was also performed for DTC and neuropsychological test scores (scores of WCST completed categories and Stroop Color-Word Page) or gait parameters. The gait parameters introduced in the correlation analysis were relative stance time and speed, since they were significantly different between groups in all experimental conditions.

No significant correlations were found for the different cognitive parameters (text comprehension, phoneme counting, arithmetic task) during walking and WCST scores (all p values >0.05). Performance on the Stroop Color-Word Page was significantly correlated with the serial subtractions dual-task ($r = 0.35$, $p = 0.036$). No significant correlations were found for relative stance time and cognitive parameters during walking (all p values >0.05), or for gait speed and cognitive performance in dual-tasks (all p values >0.05). There were no significant correlations between DTCs for the different cognitive tasks and scores on WCST (all p values >0.05) nor between DTCs and performance on the Stroop Color-Word Page (all

p values >0.05) or between gait parameters (relative stance time and gait speed) and DTCs for the different cognitive tasks during walking (all p values >0.05).

Discussion

The aim of the present study was to compare the ability of performing cognitive tasks while walking in PD patients and healthy elderly controls under different combinations of a cognitive-only and a cognitive-walking task. We sought to determine which task characteristics contribute to impairments in cognitive performance and to identify associations between cognitive performance, general motor parameters and cognitive measures.

Cognitive performance was decreased in PD patients during all dual-tasking conditions (i.e., phoneme monitoring, text comprehension and arithmetic test) compared to baseline cognitive-only testing. Alternatively, cognitive performance of healthy controls did not significantly differ between baseline and dual-tasking conditions. Relative dual-task cognitive costs were greater for PD patients compared to controls in all dual-tasking conditions, however statistical significance was reached only in the arithmetic-walking condition. Changes in gait parameters under dual-tasking conditions were affected by task complexity to a greater extent in healthy controls than in PD patients. Control participants exhibited a progressive decrease in gait speed and increase in average swing time from baseline to text comprehension and phoneme monitoring and to the arithmetic task. Gait adjustment was only significantly affected under the arithmetic-walking condition in patients with PD.

Significant between-group differences in the single-task walking condition confirm previous findings that PD patients demonstrate single-task walking deficits, even during the “on” cycle of medication. Poor performance on single-task measures of balance and functional mobility have previously been associated with increased axial rigidity in patients with Hoehn and Yahr scores of 2 or 3, [36] along with reduced movement amplitude across all lower limb joints, in all movement planes [37]. In addition, the current findings are consistent with prior studies showing that, under dual-tasking conditions, healthy older adults and PD patients demonstrate alterations in several gait parameters, such as reduced gait velocity and step length, [27, 38–41] increased stride-to-stride variability [42] and more freezing episodes [43] when compared to walking alone. Multiple mechanisms may be responsible for interference between walking and concurrent cognitive or motor tasks in people with PD (for a review see Kelly et al. [11]). Nonspecific mechanisms include theoretical information processing frameworks, such as the capacity theory [44] and the bottleneck theory [45]. These theories postulate that dual-task interference occurs when two tasks compete for attention from the same system leading to deterioration in performance of one or both tasks. PD-specific deficits include reduced movement automaticity, dopamine-mediated dysfunction of the basal ganglia and the presence of nondopaminergic pathology, which may affect both gait and cognition.

The current results indicate that healthy controls adjust gait under dual-tasking in order to maintain cognitive performance while adjusting gait according to increasing executive load. PD patients, on the other hand, gave priority to gait while cognitive performance suffered. There were no significant differences between PD patients and healthy controls in cognitive task performance at baseline, indicating that both groups were equally capable of performing the tasks, and hence emphasizing the disrupting effect of motor deficits on dual-tasking specific to PD patients. In the present study, it is possible that PD patients concentrated on gait even during the baseline walking-only condition, and thus demonstrated less gait adjustment during dual-tasking than the healthy controls. The lower performance on gait parameters of PD patients in relation to controls may not necessarily be indicative of postural instability or pathologically impaired central processing capacity, but rather as a form of ‘‘prudent’’ behavior intended to maintain balance over execution of the “secondary” mental task [46].

The greater DTC observed in PD patients was not associated with all tasks, and was specifically influenced by task nature and difficulty. Previous research in frail older adults has indicated that mathematical subtraction (which relies more on working memory) generates a greater cognitive load than, for example, verbal fluency (which relies more on semantic memory) [47]. Furthermore, language tasks impact gait performance in PD patients differently than mathematics tasks [48], and PD patients are more severely affected by more demanding cognitive tasks than healthy controls [41], as the arithmetic task in our study.

Previous studies have demonstrated that walking deficits during dual-tasking in PD patients have been associated with impairments in specific cognitive functions such as set-shifting, attention, and executive functions [4–6]. PD patients in the current study performed worse than controls on the Stroop Color-Word Page and on the WCST completed categories. However, only scores on the Stroop Color-Word Page were correlated with performance during the arithmetic dual-tasking condition. The marginal statistical difference between PD patients and healthy controls on the WCST my explain the absence of a significant correlation between WCST completed categories scores and arithmetic dual-tasking. Specifically, the response inhibition necessary for Stroop Color-Word Page performance is an ability closely related to selective attention, which is critical when walking in complex, everyday environments, allowing subjects to focus on gait and give it the appropriate attention and priority, despite numerous distractions [7].

There are limitations to the current study that should be considered in result interpretations. While kinemetry is a well-established method in the evaluation of gait [28, 29] we assessed only one stride, excluding the evaluation of other gait parameters, including gait variability. Another limitation in the current study is the small number of subjects in each group. Our inclusion criteria (i.e., patients classified as mild Hoehn and Yahr stage and in the “on” medication cycle) restricted patient recruitment. Moreover, we did not take into account the possible contribution of clinical symptoms (such as fatigue) on the cognitive and motor dual-task impairments in PD [6]. Additionally, we have not looked for the presence of mild cognitive impairment (MCI) in PD patients [49]. As shown by different studies, prevalence of MCI in PD is greater than in general population [1, 50]. Thus, future studies should address this issue to verify if our findings are specific for PD patients or if they could be related to more general conditions which are at risk for developing cognitive impairment [51].

In conclusion, the present findings demonstrate that baseline motor functioning and task executive/attentional load affect the performance of cognitive tasks while walking. These findings provide important insight into the different functional strategies used by PD patients in the initial phases of the disease and by healthy older adults in the adjustment of gait under dual-tasking conditions. Moreover, these findings should be taken into account for the development of gait rehabilitation programs. Cognitive tasks are frequently performed during walking in many everyday situations and training programs should be designed to ameliorate motor and cognitive aspects of dual tasking, since the cognitive status of PD patients is also associated to health-related quality of life [52]. It is not possible for a rehabilitation program to include all tasks likely to be performed when walking in daily life. Thus, it is important to know the effects of walking on cognition to develop more appropriate training protocols. Recent studies have begun to examine the effects of dual-tasking training on walking parameters of PD patients. Although the primary goal of such studies is the improvement of gait [53, 54], there are some indications that this type of training could also benefit cognitive performance during walking [55]. Brauer and Morris [55] showed that training people with PD to walk with larger steps while concurrently performing working memory tasks resulted in improved gait and cognitive performance of visuospatial and word association tests. Moreover, these cognitive tests were not part of the dual-task training, indicating that such a program has potential to improve general ability to divide, switch or maintain attention. Additionally, a randomized controlled trial is being performed with PD patients to determine the short and long-term effects of dual-task training on gait impairment, executive function, community mobility and quality of life [56]. Although the primary goal of this study continues to be walking improvement, these is the first time, to our knowledge, that the effects of dual tasking during walking were designed to also address cognitive aspects. However, further studies are necessary to investigate the effects of cognitive training focused on attentional/executive strategies on the ability to perform concomitant tasks in patients with different severities of PD.

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Conflicts of interest The authors also declare that they have no conflict of interest.

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