American Psychological Association

Neuropsychology

0894-4105/19/$12.00

2019, Vol. 33, No. 2, 147–156
http://dx.doi.org/10.1037/neu0000496

The Effects of Integrated Single- and Dual-Task Training on Automaticity and Attention Allocation in Parkinson's Disease: A Secondary Analysis From a Randomized Trial

Niklas Löfgren and David Conradsson
Karolinska Institutet and Karolinska University Hospital, Stockholm, Sweden

Linda Rennie
Sunnaas Rehabilitation Hospital, Oslo, Norway

Rolf Moe-Nilssen
University of Bergen

Erika Franzén
Karolinska Institutet and Karolinska University Hospital, Stockholm, Sweden

Objective: People with Parkinson's disease (PwPD) demonstrate impaired automaticity of motor and cognitive tasks, with unclear prioritization strategies when exposed to dual-task situations. However, no randomized trials have investigated the effects of training on automaticity and prioritization strategies in this population. The purpose of this study was to investigate the effects of training on the automaticity of gait and cognitive processing in PwPD and the allocation of attention between gait and a cognitive task. ***Method:*** One-hundred PwPD were randomized to 10 weeks of challenging gait and balance training (including single and dual-task conditions) or to a control group (care as usual). Outcome measure was the absolute dual-task interference (difference between single- and dual-tasks) for gait and cognitive parameters. Differences between baseline and follow-up were compared between the groups. The Mann–Whitney U test was used to assess potential differences. Significance level was set to $p = .05$. The direction and magnitude of nonparametric effect sizes were used to investigate attention allocation. ***Results:*** No significant between-groups differences were found regarding any gait parameter. The training group significantly improved the dual-task interference of the cognitive task. The direction of between-groups effect sizes indicated that the training group primarily allocated attention to the cognitive task, whereas the control group appeared to prioritize gait. ***Conclusions:*** The results indicate that challenging training can improve automaticity of cognitive processing during walking. This may have a beneficial effect on the ability to ambulate safely in the community, thereby improving independence and the quality of life in this population.

General Scientific Summary
This study provides the first findings regarding how challenging training entailing the simultaneous performance of walking and cognitive tasks affect people with Parkinson's disease and suggests that the training improved the performance on a cognitive task rather than gait. This implies that the training enabled people with Parkinson's disease to pay attention to the surrounding environment while walking, thereby reducing the risk of fall accidents when walking in the community.

Keywords: neurodegenerative, executive function, attention, rehabilitation, gait impairment

This article was published Online First November 8, 2018.

Niklas Löfgren and David Conradsson, Department of Neurobiology, Care Sciences and Society, Division of Physiotherapy, Karolinska Institutet, and Allied Health Professionals Function, Function Area Occupational Therapy and Physiotherapy, Karolinska University Hospital, Stockholm, Sweden; Linda Rennie, Department of Research, Sunnaas Rehabilitation Hospital, Oslo, Norway; Rolf Moe-Nilssen, Department of Global Public Health and Primary Health Care, Physiotherapy Research Group, University of Bergen; Erika Franzén, Department of Neurobiology, Care Sciences and Society, Division of Physiotherapy, Karolinska Institutet, and Allied Health Professionals Function, Function Area Occupational Therapy and Physiotherapy, Karolinska University Hospital.

The authors thank all the people with Parkinson's disease who participated in this study, as well as all trainers and testers. This study was funded by The Swedish Research Council, Karolinska Institutet, Karolinska University Hospital, Neuro Sweden, and the Swedish Parkinson Association.

Correspondence concerning this article should be addressed to Niklas Löfgren, Department of Neurobiology, Care Sciences and Society, Division of Physiotherapy, Karolinska Institutet, Alfred Nobels Alle 23, 141 83 Huddinge, Sweden. E-mail: niklas.lofgren@ki.se or niklas.lofgren@sll.se

People with Parkinson's disease (PwPD) have demonstrated impaired automatic processing during both motor and cognitive tasks (Clark, 2015; Dirnberger & Jahanshahi, 2013; Salazar et al., 2017; Wu, Hallett, & Chan, 2015). This has been related to the gradual loss of dopamine-producing cells in this population and is considered a contributing factor to the increased fall frequency among PwPD (Dirnberger & Jahanshahi, 2013; Gilat et al., 2017). Indeed, while tasks performed through automatic processing require minimal attention and rely on the basal ganglia; tasks requiring controlled processing rely more on cortical areas, making such tasks attention-demanding and capacity limited, which results in more interference with other tasks (Dirnberger & Jahanshahi, 2013; Schneider & Chein, 2003). This may indicate that an increased dependency on controlled processing, for example during walking, may impair the ability to detect potential hazards in the surrounding environment, hence increase the risk of falling. Therefore, it is vital to investigate if automatic processing can be improved among PwPD.

The dual-task paradigm entails the simultaneous performance of two tasks with different objectives (McIsaac, Lamberg, & Muratori, 2015) and an important aspect of this paradigm refers to the allocation of attention between the two tasks, that is, which task is prioritized (Karatekin, Couperus, & Marcus, 2004). In gait research, dual-task abilities are often assessed without taking the sole performance (single-task) of either task into account, despite the fact that the level of automaticity only can be indicated by comparing the performance of a given task during both single-task and dual-task conditions (Clark, 2015). The decrements during the dual-task condition, here termed *dual-task interference*, may then be used as a proxy for the level of automaticity (Clark, 2015; Wu et al., 2015).

In the rehabilitation setting, dual-task abilities are often investigated with one motor task (e.g., walking) and one cognitive task. However, within this field of research, the motor task has generally been considered the primary task whereas the performance of the cognitive task has often been overlooked (Plummer & Eskes, 2015; Salazar et al., 2017). This is particularly problematic because both cognition and impaired gait are established risk factors for falls in older people, including PwPD (Fasano, Canning, Hausdorff, Lord, & Rochester, 2017; Fasano, Plotnik, Bove, & Berardelli, 2012).

Furthermore, the concept of attention allocation has been promoted as an important factor for safe ambulation, particularly among PwPD where a link between neurophysiological mechanisms and impaired attention allocation has been suggested (Dubois & Pillon, 1997). This concept relates to the theory that when the demands of either task are too high and thereby requiring cortical processing, attention will primarily be allocated to one of the tasks at the expense of the other task (Kahneman, 1973). In gait research, attention allocation is commonly assessed by investigating if the performance of one task has improved but the performance of the other task is unaffected or has deteriorated, in which case it is interpreted that attention has primarily been allocated to the improved task (Plummer & Eskes, 2015). In addition, it has been suggested that attention is generally allocated to the task considered most difficult (or most important) at the time when the tasks are undertaken (Kahneman, 1973). In Parkinson's disease research, the common comprehension has for a long time been that the adequate strategy is to allocate attention to the motor task rather than the cognitive task, that is, to use a "posture-first" strategy (Bloem, Grimbergen, van Dijk, & Munneke, 2006).

PwPD have been suggested to rely on controlled processing even for basic single tasks that are predominantly automatic in healthy people (Wu et al., 2015). Based on this, dual-task training among PwPD were initially controversial and earlier guidelines for physical therapy even advised against it due to its associated risks (Keus et al., 2007), such as an increased risk of falls or festinations while walking (i.e., freezing of gait). However, an increasing number of studies show promising results, indicating that absolute dual-task performance may be improved among PwPD (Brauer & Morris, 2010; N. E. Fritz, Cheek, & Nichols-Larsen, 2015; Ginis et al., 2016; Strouwen et al., 2015; Strouwen et al., 2017). While this is encouraging, the majority of these studies have been conducted with small sample sizes or without a control group. Criticism has also been raised that this research field have tended to underreport the performance of the cognitive task despite the interdependence of both tasks during this kind of assessment (Plummer & Eskes, 2015). There is also a general lack of randomized trials specifically investigating the effects of training on dual-task interference, making it difficult to interpret if dual-task training can improve automatic processing among PwPD. In addition, it has previously been suggested that PwPD use the supposedly inadequate "posture second" strategy (Bloem et al., 2006), meaning that they tend to allocate attention to the cognitive task at the expense of gait and balance during dual-task conditions. However, this view has been challenged due to more recent findings indicating an opposite pattern (Wild et al., 2013). Nevertheless, it is yet to be investigated if attention allocation may be affected in PwPD following an exercise intervention emphasizing dual-tasking.

We have previously shown that highly challenging gait and balance training improved balance performance, gait speed, and step length during single-tasking, but not during dual-tasking (Conradsson et al., 2015). However, gait is multidimensional and different parameters may contain information representing different underlying constructs (Hollman, McDade, & Petersen, 2011; Lord, Galna, & Rochester, 2013). Therefore, the aim of this study was to, through a preplanned secondary analysis, investigate the effects of training on the automaticity of different gait domains and cognitive processing in PwPD and the allocation of attention between gait and a cognitive task.

Method

Design

This study is the secondary analysis of a randomized trial comparing the effects of challenging gait and balance training with a control group (care as usual) on dual-task interference in PwPD (trial registration: NCT01417598). The protocol and training program for this trial has been detailed elsewhere (Conradsson, Löfgren, Ståhle, Hagströmer, & Franzén, 2012). Data were collected between January 2012 and May 2013. The Regional Ethical Board in Stockholm, Sweden, approved this study. All participants gave written informed consent before data collection began.

PwPD were recruited via newspaper advertisements and outpatient clinics. Inclusion criteria were a clinical diagnosis of idiopathic Parkinson's disease according to the Queens Square Brain

Bank criteria (Hughes, Daniel, Kilford, & Lees, 1992), Hoehn and Yahr Stage 2 or 3 (Hoehn & Yahr, 1967), ≥60 years of age, the ability to independently ambulate indoors without a walking aid, and ≥3weeks of stable anti-Parkinsonian medication. To increase the ecological validity, we included individuals considered likely to be assigned to rehabilitation in clinical practice, that is, PwPD with gait or balance impairments (e.g., instability during postural transfers). Exclusion criteria consisted of cognitive impairments defined by a Mini-Mental State Examination score of <24 (Folstein, Folstein, & McHugh, 1975) and other medical conditions that might substantially influence gait and balance performance.

The data collection consisted of a structured interview, as well as the assessment of disease severity and gait performance in a movement laboratory. Data regarding demographics, Parkinson's disease duration, previous falls and dopaminergic medication dosage (Tomlinson et al., 2010) were collected during the interview. We used the Unified Parkinson's disease Rating Scale, Part III, to assess the severity of motor symptoms (Martinez-Martin et al., 1994).

Assessments were performed by physiotherapists with clinical experience in neurological rehabilitation. To synchronize the instructions and rating of the assessments between the testers, practice sessions took place prior to data collection. All participants were tested during the ON-medication state, at the same time of the day at baseline and follow-up.

Included participants were allocated into two different geographical cohorts (north and south) to minimize travel time for those randomized to the training group. Within each cohort, randomization to the training or control group was performed in blocks of four. During the baseline-assessments, both testers and participants were blinded to group allocation, however because some testers also served as trainers, blinding to group allocation was not possible to maintain at follow-up. To decrease bias, testers that had served as trainers in one of the cohorts never assessed participants from that same cohort at the follow-up assessments.

The participants who were randomized to the training group undertook 10 weeks of highly challenging balance training. The participants in the control group received care as usual during the study period and were encouraged to maintain their usual level of physical activity. They were not restricted from participation in ongoing rehabilitation programs. After the intervention's closure, the participants in the control group were offered to participate in the balance training program.

Training was performed at two similar hospitals by physiotherapists with experience in neurologic rehabilitation. The training concept relied upon the continuous progression and adaptation of exercises with regards to the participants' abilities. This was primarily performed during the planning of the training that occurred between each training session; however, minor adjustments were performed during the sessions in order to optimize the challenge level for each participant. Because this required skilled and educated trainers, the trainers had been educated in detail about the program's underlying theories and its practical applications during a 2-day workshop. Also, the trainers documented the contents of each training session and were supported in the practical aspects of the training upon request.

Intervention

This training intervention was performed in accordance with the HiBalance program, which is a highly challenging gait and balance training program, specifically developed for PwPD (Conradsson, Löfgren, Ståhle, & Franzén, 2014; Conradsson et al., 2012). This program entails three 60-min training sessions per week for 10 weeks. Two short breaks were included during each session and took place between the changes of exercises. In addition, individual participants were allowed to rest as needed. The training was performed in groups of four to seven participants, with two physiotherapists supervising each session. The HiBalance program follows a structured scheme to ensure the continuous progression of the challenge level of the participants, and gradually integrate dual-task exercises into the training. We defined highly challenging gait and balance training as "exercises inducing intermittent reactive postural adjustments," for example, having to take a reactive step to regain balance during walking on a narrow balance foam, following a sudden stop/turn, or while catching a balance ball.

The program consists of four training components specific to gait and balance impairments in PwPD: (a) Sensory integration (walking tasks on varying surfaces with or without visual constraints), (b) anticipatory postural adjustments (voluntary arm/leg/trunk movements, postural transitions, and multidirectional stepping, emphasizing movement velocity and amplitude), (c) motor agility (interlimb coordination under varying gait conditions and quick shifts of movement characteristic during predictable and unpredictable conditions), and (d) stability limits (controlled leaning tasks performed while standing with varied base of support, stimulating weight shifts in multiple directions).

The training period was divided into three blocks (A, B, and C). In Block A (Weeks 1–2), participants were introduced to the single-task exercises of each training component separately, to emphasize the movement quality and exercise objectives. In Block B (Weeks 3–6), dual-task exercises were gradually introduced and the difficulty level for each training component was increased. In Block C (Weeks 7–10), the difficulty level and the variation was increased further by using exercises combining the different training components, for example by stepping over obstacles on an unstable surface. Each session consisted of 50–70% gait exercises and the total ratio of single-task/dual-task exercises was approximately 50:50 in order to enable an equal emphasis on single-task and dual-task exercises.

The dual-task exercises used in this program were integrated into the training by adding concurrent cognitive and/or motor tasks to the exercises. The aim was to induce continuous attentional processing demands while walking under varying circumstances. Examples included (a) continuous counting of each step taken; (b) interactive tasks, such as walking with a companion while exchanging words, where new words were to begin with the last letter of the previous word uttered by their companion; or (c) throwing and catching balls with a companion. Such tasks required the participants to continuously pay attention to their companion's performance to produce an adequate response, whether cognitive or manual. To ensure an adequate difficulty level of the dual-task exercises, they were to induce consistent interference of the participants' gait and balance performance when compared to the single-task performance (e.g., interfering with speed, movements' fluency or step to step fluctuations). In addition, the program generally incorporated attention-demanding situations even during the single-task training (e.g., switching between tasks during gait in varied obstacle courses, spatial awareness in relation to obstacles, and collaborative tasks between participants). During training, the dual-task exercises were never the same as during the assessments (i.e., any task resembling alphabet reciting was prohibited).

Outcome Measures

The gait outcomes used in this study derives from a recent model that was developed for older adults (Lord, Galna, Verghese, et al., 2013) that has been validated for PwPD (Lord et al., 2013). This model entails five independent domains: pace (step velocity, step length and swing time variability), rhythm (step time, swing time and stance time), variability (step velocity variability, step length variability, step time variability and stance time variability), asymmetry (swing time asymmetry, step time asymmetry and stance time asymmetry), and postural control (step length asymmetry, step width and step width variability). The GAITRite system (Active Zone: 8.3 m, CIR Systems, Inc., Havertown, PA) was used to assess gait performance. For gait during both single-task and dual-task, participants walked back and forth on the mat at self-selected speed until six valid trials of each condition had been captured. Acceleration and deceleration distances of three meters was given on each side of the mat to ensure steady state walking upon the mat (Lindemann et al., 2008).

The cognitive task used in this study entailed the reciting of alternate letters of the Swedish alphabet at self-selected speed. This task has previously been found to predict falls in elderly people (Brandler, Oh-Park, Wang, Holtzer, & Verghese, 2012; Verghese et al., 2002) and was performed as a cognitive single-task while seated and as a dual-task while walking. The participants were instructed to pay equal attention to both tasks during the dual-task conditions, and standardized practice trials of both gait and the cognitive task during single-task and dual-task conditions were held before the commencement of the assessment. To minimize practice bias, the participants received different starting letters following a standardized scheme shortly before each trial (Brandler et al., 2012).

For the cognitive single-task, the participants performed three trials that lasted for 15 s each. The letters recited between 5 s and 15 s were recorded, in order to resemble the cognitive dual-task condition. Regarding the cognitive dual-task, the participants were instructed to start reciting as soon as they started to walk, however only the letters recited while the participants walked upon the walkway were recorded. Dual-task gait and the cognitive dual-task were recorded simultaneously.

The cognitive parameters used were cognitive performance (i.e., mean performance) and cognitive variability (i.e., the variability of the mean performance), where the latter is considered a measure of cognitive processing robustness (Li, Huxhold, & Schmiedek, 2004).

Data Analysis

The power analysis (80%, $\alpha = 0.05$) for this study was based on the dual-task interference of gait velocity, where 54 (27 per group) participants were required to obtain a large effect size ($\geq$0.80) between the groups (Conradsson et al., 2012). We aimed to include 100 participants to allow for drop-outs. Dual-task interference was calculated as the absolute difference between the dual-task and single-task conditions: dual-task interference = dual-task performance – single-task performance (Rochester, Galna, Lord, & Burn, 2014). This was performed for all gait parameters, as well as for two cognitive parameters.

For the gait parameters, the mean and variance of the right and left steps were calculated separately. Subsequently, the mean parameters were calculated as the mean of the right and left steps, the variability parameters were calculated as the square root of the mean variance of the right and left steps (i.e., the standard deviation) and the asymmetry parameters were calculated as the absolute difference between the right and left steps (Lord et al., 2013; Rochester et al., 2014). For the cognitive parameters, cognitive performance was calculated as each participant's mean percentage of errors across trials $\left(\frac{\text{number of errors}}{\text{number of letters recited per trial}}\right)$, and cognitive variability (i.e., the intraindividual variability of the cognitive performance) was calculated as the standard deviation of cognitive performance across trials (Burton, Strauss, Hultsch, Moll, & Hunter, 2006).

STATISTICA Version 13 (Statsoft, Tulsa, OK) was used for the statistical analyses in this study. The Kolmogorov–Smirnov test was used to test for data normality, combined with visual inspections. Due to a general lack of normal distributions, the Mann–Whitney *U* test was applied to analyze between-groups differences regarding change in dual-task interference following training (calculated as baseline minus follow-up) In the case of significant between-group differences, the Wilcoxon signed-ranks test was used to analyze within-group differences. The level of significance was set to $p = .05$.

Effect sizes, unlike the *p* value, provide information regarding the magnitude and direction of potential between group effects (C. O. Fritz, Morris, & Richler, 2012). In order to enable the investigation of attention allocation, nonparametric effect sizes were therefore calculated based on the z values obtained from the Mann–Whitney *U* tests according to the following formula: $r = z/\sqrt{n}$. The nonparametric effect sizes were categorized as follows: small effect = 0.1, medium effect = 0.3, and large effect = 0.5 (C. O. Fritz et al., 2012). We used the direction of effect sizes for gait and cognitive parameters as an indication of differences in attention allocation between the training group and the control group.

Results

Out of 145 PwPD screened for enrollment, 100 were included in this study. Eighty-seven participants completed all assessments at baseline and follow-up and were included in the analysis. The flowchart for this study, including the reasons for dropout, is presented in Figure 1. Data regarding participant demographics and absolute gait and cognitive measures are presented in Tables 1 and 2, respectively.

Dual-Task Interference of the Gait Domains

As shown in Table 3, there were no statistically significant differences between the groups for change in dual-task interference of any gait parameter following training ($p \geq .084$).

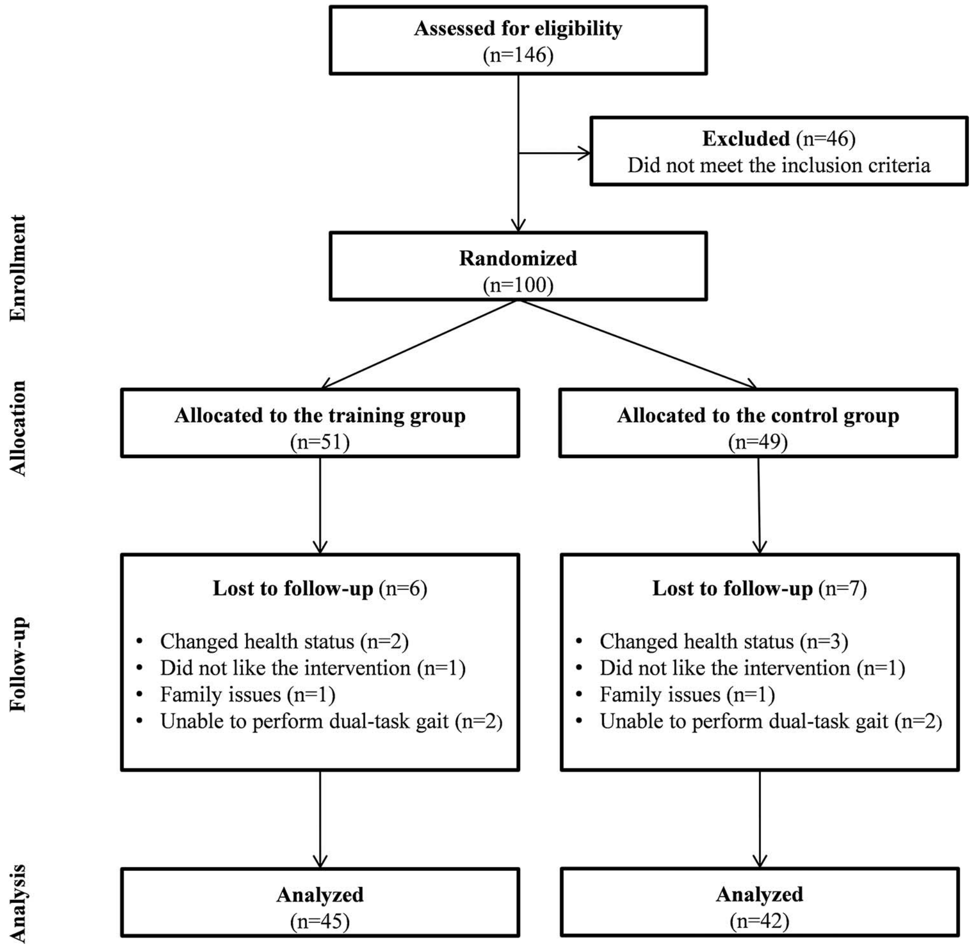

Figure 1. An illustration of the flow of participants through the study.

Dual-Task Interference of Cognitive Performance and Cognitive Variability

There were significant between-groups differences regarding change in dual-task interference following training, for both cognitive performance ($p = .018$) and cognitive variability ($p = .038$). This was due to significant improvements in the training group ($p = .038$ and $p = .032$), whereas the control group remained unchanged ($p = .114$ and $p = .378$; see Table 3).

Attention Allocation Following the Intervention

As illustrated in Figure 2, the direction of effect sizes for all investigated parameters showed the training group to primarily allocate attention to the cognitive task at follow-up, whereas the control group appeared to allocate attention to gait. Indeed, while the control group showed improvements at a small effect size for parameters related to all gait domains but the rhythm domain, the training group showed the largest improvements for the cognitive domains.

Discussion

This was the first randomized trial to investigate the effects of training on dual-task interference in PwPD. The main finding of this study was that the training- and the control groups showed opposite patterns regarding attention allocation. The training group significantly reduced dual-task interference of cognitive performance and variability in comparison to the control group. In contrast, when compared to the training group, the control group generally showed nonsignificant improvements at small effect sizes for the dual-task interference of gait parameters (see Figure 2).

These results may suggest that the training group prioritized the cognitive task during the dual-task condition at follow-up, whereas the control group appeared to allocate attention toward the gait performance. However, as previous studies mostly have shown improvements for dual-task gait in PwPD, but rarely for cognitive dual-tasking or single-task gait (N. E. Fritz et al., 2015; Strouwen et al., 2015), we expected this intervention to primarily improve the dual-task interference of gait. While interpreting these findings, it is important to bear in mind that we have previously shown improved single-task gait speed and step length as well as dynamic balance in the training group (Conradsson et al., 2015). These results are in accordance with a recent model of task prioritization during dual-task (Yogev-Seligmann, Hausdorff, & Giladi, 2012). This model suggests individuals with sufficient postural reserves to allocate their attention to the added task during dual-task conditions if the postural threat is considered to be low. Indeed, the

Table 1
Participant Characteristics

Demographic	Training group (n = 45)					Control group (n = 42)				
	n	M	SD	Range	95% CI	n	M	SD	Range	95% CI
Hoehn and Yahr										
Stage 2	19					18				
Stage 3	26					24				
Gender										
Male	27					21				
Female	18					21				
Age (y)		72.5	5.8	61–87	[70.8, 74.3]		73.5	5.6	65–87	[71.7, 75.3]
Height (cm)		171.7	9.6	149.5–190.0	[168.8, 174.6]		171.5	8.6	148.5–187.0	[168.8, 174.2]
Weight (kg)		75.8	14.4	48.0–102.0	[71.5, 80.1]		76.2	13.8	45.2–100.1	[71.9, 80.5]
UPDRS, III[a] (0–108)		32	12	12–75	[28.7, 35.7]		33	12	16–76	[29.1, 36.8]
Time since diagnosis (y)		5.8	5.3	1–25	[4.2, 7.4]		5.4	4.7	1–21	[4.0, 6.7]
Levodopa equivalency dose		591.8	287.1	100–1,487	[505.5, 678.0]		639.5	422.2	0–2,666	[507.9, 771.1]
Geriatric Depression Scale[a] (0–20)		4.3	3.1	0–14	[3.5, 5.2]		3.5	2.7	0–10	[2.7, 4.3]

Note. M = Mean; CI = Confidence interval of the mean; UPDRS, III = Unified Parkinson's Disease Rating Scale, severity of motor symptoms.
[a] Higher score signifies worse symptoms.

training group had participated in 10 weeks of highly challenging gait and balance training, with frequent exposure to single-task and dual-task walking tasks such as negotiating obstacles, turning and walking on unstable surfaces. Therefore, it is possible that they, unlike the control group, perceived the walking conditions (straight walking at comfortable speed on a level surface) to be of low threat (McIsaac et al., 2015), while likely also having increased their postural reserves and may therefore have allocated their attention more toward the cognitive task. It is possible that more challenging walking conditions (e.g., obstacle clearance) during the dual-task assessments would have yielded different results.

Alternative explanations for the results found in this study may be attributed to specific characteristics of the dual-task training,

Table 2
Absolute Single and Dual-Task Performance for Gait and Cognitive Parameters, at Baseline and Follow-Up

Domain	Baseline, *Mdn* (IQR)				Follow-up, *Mdn* (IQR)			
	Training		Control		Training		Control	
	Single task	Dual task	Single task	Dual task	Single task	Dual task	Single task	Dual task
Pace								
Step velocity (m/s)	1.21 (.28)	1.03 (.29)	1.18 (.28)	.93 (.41)	1.28 (.25)	1.08 (.27)	1.18 (.27)	1.03 (.38)
Step length (m)	.64 (.14)	.59 (.13)	.62 (.09)	.57 (.10)	.66 (.09)	.60 (.13)	.64 (.10)	.60 (.09)
Swing time variability (ms)	14.2 (5.4)	22.8 (12.6)	16.0 (5.8)	28.0 (29.6)	13.5 (4.5)	21.1 (13.5)	15.0 (8.9)	24.5 (23.2)
Rhythm								
Step time (ms)	534.3 (54.4)	580.0 (67.0)	532.6 (4.6)	593.6 (162.8)	521.4 (62.0)	558.5 (100.0)	532.7 (38.4)	572.1 (111.3)
Swing time (ms)	382.6 (39.0)	399.2 (61.0)	384.5 (46.4)	403.8 (104.6)	381.5 (45.5)	393.3 (95.5)	380.8 (34.1)	406.4 (81.5)
Stance time (ms)	684.5 (68.4)	750.8 (151.7)	675.5 (75.0)	773.6 (255.0)	670.4 (77.8)	732.8 (162.6)	683.2 (65.0)	757.3 (167.3)
Variability								
Step velocity variability (m/s)	.05 (.02)	.07 (.03)	.06 (.02)	.08 (.03)	.05 (.01)	.07 (.03)	.05 (.02)	.07 (.03)
Step length variability (m)	.02 (.01)	.03 (.02)	.02 (.01)	.03 (.02)	.02 (.01)	.03 (.02)	.03 (.01)	.03 (.02)
Step time variability (ms)	15.3 (7.4)	31.6 (20.8)	17.8 (6.2)	33.1 (40.1)	14.5 (5.2)	23.8 (20.8)	16.6 (8.8)	33.3 (28.7)
Stance time variability (ms)	17.7 (8.7)	41.8 (32.1)	20.0 (8.7)	43.2 (8.5)	16.8 (4.6)	28.0 (33.0)	19.0 (8.5)	41.0 (50.2)
Asymmetry								
Swing time asymmetry (ms)	8.8 (12.9)	11.8 (18.1)	9.7 (12.7)	12.9 (27.4)	7.2 (11.0)	12.0 (18.1)	8.7 (13.3)	13.0 (21.5)
Step time asymmetry (ms)	14.0 (16.7)	16.9 (22.6)	13.5 (18.0)	22.6 (37.3)	10.3 (14.1)	13.2 (21.4)	12.9 (19.3)	20.7 (29.5)
Stance time asymmetry (ms)	10.2 (12.0)	13.0 (22.7)	10.7 (11.6)	16.6 (25.6)	11.4 (13.2)	16.1 (17.3)	9.0 (13.4)	12.5 (25.8)
Postural control								
Step length asymmetry (m)	.03 (.03)	.03 (.03)	.03 (.02)	.02 (.04)	.03 (.04)	.03 (.03)	.03 (.03)	.03 (.04)
Step width (m)	.09 (.03)	.10 (.04)	.08 (.04)	.09 (.05)	.09 (.04)	.10 (.04)	.08 (.04)	.09 (.04)
Step width variability (m)	.02 (.01)	.02 (.01)	.02 (.01)	.02 (.01)	.02 (.01)	.02 (.01)	.02 (.01)	.02 (.01)
Cognitive task								
Letters recited per trial	6.0 (1.7)	5.8 (2.5)	5.8 (3.3)	5.8 (2.3)	6.7 (2.0)	5.7 (2.8)	5.0 (2.7)	5.7 (1.8)
Cognitive error %	11.1 (20.6)	24.1 (13.1)	16.4 (28.6)	18.9 (30.2)	9.5 (20.0)	15.6 (20.3)	12.1 (30.6)	23.7 (23.3)
Cognitive variability error %	6.0 (10.4)	8.1 (5.9)	8.3 (10.4)	7.9 (7.1)	6.4 (12.5)	5.0 (6.0)	7.0 (10.0)	7.0 (5.0)

Note. *Mdn* = Median; IQR = interquartile range; Cognitive error % = mean error percentage of the cognitive task; Cognitive variability error % = Variability of error percentage of the cognitive task.

Table 3
Absolute Dual-Task Interference for Gait and Cognitive Parameters at Baseline and Follow-Up

Domain	Training group (n = 45), *Mdn* (IQR)			Control group (n = 42), *Mdn* (IQR)			p Value between groups[a]
	Baseline	Follow-up	Diff	Baseline	Follow-up	Diff	
Pace							
Step velocity (m/s)	−.173 (.221)	−.180 (.250)	−.001 (.218)	−.184 (.310)	−.167 (.217)	−.028 (.218)	.290
Step length (m)	−.047 (.070)	−.035 (.080)	−.006 (.056)	−.044 (.076)	−.036 (.052)	−.018 (.058)	.298
Swing time variability (ms)	7.8 (11.7)	6.7 (11.4)	−.9 (10.8)	10.0 (29.1)	8.9 (19.0)	2.9 (16.1)	.084
Rhythm							
Step time (ms)	36.1 (65.5)	38.2 (65.7)	6.5 (49.4)	55.1 (114.1)	47.8 (108.8)	9.3 (64.2)	.662
Swing time (ms)	13.2 (36.2)	16.9 (43.9)	4.5 (40.8)	12.8 (59.1)	17.7 (61.6)	.9 (39.2)	.842
Stance time (ms)	72.9 (109.6)	64.9 (95.8)	3.2 (69.9)	96.0 (171.9)	75.4 (168.0)	9.9 (117.3)	.731
Variability							
Step velocity variability (m/s)	.026 (.029)	.018 (.030)	.002 (.040)	.017 (.028)	.022 (.031)	.00 (.027)	.802
Step length variability (m)	.008 (.016)	.007 (.011)	−.000 (.016)	.008 (.011)	.008 (.014)	.00 (.018)	.246
Step time variability (ms)	13.2 (19.3)	8.7 (16.7)	.9 (18.9)	12.8 (33.1)	12.9 (28.3)	3.6 (22.8)	.352
Stance time variability (ms)	18.2 (29.2)	11.4(21.9)	3.2 (69.9)	21.1 (43.9)	16.7 (43.0)	9.9 (117.3)	.731
Asymmetry							
Swing time asymmetry (ms)	1.4 (9.3)	1.9 (12.5)	−2.5 (11.3)	3.6 (16.8)	3.5 (17.5)	.3 (12.3)	.093
Step time asymmetry (ms)	3.5 (16.5)	3.5 (13.8)	3.4 (16.6)	5.4 (26.4)	4.8 (21.4)	1.2 (19.9)	.462
Stance time asymmetry (ms)	3.2 (12.7)	2.6 (11.4)	−.5 (11.8)	8.1 (19.5)	3.0 (18.0)	3.6 (19.6)	.104
Postural control							
Step length asymmetry (m)	.002 (.025)	.001 (.024)	.007 (.027)	.000 (.027)	−.001 (.029)	.003 (.021)	.422
Step width (m)	.009 (.012)	.009 (.015)	−.001 (.013)	.012 (.015)	.009 (.010)	.002 (.014)	.138
Step width variability (m)	.001 (.006)	.002 (.007)	−.001 (.008)	.000 (.005)	.001 (.006)	−.000 (.005)	.473
Cognitive task							
Cognitive error %	8.8 (18.5)	4.4 (16.2)	5.1 (29.0)	5.9 (28.2)	7.5 (25.3)	−3.6 (25.6)	**.018**
Cognitive variability error %	1.9 (9.2)	−1.6 (10.7)	3.3 (11.0)	1.3 (12.6)	1.4 (8.5)	−.6 (12.9)	**.038**

Note. *Mdn* = Median; IQR = interquartile range; Diff = difference; Cognitive error % = mean error percentage of the cognitive task; Cognitive variability error % = variability of error percentage of the cognitive task. Boldface indicates statistical significance ($p < .05$).
[a] Mann–Whitney U test to determine between-group differences (i.e., computed as the difference between follow-up and baseline performance).

which primarily focused on tasks requiring the continuous emphasis on the added task (e.g., the counting of each step during a couple of minutes). Moreover, because motivation is important both for training adherence and cognitive effort (Ennis, Hess, & Smith, 2013; Slovinec D'Angelo, Pelletier, Reid, & Huta, 2014), the participants were repeatedly instructed regarding the purpose of this type of training, while also receiving repeated encouragements and effort-related feed-back during the training sessions. This may have contributed to the improved dual-task interference of cognitive variability, a measure related to mental fatigue (Lorist, Boksem, & Ridderinkhof, 2005). Another important aspect of the dual-task training was that the participants were always instructed to walk at comfortable speed, with equal attention to both tasks. Although this may have been beneficial with regards to the added task, it may not have encouraged the participants to emphasize the gait performance enough. Indeed, one study that found improved dual-task gait abilities following training (although cognitive dual-task abilities were unaffected) instructed the participants to explicitly prioritize gait or cognition, respectively, during different phases of the training sessions (Yogev-Seligmann, Giladi, Brozgol, & Hausdorff, 2012). On the other hand, a recent randomized trial (Strouwen et al., 2017) comparing integrated dual-task training with consecutive training of both tasks among PwPD, found similar benefits for both approaches, both with regards to gait and cognitive performance. However, these results concern results regarding absolute dual-task performance rather than dual-task interference following training; therefore, further research on training interventions to reduce dual-task interference is needed to enable further conclusions regarding the potential to improve the level of automaticity among PwPD.

The cognitive task used in this study consisted of reciting alternate letters of the alphabet, and may be argued to be related to aspects of executive functions such as working memory, inhibition and verbal fluency (Rabinovici, Stephens, & Possin, 2015). Because different subdomains of executive functioning have been found to represent a common construct (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010), this task may be considered an adequate measure of executive functioning. In addition, it appears reasonable that the difficulty of the added task may impact the performance of gait and/or the added task during dual-tasking. The difficulty of this type of task has been reported to be highly challenging (McIsaac et al., 2015), indicating the requirement of higher order cognitive resources. The supervisory attention system model (Norman & Shallice, 1986) suggests that basic tasks can be performed simultaneously without interference whereas challenging tasks need to be actively supervised. Hence, it could be argued that the task used in this study might have been too difficult to enable automaticity. Rather, this model seemingly suggests the use of less demanding tasks when investigating automaticity. On the other hand, it may be argued that the training group possibly improved automaticity during gait because they improved the performance of the cognitive task while maintaining the gait performance at similar levels as during the baseline assessments. Nevertheless, future research needs to investigate which kind of added task, and at what difficulty level, most appropriately reflects automaticity in PwPD.

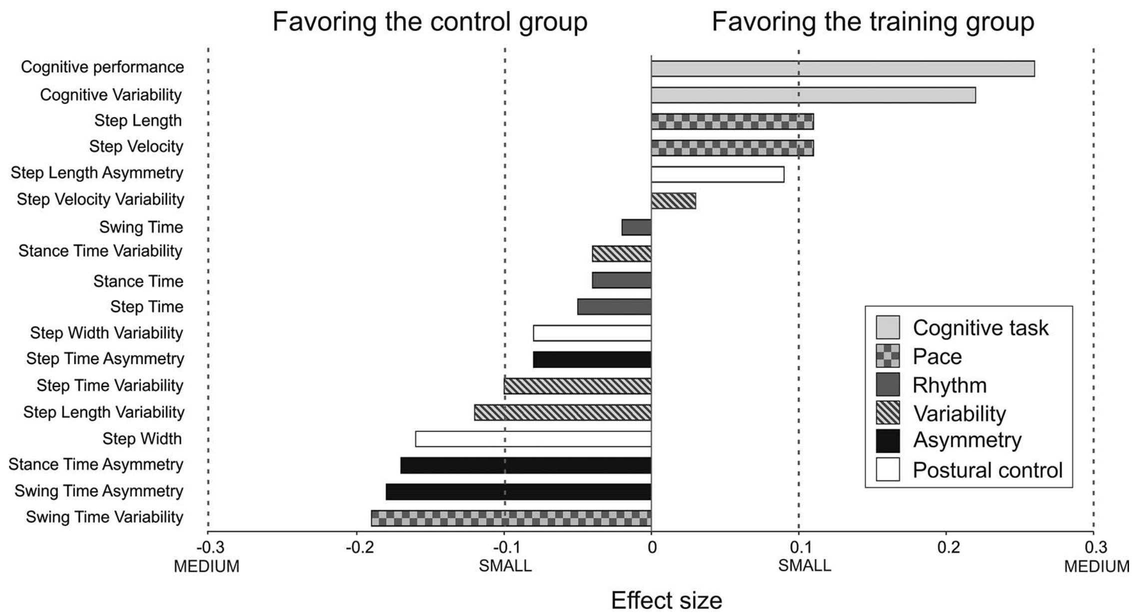

Figure 2. An illustration of between-groups effect sizes for gait and cognitive parameters. The bars pointing to the left indicate more prominent improvements in the control group in comparison to the training group, and the bars pointing to the right indicate more prominent improvements in the training group in comparison to the control group. The dotted lines illustrate small (0.1) and medium (0.3) magnitudes of differences between the groups.

Given the previous uncertainty regarding the adequacy of exposing PwPD to dual-task training, it is encouraging that a program incorporating single-task and dual-task gait as well as balance exercises was able to improve certain aspects of dual-task interference. This, in combination with the previously mentioned findings by Strouwen et al. (2017), supports the potential benefits of including dual-task training into interventions aimed at improving gait and balance abilities and reduce the risk of falling among PwPD. Nevertheless, whereas this research field has mainly focused on the effects of dual-task gait, less is known about the impact of the added task (Plummer & Eskes, 2015). For example, what might the consequences for PwPD be when trying to negotiate in a crowded area, such as a busy train station, if the cognitive processing is too impaired to detect stressed, fast moving people approaching unexpectedly? It appears that research investigating other aspects of dual-tasking, such as divided attention during driving, are more concerned with the decrements of cognitive processing, such as reaction time, than on motor performance (Haque & Washington, 2014). Because dual-task gait is inevitably intertwined with the added task, more research is warranted in order to investigate (a) if gait automaticity is possible to improve in PwPD, (b) the importance of the added task, and (c) if different training modalities target either the motor or the cognitive task more efficiently.

Limitations

This study included PwPD mild to moderate disease severity interested in participating in 10-weeks of gait and balance training. Therefore, these results can only be generalized to this specific population. Another limitation was that we were unable to blind the test assessors to group allocation at follow-up for practical reasons. Moreover, although we analyzed 87 participants, the variability in the sample indicated that future studies need to include more participants. Also, we did not evaluate the effects of dual-task training on different domains of cognitive functioning. Finally, the outcome cognitive variability used in this study is rare in dual-task gait studies. Nevertheless, it is a potentially important measure of cognitive processing robustness that is established in cognitive research, and have been found more sensitive than cognitive performance in predicting executive dysfunction (Lorist et al., 2005; Lövdén, Li, Shing, & Lindenberger, 2007). Indeed, findings from a recent study showed that during dual-task conditions, increased cognitive variability rather than gait variability occurred in PwPD, when compared to healthy controls (Salazar et al., 2017). Therefore, this outcome may be considered in future interventions to enable an improved understanding of the cognitive aspects of dual-tasking in PwPD.

Conclusions

In conclusion, these results indicate that highly challenging gait and balance training including both single-task and dual-task conditions can improve the dual-task interference of cognitive performance as well as cognitive performance variability in PwPD. On the other hand, training did not affect the automaticity of gait performance; instead, training appeared to induce the allocation of attention to the cognitive task. These results may indicate that training led to improved automaticity of cognitive processing during walking, which may have a beneficiary effect on the ability to ambulate safely in the community, thereby improving independence. Future studies are needed in order to investigate whether dual-task interventions should target gait, cognitive abilities, or both.

References

Bloem, B. R., Grimbergen, Y. A., van Dijk, J. G., & Munneke, M. (2006). The "posture second" strategy: A review of wrong priorities in Parkinson's disease. *Journal of the Neurological Sciences, 248,* 196–204. http://dx.doi.org/10.1016/j.jns.2006.05.010

Brandler, T. C., Oh-Park, M., Wang, C., Holtzer, R., & Verghese, J. (2012). Walking while talking: Investigation of alternate forms. *Gait & Posture, 35,* 164–166. http://dx.doi.org/10.1016/j.gaitpost.2011.08.003

Brauer, S. G., & Morris, M. E. (2010). Can people with Parkinson's disease improve dual tasking when walking? *Gait & Posture, 31,* 229–233. http://dx.doi.org/10.1016/j.gaitpost.2009.10.011

Burton, C. L., Strauss, E., Hultsch, D. F., Moll, A., & Hunter, M. A. (2006). Intraindividual variability as a marker of neurological dysfunction: A comparison of Alzheimer's disease and Parkinson's disease. *Journal of Clinical and Experimental Neuropsychology, 28,* 67–83. http://dx.doi.org/10.1080/13803390490918318

Clark, D. J. (2015). Automaticity of walking: Functional significance, mechanisms, measurement and rehabilitation strategies. *Frontiers in Human Neuroscience, 9,* 246. http://dx.doi.org/10.3389/fnhum.2015.00246

Conradsson, D., Löfgren, N., Nero, H., Hagströmer, M., Ståhle, A., Lökk, J., & Franzén, E. (2015). The effects of highly challenging balance training in elderly with Parkinson's disease: A randomized controlled trial. *Neurorehabilitation and Neural Repair, 29,* 827–836. http://dx.doi.org/10.1177/1545968314567150

Conradsson, D., Löfgren, N., Ståhle, A., & Franzén, E. (2014). Is highly challenging and progressive balance training feasible in older adults with Parkinson's disease? *Archives of Physical Medicine and Rehabilitation, 95,* 1000–1003. http://dx.doi.org/10.1016/j.apmr.2013.10.024

Conradsson, D., Löfgren, N., Ståhle, A., Hagströmer, M., & Franzén, E. (2012). A novel conceptual framework for balance training in Parkinson's disease-study protocol for a randomised controlled trial. *BMC Neurology, 12,* 111. http://dx.doi.org/10.1186/1471-2377-12-111

Dirnberger, G., & Jahanshahi, M. (2013). Executive dysfunction in Parkinson's disease: A review. *Journal of Neuropsychology, 7,* 193–224. http://dx.doi.org/10.1111/jnp.12028

Dubois, B., & Pillon, B. (1997). Cognitive deficits in Parkinson's disease. *Journal of Neurology, 244,* 2–8. http://dx.doi.org/10.1007/PL00007725

Ennis, G. E., Hess, T. M., & Smith, B. T. (2013). The impact of age and motivation on cognitive effort: Implications for cognitive engagement in older adulthood. *Psychology and Aging, 28,* 495–504. http://dx.doi.org/10.1037/a0031255

Fasano, A., Canning, C. G., Hausdorff, J. M., Lord, S., & Rochester, L. (2017). Falls in Parkinson's disease: A complex and evolving picture. *Movement Disorders, 32,* 1524–1536. http://dx.doi.org/10.1002/mds.27195

Fasano, A., Plotnik, M., Bove, F., & Berardelli, A. (2012). The neurobiology of falls. *Neurological Sciences, 33,* 1215–1223. http://dx.doi.org/10.1007/s10072-012-1126-6

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189–198. http://dx.doi.org/10.1016/0022-3956(75)90026-6

Fritz, C. O., Morris, P. E., & Richler, J. J. (2012). Effect size estimates: Current use, calculations, and interpretation. *Journal of Experimental Psychology: General, 141,* 2–18. http://dx.doi.org/10.1037/a0024338

Fritz, N. E., Cheek, F. M., & Nichols-Larsen, D. S. (2015). Motor-cognitive dual-task training in persons with neurologic disorders: A systematic review. *Journal of Neurologic Physical Therapy, 39,* 142–153. http://dx.doi.org/10.1097/NPT.0000000000000090

Gilat, M., Bell, P. T., Ehgoetz Martens, K. A., Georgiades, M. J., Hall, J. M., Walton, C. C., . . . Shine, J. M. (2017). Dopamine depletion impairs gait automaticity by altering cortico-striatal and cerebellar processing in Parkinson's disease. *NeuroImage, 152,* 207–220. http://dx.doi.org/10.1016/j.neuroimage.2017.02.073

Ginis, P., Nieuwboer, A., Dorfman, M., Ferrari, A., Gazit, E., Canning, C. G., . . . Mirelman, A. (2016). Feasibility and effects of home-based smartphone-delivered automated feedback training for gait in people with Parkinson's disease: A pilot randomized controlled trial. *Parkinsonism & Related Disorders, 22,* 28–34. http://dx.doi.org/10.1016/j.parkreldis.2015.11.004

Haque, M. M., & Washington, S. (2014). A parametric duration model of the reaction times of drivers distracted by mobile phone conversations. *Accident; Analysis and Prevention, 62,* 42–53. http://dx.doi.org/10.1016/j.aap.2013.09.010

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

Hollman, J. H., McDade, E. M., & Petersen, R. C. (2011). Normative spatiotemporal gait parameters in older adults. *Gait & Posture, 34,* 111–118. http://dx.doi.org/10.1016/j.gaitpost.2011.03.024

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

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice Hall.

Karatekin, C., Couperus, J. W., & Marcus, D. J. (2004). Attention allocation in the dual-task paradigm as measured through behavioral and psychophysiological responses. *Psychophysiology, 41,* 175–185. http://dx.doi.org/10.1111/j.1469-8986.2004.00147.x

Keus, S. H., Bloem, B. R., Hendriks, E. J., Bredero-Cohen, A. B., & Munneke, M., & the Practice Recommendations Development Group. (2007). Evidence-based analysis of physical therapy in Parkinson's disease with recommendations for practice and research. *Movement Disorders, 22,* 451–460. http://dx.doi.org/10.1002/mds.21244

Li, S. C., Huxhold, O., & Schmiedek, F. (2004). Aging and attenuated processing robustness. Evidence from cognitive and sensorimotor functioning. *Gerontology, 50,* 28–34. http://dx.doi.org/10.1159/000074386

Lindemann, U., Najafi, B., Zijlstra, W., Hauer, K., Muche, R., Becker, C., & Aminian, K. (2008). Distance to achieve steady state walking speed in frail elderly persons. *Gait & Posture, 27,* 91–96. http://dx.doi.org/10.1016/j.gaitpost.2007.02.005

Lord, S., Galna, B., & Rochester, L. (2013). Moving forward on gait measurement: Toward a more refined approach. *Movement Disorders, 28,* 1534–1543. http://dx.doi.org/10.1002/mds.25545

Lord, S., Galna, B., Verghese, J., Coleman, S., Burn, D., & Rochester, L. (2013). Independent domains of gait in older adults and associated motor and nonmotor attributes: Validation of a factor analysis approach. *The Journals of Gerontology Series A, Biological Sciences and Medical Sciences, 68,* 820–827. http://dx.doi.org/10.1093/gerona/gls255

Lorist, M. M., Boksem, M. A., & Ridderinkhof, K. R. (2005). Impaired cognitive control and reduced cingulate activity during mental fatigue. *Cognitive Brain Research, 24,* 199–205. http://dx.doi.org/10.1016/j.cogbrainres.2005.01.018

Lövdén, M., Li, S. C., Shing, Y. L., & Lindenberger, U. (2007). Within-person trial-to-trial variability precedes and predicts cognitive decline in old and very old age: Longitudinal data from the Berlin Aging Study. *Neuropsychologia, 45,* 2827–2838. http://dx.doi.org/10.1016/j.neuropsychologia.2007.05.005

Martínez-Martín, P., Gil-Nagel, A., Gracia, L. M., Gómez, J. B., Martínez-Sarriés, J., & Bermejo, F., & the Cooperative Multicentric Group. (1994). Unified Parkinson's Disease Rating Scale characteristics and structure. *Movement Disorders, 9,* 76–83. http://dx.doi.org/10.1002/mds.870090112

McCabe, D. P., Roediger, H. L., McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The relationship between working memory capacity and executive functioning: Evidence for a common executive attention construct. *Neuropsychology, 24,* 222–243. http://dx.doi.org/10.1037/a0017619

McIsaac, T. L., Lamberg, E. M., & Muratori, L. M. (2015). Building a framework for a dual task taxonomy. *BioMed Research International, 2015,* 591475. http://dx.doi.org/10.1155/2015/591475

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behaviour. In G. S. R. Davidson & D. Shapiro (Eds.), *Consciousness and self-regulation: Advances in research and theory* (Vol. 4, pp. 1–18). Boston, MA: Springer. http://dx.doi.org/10.1007/978-1-4757-0629-1_1

Plummer, P., & Eskes, G. (2015). Measuring treatment effects on dual-task performance: A framework for research and clinical practice. *Frontiers in Human Neuroscience, 9,* 225. http://dx.doi.org/10.3389/fnhum.2015.00225

Rabinovici, G. D., Stephens, M. L., & Possin, K. L. (2015). Executive dysfunction. *Continuum: Lifelong Learning in Neurology, 21,* 646–659. http://dx.doi.org/10.1212/01.CON.0000466658.05156.54

Rochester, L., Galna, B., Lord, S., & Burn, D. (2014). The nature of dual-task interference during gait in incident Parkinson's disease. *Neuroscience, 265,* 83–94. http://dx.doi.org/10.1016/j.neuroscience.2014.01.041

Salazar, R. D., Ren, X., Ellis, T. D., Toraif, N., Barthelemy, O. J., Neargarder, S., & Cronin-Golomb, A. (2017). Dual tasking in Parkinson's disease: Cognitive consequences while walking. *Neuropsychology, 31,* 613–623. http://dx.doi.org/10.1037/neu0000331

Schneider, W., & Chein, J. M. (2003). Controlled & automatic processing: Behavior, theory, and biological mechanisms. *Cognitive Science, 27,* 525–559. http://dx.doi.org/10.1207/s15516709cog2703_8

Slovinec D'Angelo, M. E., Pelletier, L. G., Reid, R. D., & Huta, V. (2014). The roles of self-efficacy and motivation in the prediction of short- and long-term adherence to exercise among patients with coronary heart disease. *Health Psychology, 33,* 1344–1353. http://dx.doi.org/10.1037/hea0000094

Strouwen, C., Molenaar, E. A., Münks, L., Keus, S. H., Bloem, B. R., Rochester, L., & Nieuwboer, A. (2015). Dual tasking in Parkinson's disease: Should we train hazardous behavior? *Expert Review of Neurotherapeutics, 15,* 1031–1039. http://dx.doi.org/10.1586/14737175.2015.1077116

Strouwen, C., Molenaar, Ealm, Munks, L., Keus, S. H. J., Zijlmans, J. C. M., Vandenberghe, W., . . . Nieuwboer, A. (2017). Training dual tasks together or apart in Parkinson's disease: Results from the DUALITY trial. *Movement Disorders, 32,* 1201–1210. http://dx.doi.org/10.1002/mds.27014

Tomlinson, C. L., Stowe, R., Patel, S., Rick, C., Gray, R., & Clarke, C. E. (2010). Systematic review of levodopa dose equivalency reporting in Parkinson's disease. *Movement Disorders, 25,* 2649–2653. http://dx.doi.org/10.1002/mds.23429

Verghese, J., Buschke, H., Viola, L., Katz, M., Hall, C., Kuslansky, G., & Lipton, R. (2002). Validity of divided attention tasks in predicting falls in older individuals: A preliminary study. *Journal of the American Geriatrics Society, 50,* 1572–1576. http://dx.doi.org/10.1046/j.1532-5415.2002.50415.x

Wild, L. B., de Lima, D. B., Balardin, J. B., Rizzi, L., Giacobbo, B. L., Oliveira, H. B., . . . Bromberg, E. (2013). Characterization of cognitive and motor performance during dual-tasking in healthy older adults and patients with Parkinson's disease. *Journal of Neurology, 260,* 580–589. http://dx.doi.org/10.1007/s00415-012-6683-3

Wu, T., Hallett, M., & Chan, P. (2015). Motor automaticity in Parkinson's disease. *Neurobiology of Disease, 82,* 226–234. http://dx.doi.org/10.1016/j.nbd.2015.06.014

Yogev-Seligmann, G., Giladi, N., Brozgol, M., & Hausdorff, J. M. (2012). A training program to improve gait while dual tasking in patients with Parkinson's disease: A pilot study. *Archives of Physical Medicine and Rehabilitation, 93,* 176–181. http://dx.doi.org/10.1016/j.apmr.2011.06.005

Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2012). Do we always prioritize balance when walking? Towards an integrated model of task prioritization. *Movement Disorders, 27,* 765–770. http://dx.doi.org/10.1002/mds.24963

Received February 23, 2018
Revision received July 11, 2018
Accepted July 17, 2018 ■