Are factors related to dual-task performance in people with Parkinson's disease dependent on the type of dual task?

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ABSTRACT

Background: Impaired dual-task performance significantly impacts upon functional mobility in people with Parkinson's disease (PD). The aim of this study was to identify determinants of dual-task performance in people with PD in three different dual tasks to assess their possible task-dependency.

Methods: We recruited 121 home-dwelling patients with PD (mean age 65.93 years; mean disease duration 8.67 years) whom we subjected to regular walking (control condition) and to three dual-task conditions: walking combined with a backwards Digit Span task, an auditory Stroop task and a Mobile Phone task. We measured dual-task gait velocity using the GAITRite mat and dual-task reaction times and errors on the concurrent tasks as outcomes. Motor, cognitive and descriptive variables which correlated to dual-task performance ($p < 0.20$) were entered into a stepwise forward multiple linear regression model.

Results: Single-task gait velocity and executive function, tested by the alternating intake test, was significantly associated with gait velocity during the Digit Span ($R^2 = 0.65$; $p < 0.001$), the Stroop ($R^2 = 0.73$; $p < 0.001$) and the Mobile Phone task ($R^2 = 0.62$; $p < 0.001$). In addition, disease severity proved correlated to gait velocity during the Stroop task. Age was a surplus determinant of gait velocity while using a mobile phone.

Conclusion: Single-task gait velocity and executive function as measured by a verbal fluency switching task were independent determinants of dual-task gait performance in people with PD. In contrast to expectation, these factors were the same across different tasks, supporting the robustness of the findings. Future study needs to determine whether these factors predict dual-task abnormalities prospectively.

INTRODUCTION

Compared to healthy elderly, people with Parkinson's disease (PD) generally show greater problems when performing dual tasks [1]. Loss of automaticity as a result of basal ganglia dysfunction and cognitive impairment may underlie dual-task (DT) deficits in PD [2,3].

Several studies showed that DT performance in PD was significantly associated to falling [4], gait quality [1], freezing [5], disability [6] and disease severity [6], illustrating its direct relation to functional mobility. Assessing determining factors of DT performance that are easy to administer and time-saving for clinical practice is therefore important.

So far, few studies looked at determinants of DT gait performance in PD. Depression, fatigue and executive function were found to predict both single-task (ST) and DT gait velocity when carrying a tray with glasses [7]. In a study on 153 PD patients [8], 34% of the variance of DT gait velocity was explained by increased fear of falling, disease severity, medication and depression. When calculating DT interference as a percentage of ST gait velocity, only 12% of the variance was explained by disease severity and impaired executive function [8].

Finally, when different cognitive domains were investigated in relation to specific spatiotemporal gait parameters during ST and DT walking in PD, gait velocity and stride length correlated with processing speed [9], while postural features, such as step width, were influenced by executive function [9].

In older people, usual walking abilities and cognitive function were demonstrated to contribute to DT gait outcomes [10]. Relationships, however, depended on the nature of the dual task, the gait feature being studied and the particulars of the cognitive domain involved [10,11].

So far, no studies have investigated the determinants of DT performance in PD, addressing both motor and cognitive dependent variables using a variety of concurrent tasks. Therefore, the first aim of this study was to identify the factors that are associated with motor and

cognitive DT outcomes in three different dual tasks in people with PD. We hypothesized that ST performance, cognitive function and age would be important contributors of DT performance [8,10,11]. A second aim of this study was to assess whether determinants of DT performance were task-dependent, as was previously found in the elderly [10].

METHODS

Participants

Data were collected as part of the DUALITY trial, investigating the efficacy of DT training in PD [12]. Inclusion criteria were: (a) diagnosis of PD according to the UK Brain Bank criteria [13]; (b) Hoehn and Yahr (H&Y) stage ≤ 3 in the ON-phase of the medication cycle [14]; (c) ability to walk for 10 minutes continuously; (d) presence of DT effects as established by a structured checklist; (e) a score ≥ 24 on the Mini Mental State Examination (MMSE) [15]; (f) stable medication over the past 3 months; (g) no hearing or visual problems that interfere with testing or training; and (h) stable deep brain stimulator (DBS) settings over the past year.

Ethical approval for the study was obtained in both centers participating in the study (Belgium: CME KU Leuven - B322201213165/S53419 and the Netherlands: CMO Regio Arnhem-Nijmegen - NL39530.091.12). The DUALITY trial was registered in clinicaltrials.gov (NTC01375413). Informed consent forms were signed by patients before study participation.

Dependent and independent variables

A detailed description of the clinical test battery was published earlier [12]. For the present study, only data from the first baseline test were used. Table 1 shows the independent variables divided in three categories: 1) descriptors, 2) cognitive measures, and 3) motor outcomes. Age, disease duration, freezing (yes/no), levodopa-equivalent dose (LED) [16] and the presence of DBS were recorded as patient descriptors. Cognitive ability was assessed using Mini-Mental State Examination (MMSE) [15], Montreal Cognitive Assessment (MoCA) [17], Frontal Assessment Battery (FAB) [18] and Scales for Outcome in Parkinson's disease – Cognition (ScopaCog) [19]. In addition, we performed two executive verbal fluency tests: 1) the Alternating Names Test (ANT) [20] in which 10 boy's and girl's names had to be given alternatingly and 2) the Alternating Intakes Test (AIT) [20] which involved naming 10

foods and drinks while switching between categories. Disease specific motor assessments included H&Y stage [14] (ON- medication), Unified Parkinson's disease rating scale - part 3 (UPDRS-III) [21], Freezing of Gait questionnaire (FOGQ) [22] and Activities specific Balance Confidence scale (ABC) [23]. Gait velocity (cm/sec) at preferred speed was assessed with the GAITRite Walkway System [24] during ST and DT performance. Walking started and ended 1m before and after the mat after a verbal signal. Concurrent tasks consisted of 1) the backwards Digit Span task, 2) the auditory Stroop task and 3) the Mobile Phone task, starting at the same time as walking. The number of digits in the backward Digit Span task, verbally repeated in reverse order, were adapted to the individual's ability [25] and conveyed via headphones (Beyerdynamic; transmitter: t-bone DS16T – receiver: t-bone IEM100R). Numbers were provided to the participant once the verbal signal to walk was given. The same headphones were used for the Stroop task in which subjects had to verbally respond to the words “high” and “low” pronounced with congruent or incongruent high and low tones. Stimuli were presented with a variable interval (1.5 – 2 seconds) to control for cueing effects. Concurrent Digit Span and Stroop tasks were assessed in three different versions that were repeated twice in each condition. For the functional Mobile Phone task, patients were asked to type the test date into a mobile phone with large buttons (Emporia Talk Premium; Austria). This task was repeated twice under ST and DT conditions. Concurrent tasks were assessed in sitting and walking in a random order. Patients were instructed to concentrate equally on both tasks during DT walking.

Cognitive task performance (Digit Span and Stroop task), performed in sitting and walking, was calculated as reaction times and error rates. Verbal responses were recorded through the same channel as the sound fragments using Audacity 1.3 Beta software and reaction times were calculated using a custom-made script with Matlab R2011b software (See

supplementary material 1). Mobile Phone task performance was calculated as the number of errors.

We built regression models for the following dependent variables (Table 1): Gait velocity while performing 1) the Digit Span, 2) the Stroop and 3) the Mobile Phone task; reaction times of the 4) Digit Span and 5) Stroop task when walking; and errors (yes/no) on the 6) Digit Span, 7) Stroop and 8) Mobile Phone task when walking. Dependent variables were based on absolute outcomes only and not on % interference measures. However, to compare differences in task load and prioritization between the three concurrent tasks, we also calculated DT effects as the difference between ST and DT performance expressed as a percentage of ST performance (See supplementary material 2).

Statistical analysis

IBM SPSS version 22 (IBM corp., Armonk, NY, USA) was used for data analysis [26]

Missing data were due to technical problems and occurred in 3.31 to 4.95% of cases. We built regression models for absolute DT values rather than for DT effects, as the latter were found to be less stable in a recent reliability study [27].

Univariate correlations between dependent and independent variables were assessed using simple linear regression models [26]. Potential determinants (Table 2) were included in a multivariate linear regression model if they had a p-value of less than 0.20 [26]. To avoid multi-collinearity (Pearson correlation coefficient exceeding 0.70), we only entered the determinant with the highest correlation [26]. A stepwise forward regression procedure was performed to obtain a limited number of significant factors [26]. Distribution, linearity, homoscedasity and independency of the residuals were plotted and checked visually. In case of binary outcomes (error scores), we performed a stepwise forward (likelihood ratio based) binary logistic regression [26].

RESULTS

Descriptive data are presented in table 1. One-hundred and twenty one participants were included in the analyses. In the subjective best ON-phase of the medication, eighty patients were classified as H&Y stage 2 and 40 as stage 3. Data from 1 patient was missing.

Supplementary material 2 shows that DT effects were significantly greater for gait than for the concurrent tasks, indicating that patients tended to prioritize the concurrent tasks. DT effects for gait were significantly greater for the Mobile Phone task compared to the Digit Span and Stroop task ($p < 0.05$). Univariate correlations between dependent and independent variables are presented in Table 2.

Gait velocity during the Digit Span task

Stepwise forward linear regression (Table 3) revealed that lower ST gait velocity ($\beta = 0.77$; $p < 0.001$) and worse AIT performance ($\beta = -0.12$; $p = 0.03$) contributed significantly to lower DT gait velocity ($R^2 = 0.65$; $p < 0.001$) with ST gait velocity explaining the largest proportion of variance (partial $R^2 = 0.62$). Figure 1.1 represents the difference between the predicted values based on the linear regression model and the observed values and shows overall good agreement, as is apparent from the close distribution of points around the identity line.

Gait velocity during the auditory Stroop task

Table 3 reveals that lower ST gait velocity ($\beta = 0.86$; $p < 0.001$), worse AIT performance ($\beta = -0.22$; $p < 0.001$) and lower UPDRS-III score ($\beta = 0.17$; $p = 0.003$) determined lower DT gait velocity ($R^2 = 0.73$; $p < 0.001$). Of these factors, ST gait velocity had the highest weight in explaining the variance (partial $R^2 = 0.69$). Good agreement between observed and predicted scores is visualized in figure 1.2 and confirms the robustness of the model.

Gait velocity during the Mobile Phone task

Table 3 showed that ST gait velocity ($\beta=0.57$; $p<0.001$), AIT performance ($\beta=-0.26$; $p<0.001$) and age ($\beta=-0.19$; $p=0.006$) were maintained as significant determinants in the regression model for the Mobile Phone task ($R^2=0.62$; $p<0.001$). Again, ST gait velocity explained the largest proportion of variance (partial $R^2 = 0.42$). Figure 1.3 shows good agreement between the observed values and the predicted ones, confirming the soundness of the model.

Concurrent task outcomes

Table 3 indicates that higher ST reaction time on the Digit Span task ($\beta=0.78$; $p<0.001$) was associated with worse DT performance on the Digit Span ($R^2=0.61$; $p<0.001$). Higher ST reaction time ($\beta=0.68$; $p<0.001$) and a lower FAB score ($\beta=-0.27$; $p<0.001$) were significantly correlated to worse DT performance on the Stroop task ($R^2=0.61$; $p<0.001$) (Table 3). Agreement between observed and predicted values appeared to be good for the Stroop task only (Figure 1.4 and figure 1.5). Similarly, ST errors on the Digit Span task was a significant contributor to the DT errors ($\exp(B) = 0.13$; $p<0.001$), while ST errors on the Stroop task ($\exp(B) = 0.38$; $p = 0.03$) and FAB ($\exp(B) = 0.75$; $p = 0.006$) proved to be significant determinants for DT errors on the same task. As for the Mobile Phone task, the MMSE ($\exp(B)=0.67$; $p=0.006$) and performance on ANT ($\exp(B)=1.05$; $p=0.001$) proved to be significant determinants for the errors scores (binary) during walking ($R^2=0.32$; $p<0.001$) (Table 3).

DISCUSSION

The aims of this cross-sectional study were to identify determinants of DT performance in people with PD for both motor and cognitive outcomes of three different dual tasks and to assess whether these factors depended on the nature of the dual task. We found remarkable consistency across tasks as DT gait velocity was determined by ST gait velocity and a test for executive function, the Alternating Intake Test which tested verbal fluency and task switching. ST performance was also the strongest determinant of DT cognitive performance, as reflected in the reaction times of the Digit Span and Stroop task while walking.

Gait velocity during concurrent tasks

The present study revealed that ST gait velocity had the highest association with DT gait velocity, suggesting that the loss of motor function is the most important explanatory factor of DT impairment in PD. This finding is not surprising as strong correlations between ST and DT gait performance have been demonstrated previously [10]. The striking predictive capacity of ST performance is a useful finding as it will enable clinicians to quickly ascertain patients' dual tasking ability by assessing their regular walking. However, to be able to fully account for the variability of DT capacity between subjects, we also recommend to perform actual DT tests or to add a test of executive function, such as the AIT test.

The AIT test was the second most important determinant of DT gait velocity in all three concurrent tasks. AIT is a test of executive function, which lends itself very easily to be administered in a clinical context without the need for elaborate equipment other than a stopwatch [20]. During this test, patients are timed on how long it takes to name 10 foods and drinks in an alternating fashion [20]. The finding that executive testing is involved in dual tasking is in line with previous studies in the elderly which show a close relationship between executive tests and DT gait velocity [10,11,28]. AIT showed to be consistently more sensitive in determining DT gait velocity compared to other tests of executive function, and most

notably the ANT, in which subjects have to alternate between boys and girls names. The descriptive data show that the time needed to complete the AIT was higher than that of the ANT, suggesting that the former loads executive function to a greater extent. According to age-related norm values of the AIT [20], average performance (35.01 seconds, IQR [25.86-46.50]) of participants in this study was within the normal range (0 to 49 seconds) for 60-75 year olds. However, 23.14% of our sample exceeded this range, indicating impaired executive function. Although we excluded people with a MMSE score lower than 24, our sample included twenty-two patients (18.18%) with a score lower than 24 on the MoCA and nine patients (7.44%) with a FAB score lower than 13, confirming cognitive dysfunction in subgroups of participants [29]. Why the AIT proved to be more associated to DT gait velocity compared to other more general executive or cognitive tests is unclear. Tests of verbal fluency, without the added component of task switching such as required for the AIT, however, have been demonstrated previously to be highly sensitive to executive function in PD [11,30].

Differences between concurrent tasks

The different concurrent tasks used in this study were designed to load different aspects of executive function to reveal differential associations with DT gait performance. The Stroop task assessed set shifting ability and inhibition of responses to incongruent stimuli [31]. The Digit Span and Mobile Phone task loaded working memory [31], while the latter also required vision and fine motor skills and related to daily function. In contrast to our hypotheses, we found similar determinants for DT performance irrespective of the nature of the concurrent task and the cognitive domain involved. However, for gait velocity during the Stroop and Mobile Phone task, additional determinants were found, most likely reflecting the extra or specific task demands of these tests [8]. Generally, patients seemed to prioritize the concurrent task performance at the expense of gait (See supplementary material 2), which has

also been shown in earlier work [32]. UPDRS-III proved a significant factor in determining gait velocity during the Stroop task. Different neural correlates involved in response inhibition and working memory tasks have been found previously [33]. In the Stroop task, which is considered to be a more classic test of executive function, PD patients were relatively more impaired than on the Digit Span task compared to controls [29]. This task may therefore reflect a greater disease burden. For the Mobile Phone task, age was an extra determinant, which may be attributed to the fact that older patients are less used to dealing with mobile devices. Seventy nine percent of our sample possessed a mobile phone, but we did not collect data on how often these devices were actually used. The Mobile Phone task also proved to be the most difficult task as DT effects were almost twice as high as in the other tasks, probably due to the multiple task components involved.

Cognitive performance during gait

This study is the first to look at the determinants of DT cognitive performance in PD. Comparable to the previously discussed findings, we found that ST performance proved to be the most important contributor. Furthermore, it is not surprising that other cognitive tests also made an independent contribution to explaining the DT load in the cognitive domain, such as the MMSE, the ANT and the Frontal Assessment Battery. Motor scores and disease severity did not impact upon DT cognitive outcomes, contrary to what was found in earlier work [34].

Future work and limitations

The models in the current study explained between 61.6% and 72.8% of the variance, which is higher than in previous study [8]. We used absolute DT performance as an outcome, as interference proved to be a less reliable measure of dual tasking [27]. Despite the fact that the regression models were mostly determined by ST outcomes, and based on a large and varied group of patients including patients with DBS, part of the variance remained unexplained. Other determining factors, such as emotional state, depression and fatigue [8] may be

important for future refinement of the current models. Most importantly, future work is required to confirm whether the associated factors also predict DT performance prospectively. The limitations of this study were the fact that we did not record reaction time data for the Mobile Phone task. Also, assumptions for the linear regression model for DT reaction time on the Digit Span task were not met, implying a cautious interpretation of this part of the dataset. Standard deviations for this parameter were very large, pointing to the inherent between-patients' variability.

Conclusion and clinical feasibility

Overall, we conclude that worse ST performance proved to be the most important determinant of lower DT ability in the motor as well as the cognitive domain in patients with PD. In addition, a verbal fluency switching task of executive function, which is quick and easy to administer in the clinic without additional equipment [20], was found to contribute independently to DT gait performance. The determinants found were largely independent of the nature of the concurrent tasks, supporting the robustness of the regression models. Using a Mobile Phone task during walking proved particularly sensitive to detect DT problems in our sample. However, this task was also age-dependent and therefore deserves a more careful clinical interpretation.

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CONFLICTS OF INTEREST

None

AUTHORS' CONTRIBUTIONS

AN, SK and BB were involved in the conception and design of the research project. CS, EM and LM were involved in the organization and execution of the research project and in the acquisition of data. BB and WV were involved in patient recruitment. CS and AN were involved in the design and execution of statistical analyses. AN, EM, SK, LM and BB were involved in review and critique of statistical analyses. CS and AN were involved in writing the first draft of the manuscript. AN, BB, SK, EM, EH, WV and LM were involved in review and critique of the manuscript. All authors approved the final version of the article.

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FIGURE CAPTIONS

Figure 1: Difference between observed and predicted values based on the multiple linear regression analysis for five dependent variables.

Figure 1.1, 1.2, 1.3 and 1.5 show good agreement between observed and predicted scores.

Figure 1.4 shows that observed reaction time values during the Digit Span task did not correspond well to the predicted values.

Identity line = regression line which represents perfect agreement between observed and predicted values.

1)

2)

3)

4)

5)

Table 1: Descriptive data of 121 patients with Parkinson's disease for independent and dependent variables.

DESCRIPTIVE	Age (years)	65.93 (9.22)
	Disease duration (years)	8.67 (5.83)
	Freezing (Y/N)	68/53
	LED #	610.00 [387.50-865.80]#
	DBS (Y/N)	18/103
COGNITIVE	MMSE (/30)	27.94 (1.59)
	MoCA (/30)#	26.00 [24.00-28.00]#
	FAB (/18)	15.76 (1.99)
	ScopaCog (/42)	27.02 (5.67)
	ANT (sec)#	24.19 [17.12-35.35]#
	AIT (sec)#	35.01[25.86-46.50]#
	Single-task reaction time Digit Span task (msec)#	874.50 [559.17-1234.69]#
	Single-task reaction time Stroop task (msec)	1174.26 (201.98)
MOTOR	Single-task errors Mobile Phone task (Y/N)	32/89
	H&Y #	2.00 [2.00-3.00]#
	UPDRS-III (/132)	32.39 (12.79)
	FOGQ (/28)#	0.00 [0.00-13.00]#
	ABC (/100)#	78.75 [66.88-92.50]#
OUTCOMES	Single-task gait velocity (cm/sec)	106.70 (20.07)
	Gait velocity during Digit Span task (cm/sec)	90.57 (20.56)
	Gait velocity during Stroop task (cm/sec)	92.07 (20.83)
	Gait velocity during Mobile Phone task (cm/sec)	79.41 (22.08)
	Dual-task reaction time Digit Span task (msec)#	795.48[556.23-1168.84]#
	Dual-task reaction time Stroop task (msec)	1194.56 (199.24)
	Dual-task errors on Digit Span task (Y/N)	92/25
	Dual-task errors on Stroop task (Y/N)	50/70
	Dual-task errors Mobile Phone task (Y/N)	42/79

Normal distributed data are presented by mean and standard deviation. Not normally distributed data are presented by median and interquartile range#. Y/N = yes/no; LED = levodopa-equivalent dose; DBS = deep brain stimulator; MMSE = Mini Mental State Examination; MoCA = Montreal Cognitive Assessment; FAB = Frontal Assessment Battery; ScopaCog = Scale for Outcomes in Parkinson's disease – cognition; ANT = Alternating Names Test; AIT = Alternating Intakes Test; H&Y = Hoehn and Yahr stage; UPDRS-III = Unified Parkinson's Disease Rating Scale; FOGQ = Freezing of Gait Questionnaire; ABC = Activities specific Balance Confidence scale.

Table 2: Pearson correlation coefficients resulting from the univariate correlation analysis significant at a level of $p < 0.20$.

	DESCRIPTIVE					COGNITIVE							MOTOR				
	Age	Disease duration	Freezing	LED	DBS	MMSE	MoCA	FAB	ScopaCog	ANT	AIT	Single-task cognitive performance	H&Y	UPDRS III	FOGQ	ABC	Single-task gait velocity
Gait velocity during the Digit Span task	$r = -0.43$ $p < 0.001$	/	$r = -0.16$ $p = 0.08$	/	/	$r = 0.15$ $p = 0.10$	/	$r = 0.15$ $p = 0.10$	$r = 0.28$ $p = 0.002$	$r = -0.27$ $p = 0.003$	$r = -0.27$ $p = 0.003$	/	$r = -0.40$ $p < 0.001$	$r = -0.33$ $p < 0.001$	/	$r = 0.31$ $p = 0.001$	$r = 0.79$ $p < 0.001$
Gait velocity during the Stroop task	$r = -0.42$ $p < 0.001$	/	$r = -0.13$ $p = 0.16$	/	/	$r = 0.21$ $p = 0.02$	$r = 0.14$ $p = 0.14$	$r = 0.18$ $p = 0.05$	$r = 0.35$ $p < 0.001$	$r = -0.32$ $p < 0.001$	$r = -0.33$ $p < 0.001$	$r = -0.27$ $p = 0.003$	$r = -0.38$ $p < 0.001$	$r = 0.30$ $p = 0.001$	/	$r = 0.30$ $p = 0.001$	$r = 0.81$ $p < 0.001$
Gait velocity during the Mobile Phone task	$r = -0.55$ $p < 0.001$	/	/	/	/	$r = 0.28$ $p = 0.002$	$r = 0.19$ $p = 0.04$	$r = 0.24$ $p = 0.01$	$r = 0.43$ $p < 0.001$	$r = -0.39$ $p < 0.001$	$r = -0.45$ $p < 0.001$	/	$r = -0.39$ $p < 0.001$	$r = -0.35$ $p < 0.001$	/	$r = 0.31$ $p = 0.001$	$r = 0.64$ $p < 0.001$
Reaction time on the Digit Span task when walking	/	/	/	$r = 0.15$ $p = 0.10$	/	/	/	/	$r = 0.12$ $p = 0.20$	/	/	$r = 0.78$ $p < 0.001$	/	/	/	/	/
Reaction time on the Stroop task when walking	/	$r = 0.17$ $p = 0.07$	$r = 0.19$ $p = 0.04$	/	$r = 0.17$ $p = 0.06$	$r = -0.21$ $p = 0.03$	$r = -0.21$ $p = 0.02$	$r = -0.41$ $p < 0.001$	$r = -0.36$ $p < 0.001$	$r = 0.41$ $p < 0.001$	$r = 0.32$ $p < 0.001$	$r = 0.73$ $p < 0.001$	$r = 0.14$ $p = 0.13$	$r = 0.25$ $p = 0.006$	/	$r = -0.20$ $p = 0.03$	$r = -0.25$ $p = 0.01$
Errors on the Digit Span task when walking	/	/	/	$R = 0.17$ $P = 0.07$	/	/	/	/	/	/	/	$R = 0.41$ $P < 0.001$	/	/	/	/	/
Errors on the Stroop task when walking	/	/	/	/	/	/	$R = -0.15$ $P = 0.10$	$R = -0.24$ $P = 0.009$	$R = -0.15$ $P = 0.10$	$R = 0.14$ $P = 0.13$	$R = 0.14$ $P = 0.13$	$R = 0.19$ $P = 0.04$	/	/	/	/	/
Errors on the Mobile Phone task when walking	$r = 0.31$ $p < 0.001$	/	$r = 0.12$ $p = 0.19$	/	/	$r = 0.37$ $p < 0.001$	$r = -0.32$ $p < 0.001$	$r = -0.33$ $p < 0.001$	$r = -0.41$ $p < 0.001$	$r = 0.43$ $p < 0.001$	$r = 0.36$ $p < 0.001$	$r = 0.31$ $p = 0.001$	/	$r = 0.23$ $p = 0.01$	/	/	/

r = Pearson correlation coefficient; p = p -value; LED = levodopa-equivalent dose; DBS = deep brain stimulator; MMSE = Mini Mental State Examination; MoCA = Montreal Cognitive Assessment; FAB = Frontal Assessment Battery; ScopaCog = Scale for Outcomes in Parkinson's disease – cognition; ANT = Alternating Names Test; AIT = Alternating Intakes Test; H&Y = Hoehn and Yahr stage; UPDRS-III = Unified Parkinson's Disease Rating Scale; FOGQ = Freezing of Gait Questionnaire; ABC = Activities specific Balance Confidence scale.

Table 3: Results from the multiple regression analysis with stepwise forward regression.

<i>Linear regression</i>		<i>Beta [95%CI]</i>	<i>Standardized beta</i>	<i>t-value</i>	<i>p-value</i>	<i>Partial R²</i>	<i>VIF</i>	<i>R²</i>	<i>Significance of model</i>
Gait velocity during Digit Span task (N = 116)	Constant	9.12 [-4.92 to 23.16]		1.29	0.20			0.65	<0.001
	Single-task gait velocity	0.81 [0.69 to 0.92]	0.77	13.65	<0.001	0.62	1.04		
	AIT	- 0.11 [-0.21 to 0.01]	-0.12	-2.19	0.03	0.04	1.04		
Gait velocity during Stroop task (N = 115)	Constant	- 6.63 [-23.15 to 9.88]		-0.80	0.43			0.73	<0.001
	Single-task gait velocity	0.91 [0.80 to 1.03]	0.86	15.56	<0.001	0.69	1.28		
	AIT	- 0.20 [-0.30 to -0.11]	-0.22	-4.37	<0.001	0.15	1.09		
	UPDRS III	0.29 [0.10 to 0.47]	0.17	3.05	0.003	0.08	1.33		
Gait velocity during Mobile Phone task (N = 117)	Constant	51.24[21.57 to 80.90]		3.42	0.001			0.62	<0.001
	Single-task gait velocity	0.64 [0.50 to 0.78]	0.57	9.02	<0.001	0.42	1.22		
	AIT	- 0.25 [-0.38 to -0.13]	-0.26	-4.15	<0.001	0.13	1.20		
	age	- 0.46 [-0.78 to -0.13]	-0.19	-2.81	0.006	0.07	1.42		
Reaction time on the Digit Span task when walking (N = 117)	Constant	0.44 [0.34 to 0.54]		8.83	<0.001			0.61	<0.001
	Single-task reaction time on digit span task	0.44 [0.38 to 0.51]	0.78	13.39	<0.001	0.61	1.00		
Reaction time on the Stroop task when walking (N = 115)	Constant	0.82 [0.57 to 1.08]		6.36	<0.001			0.61	<0.001
	Single-task reaction time on stroop task	0.66 [0.55 to 0.78]	0.68	11.25	<0.001	0.53	1.06		
	FAB	- 0.03 [-0.04 to -0.01]	-0.27	-4.42	<0.001	0.15	1.06		
<i>Logistic regression</i>		<i>B (SE)</i>	<i>Exp B [95%CI]</i>	<i>Wald</i>	<i>p-value</i>	<i>% predicted accuracy</i>		<i>Nagelkerke R²</i>	<i>Significance of model</i>
Errors on the Digit Span task when walking (N = 117)	Constant	1.91 (0.31)	6.75	38.11	<0.001	80.3		0.21	<0.001
	Single-task errors on digit span task	-2.08 (0.51)	0.13 [0.05-0.34]	16.37	<0.001				
Errors on the Stroop task when walking (N =)	Constant	4.86 (1.73)	129.01	7.88	0.005	67.8		0.14	0.002
	Single-task errors on stroop task	-0.98 (0.44)	0.38 [0.16-0.89]	5.02	0.03				
	FAB	-0.29 (0.11)	0.75 [0.61-0.92]	7.62	0.006				
Errors on the Mobile Phone task when walking (N = 119)	Constant	8.96 (4.15)	7793.24	4.67	0.03	73.9		0.32	<0.001
	MMSE	-0.40 (0.15)	0.67 [0.50-0.89]	7.57	0.006				
	ANT	0.05 (0.02)	1.05 [1.02-1.09]	10.47	0.001				

N = number of participants; FAB = Frontal Assessment Battery; AIT = Alternating Intakes Test; UPDRS-III = Unified Parkinson's Disease Rating Scale; CI = confidence interval; VIF = variance inflation factor.

SUPPLEMENTARY MATERIAL 1 “Reaction time calculation”

We used the Audacity 1.3 Beta software application to record patients’ oral responses to the auditory Stroop task and the backwards Digit Span task in the same channel at which the sound fragments were provided, guaranteeing an optimal signal synchronization. In order to calculate reaction times, we uploaded the Audacity recordings into the Matlab program and ran these files through a custom-made script. For the Stroop task, we manually detected the start of the auditory signal of the Stroop task and the start of each patient response. The difference between these time points was used to calculate the reaction time for the Stroop task. The reason why onset of each sound was used instead of termination was because some patients already answered before the sound was completely finished, which would have generated negative values. For the Digit Span task, we detected the end of the sound fragment and the start of the patient response. Again, the difference between these points was used to calculate the reaction time for the Digit Span task. A visual representation of these reaction times in Matlab R2011b can be found in a previously published paper [1].

[1] C. Strouwen, E.A. Molenaar, S.H. Keus, et al., Protocol for a randomized comparison of integrated versus consecutive dual task practice in Parkinson's disease: the DUALITY trial, BMC. Neurol. 14 (1) (2014) 61.

SUPPLEMENTARY MATERIAL 2 “Task load and task prioritization”

In the table below, we present the dual-task effect (%) on gait velocity and on cognition for each of the three concurrent tasks.

For the calculation of DT effect on gait velocity we used the following formula:

$$DT \text{ effect on gait velocity} = 100 * \frac{ST \text{ gait velocity} - DT \text{ gait velocity}}{ST \text{ gait velocity}}$$

For the calculation of DT effect on cognition, we used following formula:

Digit Span and Stroop task

$$DT \text{ effect on reaction times} = -100 * \frac{ST \text{ reaction time} - DT \text{ reaction time}}{ST \text{ reaction time}}$$

AND

$$DT \text{ effect on percentage correct responses} = 100 * \frac{ST \% \text{ correct responses} - DT \% \text{ correct responses}}{ST \% \text{ correct responses}}$$

$$DT \text{ effect on cognition} = \frac{DT \text{ effect on reaction time} + DT \text{ effect on \% correct responses}}{2}$$

Mobile Phone task

$$DT \text{ effect on cognition} = 100 * \frac{ST \% \text{ correct responses} - DT \% \text{ correct responses}}{ST \% \text{ correct responses}}$$

DT effect (%) on	Mean (SD)	
Gait velocity during Digit span task	14.68 (12.25)**	A
Gait velocity during Stroop task	13.33 (12.58)**	B
Gait velocity during Mobile Phone task	25.17 (17.01)**	C
Cognition (reaction time + % correct responses) – Digit Span task	4.87 (22.81)*	A
Cognition (reaction time + % correct responses) – Stroop task	1.38 (10.39)	B
Cognition (% correct responses) – Mobile Phone task	1.85 (9.98)*	C

Table: DT effects on gait velocity and cognition for the three concurrent tasks. DT effect (%) is presented by mean and standard deviation (SD). Positive values indicate worse performance during dual tasking. Significant differences from zero are indicated by * (p<0.05) or by ** (p<0.001). The alphabetic letters (A, B and C) indicate significant differences between gait and cognitive components.

The task prioritization plots below represent the DT effect on gait velocity plotted against the DT effect on cognition for each of the tasks. The plots show that points are situated in the upper part of the graph and are equally spread between left and right quadrants, indicating that the effects of the concurrent task was larger on gait than vice versa. The plots illustrate that despite the instruction to concentrate equally on both tasks, patients were prioritizing the concurrent tasks.