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The Effects of a Secondary Task on Forward and Backward Walking in Parkinson's Disease

Madeleine E. Hackney, PhD[1] and Gammon M. Earhart, PhD[1]

Abstract

Background. People with Parkinson's disease (PD) often fall while multitasking or walking backward, unavoidable activities in daily living. Dual tasks involving cognitive demand during gait and unfamiliar motor skills, such as backward walking, could identify those with fall risk, but dual tasking while walking backward has not been examined in those with PD, those who experience freezing of gait (FOG), or healthy older controls. *Methods.* A total of 78 people with PD (mean age = 65.1 ± 9.5 years; female, 28%) and 74 age-matched and sex-matched controls (mean age = 65.0 ± 10.0 years; female, 23%) participated. A computerized walkway measured gait velocity, stride length, swing percent, stance percent, cadence, heel to heel base of support, functional ambulation profile, and gait asymmetry during forward and backward walking with and without a secondary cognitive task. *Results.* Direction and task effects on walking performance were similar between healthy controls and those with PD. However, those with PD were more affected than controls, and freezers were more affected than nonfreezers, by backward walking and dual tasking. Walking backward seemed to affect gait more than dual tasking in those with PD, although the subset of freezers appeared particularly affected by both challenges. *Conclusion.* People with PD are impaired while performing complex motor and mental tasks simultaneously, which may put them at risk for falling. Those with FOG are more adversely affected by both motor and mental challenges than those without. Evaluation of backward walking while performing a secondary task might be an effective clinical tool to identify locomotor difficulties.

Introduction

Falls are common among individuals with Parkinson's disease (PD), a progressive neurodegenerative movement disorder affecting more than 1 million people in the United States.[1,2] Many falls occur while those with PD attempt to perform multiple tasks simultaneously[3] or are moving backward or perturbed in the backward direction.[4] Some clinicians may recommend that those with PD are taught to avoid multitasking and walking backward, but these skills are unavoidable and are necessary in activities of daily living (ADLs), such as when backing out of the closet after removing an item of clothing.[5]

Both dual tasking and walking backward may impair gait and balance in those with PD. Gait speed, stride length, and stability decrease when individuals with PD walk while concurrently performing another task such as mental arithmetic.[6-9] Impaired multiple task performance may double the risk of sustaining a fall while performing an ADL.[3] Backward gait of older individuals is characterized by lesser velocity, cadence, increased double support time, and shorter stride length and swing phase than younger people[10] (M.E.H and G.M.E, unpublished data). Walking backward is further impaired in those with PD and particularly in those who experience freezing of gait (FOG).[11]

Freezing of gait is a debilitating phenomenon, affecting 53% of patients who have had PD more than 5 years.[12] FOG correlates with balance and lower limb/gait-related symptoms at the onset of PD.[13,14] Gait variability, asymmetry, and dysrhythmicity may contribute to FOG, as bilateral coordination appears to be impaired in those who experience FOG.[15-17] Dual tasking can elicit FOG in some individuals with PD, and affective and cognitive characteristics may be predisposing factors for FOG development,

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perhaps even playing an intrinsic role in its underlying mechanisms.[18]

Because individuals with PD in general, and particularly those with FOG, may have difficulty modulating gait parameters according to task, gait analysis in PD should include functional locomotor tasks beyond simple forward walking.[19] Dual tasks involving mental operations during gait might be used as clinical tests to identify those at greater risk for falling.[20,21] No study has examined dual tasking while walking backward in PD. This study aimed to quantify dual tasking while walking forward and backward in those with mild to moderate PD in comparison to a matched control group. A portion of the data for forward and backward walking in the absence of a secondary task has been published previously[11] and these data are included only as reference points for the dual task forward and dual task backward walking conditions. Dual task data have not been published previously in any form.

Methods

This work was approved by the Human Research Protection Office at Washington University in St. Louis. All participants provided written informed consent before participation.

Participants

All participants, both individuals with PD and healthy age-matched controls were recruited from the St. Louis community through advertisement at support groups and community events, from a database that follows approximately 2000 people with PD and from Volunteers for Health, a Washington University database of individuals interested in research. Although some participants self-identified, most were directly recruited via telephone, and several were randomly asked to participate at a public site distant to the laboratory. Data files were coded for participant confidentiality. Participants were informally scrutinized for cognitive dysfunction during a health screening questionnaire in an interview process. All participants were personally able to answer the questions during the health screening and all participants with PD had been previously screened by their neurologists for cognitive dysfunction. None of the participants had been diagnosed with dementia. All participants signed their own consent forms and were fully cognizant of the study procedures to which they were agreeing.

A total of 78 people with PD (mean age = 65.1 ± 9.5 years; female, 28%) and 74 age-matched and sex-matched controls (mean age = 65.0 ± 10.0 years; female, 23%) participated. Potential participants with PD were excluded if they had history or evidence of neurological deficit other than PD. All participants with PD had a diagnosis of idiopathic PD using criteria for clinically defined "definite PD,"[22-24] demonstrated clear benefit from levodopa, were tested on medications at a time of self-determined optimal performance, and could walk at least 3 m without an assistive device. Participants were evaluated using the Unified Parkinson's Disease Rating Scale Motor Subscale 3 (UPDRS)[25,26] and classified according to Hoehn and Yahr stages.[27] Freezing status was determined by the Freezing of Gait questionnaire.[28] Participants were considered freezers if they had a score >1 on item 3 on this questionnaire, indicating freezing frequency of more than once per week.[29]

Spatiotemporal Gait Parameters

A 5-m instrumented, computerized GAITRite walkway (CIR Systems, Inc, Havertown, PA) measured gait parameters. Participants began walking prior to reaching the mat and were requested to walk completely across and off the mat for several feet before stopping. First, participants performed "simple" conditions by walking at their normal or "comfortable" pace forward and then backward, performing 3 trials of each direction. Next, participants performed "dual" conditions by walking forward while performing a mental arithmetic task aloud. This procedure was repeated while participants walked backward. Participants were not given any practice attempts at the tasks. Tasks consisted of one trial each of counting backward from 100 by threes, from 50 by fours and from 75 by sixes. This order, that is, beginning from 100, then from 50, and so on, was observed for all participants for both forward and backward dual task conditions. This strict task order may have resulted in potential practice effects. Performance in backward dual task may have been better than it would have been if novel operations had been used. Nevertheless, most individuals commented only on task difficulty and did not appear to notice task repetition. Furthermore, as all groups were tested identically, the test order and use of identical math operations for forward and backward directions should not have differentially affected groups and likely cannot account for differences noted between groups. Responses were categorized as "correct" or "error" if the given mathematical operation was conducted successfully or unsuccessfully. If participants erred once in calculation but were correct subsequently, only one error was noted. To compare performance across subjects, we calculated the percentage of correct answers given on each trial.

Participants were given adequate rest time and allowed to sit between trials as needed. No participants reported fatigue, likely because of the short walking distance and limited number of trials. Results from trials of each condition were averaged. Primary variables of interest were gait velocity, stride length, swing percent, stance percent, cadence, heel to heel base of support (BOS), functional ambulation profile (FAP, also known as Functional Ambulation Performance) and gait asymmetry (GA). GA reflects

the bilateral lower extremity coordination of swing durations during gait and was calculated as follows:

GA = 100 × abs (ln (Swing time right/Swing time left))

as per the method of Yogev et al.[30] Higher values of GA indicate more asymmetry. FAP values range from 0 to 100 and comprise the linear relationship of step length/leg length ratio to step time when velocity is normalized to leg length. A valid and reliable numerical representation of gait performance,[31] FAP aims to quantify variability in gait and distinguishes between people with and without PD.[32] Higher values of FAP indicate less variable performance from stride to stride. For more specifics about FAP calculation, please see Hackney and Earhart.[11]

Statistical Analyses

Statistical significance was determined by $2 \times 2 \times 2$ repeated-measures analyses of variance (ANOVAs; group [PD vs Control or Freezer vs Nonfreezer] × direction [forward vs backward] × task [simple vs dual]) when comparing those with PD with Controls, and when comparing Freezers with Nonfreezers. Tukey–Kramer multiple-comparison tests were used to examine pair-wise differences between means. Values presented are mean ± standard deviation (SD). The overall level of significance was set at $P = .05$, but was Bonferroni-corrected to account for multiple comparisons; therefore, the level of significance for any given test in the 8 spatiotemporal gait parameters was $P \leq .00625$, whereas the significance level set for the 4 variables related to the performance on the mental arithmetic task was $P < .0125$.

Results

Individuals With PD Versus Age-Matched and Sex-Matched Controls

Hoehn and Yahr scale scores of those with PD ranged from 0.5 to 3 (1 each at stages 0.5 and 1, 11 at stage 1.5, 49 at stage 2, 8 at stage 2.5, and 8 at stage 3). They had an average UPDRS motor subscale 3 score of 27.5 ± 9.2 and disease duration of 8.2 ± 5.0 years. A total of 45% of those with PD were freezers. Those with PD and Controls did not differ significantly in age.

Performance on the mental arithmetic task. Individuals with PD performed the mental arithmetic tasks with 83.4% ± 20% accuracy while walking forward (mean correct, 4.2 ± 2.3; errors, 0.6 ± 0.6; rate of answering, 0.71 ± 0.4 answers/s) and 85.1% ± 22% accuracy while walking backward (mean correct, 5.2 ± 3.2; errors, 0.6 ± 0.8; rate of answering, 0.50 ± 0.3 answers/s). Controls performed the

mental arithmetic task with 85.5% ± 15% accuracy while walking forward (mean correct, 4.6 ± 1.9; errors, 0.7 ± 1.2; rate of answering, 0.84 ± 0.4 answers/s) and 89.9% ± 10% accuracy while walking backward (mean correct, 6.0 ± 2.5; errors, 0.6 ± 0.8; rate of answering, 0.76 ± 0.3 answers/s).

With respect to group, there were no significant differences in percentage of answers correctly given, average number of correct answers given or average number of errors made between those with PD and Controls. Individuals with PD gave fewer answers per second than Controls ($P < .001$). With respect to direction, more correct answers were given, the percentage of correct answers was higher, and fewer answers per second were given while walking backward as compared with walking forward ($P < .001$ for all).

Spatiotemporal gait parameters. There were significant main effects of group, direction, and task, significant 2-way group × task, direction × task, and group × direction interactions, and significant 3-way interactions between group, direction, and task (Table 1). Only significant interactions are presented in the following paragraphs.

Main effects of group, task, and direction. With respect to group, those with PD walked more slowly (Figure 1A), with shorter strides (Figure 1B), lesser swing percent (Figure 1C), greater stance percent (Figure 1D), and lower FAP values (Figure 1G) than Controls. With respect to task, participants walked more slowly, with shorter strides, lesser swing percent, greater stance percent, lower FAP values, wider BOS (Figure 1F), and greater asymmetry (Figure 1H) with the addition of a secondary cognitive task. With respect to direction, participants walked backward more slowly, with shorter strides, lesser swing percent, greater stance percent, lower FAP values, and wider BOS as compared with forward walking.

Interactions between group and task. Those with PD had shorter strides and lower FAP values than controls while performing simple tasks or dual tasks, and lesser swing percent than controls while performing dual tasks. Both groups had shorter strides, lesser swing percent and lower FAP values while performing dual tasks than while performing simple tasks (Figures 1B, 1C, and 1G).

Interactions between direction and task. Participants completed dual task forward walking and simple backward walking more slowly, with shorter strides, lesser swing percent, greater stance percent, and lower FAP values relative to simple forward walking. Participants walked more slowly, with shorter strides, and lower FAP values during simple backward walking as compared with dual task forward walking. Participants also walked more slowly with shorter strides and lower FAP values during dual task backward as compared with simple backward walking (Figures 1A, 1B, and 1G). Finally, participants demonstrated less swing percent and greater stance percent during dual task

Table 1. Main Effects and 2-Way Interactions[a]: Parkinson Disease (PD) Versus Control

Main Effects	Velocity (m/s)	Stride Length (m)	Swing Percent	Stance Percent	Cadence (steps/min)	Base of Support (m)	Functional Ambulation Profile	Gait Asymmetry
Group								
Control	**0.9 ± 0.3**	**1.12 ± 0.27**	**34.5 ± 3.3**	**65.5 ± 3.5**	92 ± 23	0.15 ± 0.06	**78 ± 19**	6.7 ± 11
PD	**0.8 ± 0.4**	**0.93 ± 0.36**	**31.4 ± 5.0**	**68.7 ± 5.1**	98 ± 25	0.15 ± 0.06	**71 ± 21**	8.3 ± 14
Task								
Simple	**1.0 ± 0.3**	**1.08 ± 0.32**	**34.1 ± 3.5**	**66.0 ± 3.6**	**108 ± 17**	**0.14 ± 0.06**	**81 ± 19**	**5.5 ± 11**
Dual	**0.7 ± 0.3**	**0.97 ± 0.31**	**31.8 ± 5.1**	**68.3 ± 5.3**	**82 ± 24**	**0.15 ± 0.07**	**68 ± 19**	**9.6 ± 14**
Direction								
Forward	**1.0 ± 0.3**	**1.22 ± 0.32**	**34.1 ± 3.6**	**65.9 ± 3.6**	95 ± 22	**0.10 ± 0.04**	**86 ± 16**	6.5 ± 10
Backward	**0.65 ± 0.3**	**0.82 ± 0.29**	**31.7 ± 5.0**	**68.4 ± 5.2**	95 ± 27	**0.19 ± 0.05**	**62 ± 16**	8.6 ± 15
Group × task								
Control simple	1.0 ± 0.3	**1.16 ± 0.27**	35.3 ± 2.5	64.8 ± 2.3	106 ± 12	0.15 ± 0.06	86 ± 15	3.8 ± 5.1
PD simple	0.9 ± 0.4	**1.00 ± 0.37**	33.0 ± 3.9	67.1 ± 4.2	110 ± 20	0.14 ± 0.06	77 ± 20	7.1 ± 15
Control dual	0.7 ± 0.3	**1.09 ± 0.27**	33.8 ± 3.9	66.3 ± 4.2	79 ± 23	0.15 ± 0.07	71 ± 19	9.7 ± 15
PD dual	0.6 ± 0.3	**0.86 ± 0.34**	29.9 ± 5.4	70.2 ± 5.5	86 ± 25	0.15 ± 0.07	65 ± 19	9.6 ± 13
Direction × task								
Simple forward	**1.2 ± 0.2**	**1.30 ± 0.20**	**35.1 ± 2.1**	**64.9 ± 2.1**	107 ± 11	0.10 ± 0.03	**95 ± 6.7**	3.7 ± 4
Dual forward	**0.8 ± 0.3**	**1.15 ± 0.28**	**33.2 ± 4.4**	**66.8 ± 4.5**	83 ± 23	0.10 ± 0.04	**78 ± 18**	9.4 ± 14
Simple backward	**0.8 ± 0.3**	**0.85 ± 0.28**	**33.1 ± 4.2**	**67.1 ± 4.4**	109 ± 21	0.19 ± 0.05	**67 ± 16**	7.3 ± 15
Dual backward	**0.5 ± 0.2**	**0.79 ± 0.28**	**30.4 ± 5.4**	**69.8 ± 5.6**	82 ± 25	0.20 ± 0.05	**57 ± 14**	9.9 ± 14
Group × direction								
Control forward	**1.0 ± 0.3**	**1.29 ± 0.22**	**35.3 ± 2.6**	**64.7 ± 2.6**	92 ± 21	**0.10 ± 0.04**	**89 ± 16**	6.4 ± 12
PD forward	**1.0 ± 0.3**	**1.16 ± 0.27**	**33.0 ± 4.0**	**67.0 ± 4.1**	98 ± 22	**0.11 ± 0.04**	**84 ± 16**	6.6 ± 9
Control backward	**0.7 ± 0.3**	**0.95 ± 0.24**	**33.8 ± 3.8**	**66.4 ± 4.0**	92 ± 24	**0.20 ± 0.04**	**68 ± 15**	7.1 ± 11
PD backward	**0.6 ± 0.3**	**0.69 ± 0.29**	**29.8 ± 5.3**	**70.3 ± 5.5**	99 ± 29	**0.19 ± 0.06**	**57 ± 15**	10 ± 17

[a] Values are mean ± standard deviation. Bold entries indicate significant results.

backward walking as compared with either simple backward or dual task forward walking.

Interactions between group and direction. Participants with PD walked more slowly, with shorter strides, lesser swing percent, greater stance percent, and lower FAP values than Controls in forward and backward walking (Figures 1A, 1B, 1C, 1D, and 1G).

Interactions between group, task, and direction. Participants with PD and Controls walked with a wider BOS in simple backward walking and dual task backward walking as compared with simple forward walking and dual task forward walking. In addition, those with PD walked with a wider BOS than did Controls during dual task forward walking (Figure 1F). Those with PD also had lesser swing percent ($P = .031$) and greater stance percent ($P = .013$) than Controls in all 4 walking conditions, but these results were not statistically significant given the Bonferroni correction.

Freezer Versus Nonfreezer Comparisons

This section compares the performance of those with PD who were classified as Freezers to those with PD who were classified as Nonfreezers. Freezers had PD for a greater duration than Nonfreezers (Freezers, 10.5 ± 5.9 years; Nonfreezers, 6.4 ± 3.7 years; $P = .002$), but did not differ from Nonfreezers with respect to disease severity (UPDRS Freezers, 29.2 ± 9.6; Nonfreezers, 26.2 ± 8.7; $P = .150$).

Performance on the mental arithmetic task: freezers versus nonfreezers. Freezers performed the mental arithmetic tasks with 81.9% ± 20% accuracy while walking forward (mean correct, 4.6 ± 2.3; errors, 0.7 ± 0.6; rate of answering, 0.62 ± 0.3 answers/s) and 80.6% ± 26% accuracy while walking backward (mean correct, 5.6 ± 3.6; errors, 0.8 ± 1.1; rate of answering, 0.46 ± 0.3 answers/s). Nonfreezers performed the mental arithmetic task with 84.6% ± 21% accuracy while walking forward (mean correct, 3.9 ± 2.2; errors, 0.5 ± 0.5; rate of answering, 0.78 ± 0.4 answers/s) and 88.6% ± 19% accuracy while walking backward (mean correct, 4.9 ± 2.8; errors, 0.4 ± 0.4; rate of answering, 0.53 ± 0.4).

With respect to group, there were no significant differences in percentage of answers correctly given, or number of correct answers given between Freezers and Nonfreezers. Freezers made more errors than Nonfreezers ($P = .020$), but this was not significant with the Bonferroni correction. With respect to direction, more correct answers were given and fewer answers per second were given while walking backward as compared with walking forward ($P < .001$ for both).

Spatiotemporal gait parameters: freezers versus nonfreezers. There were significant main effects of group, task, and
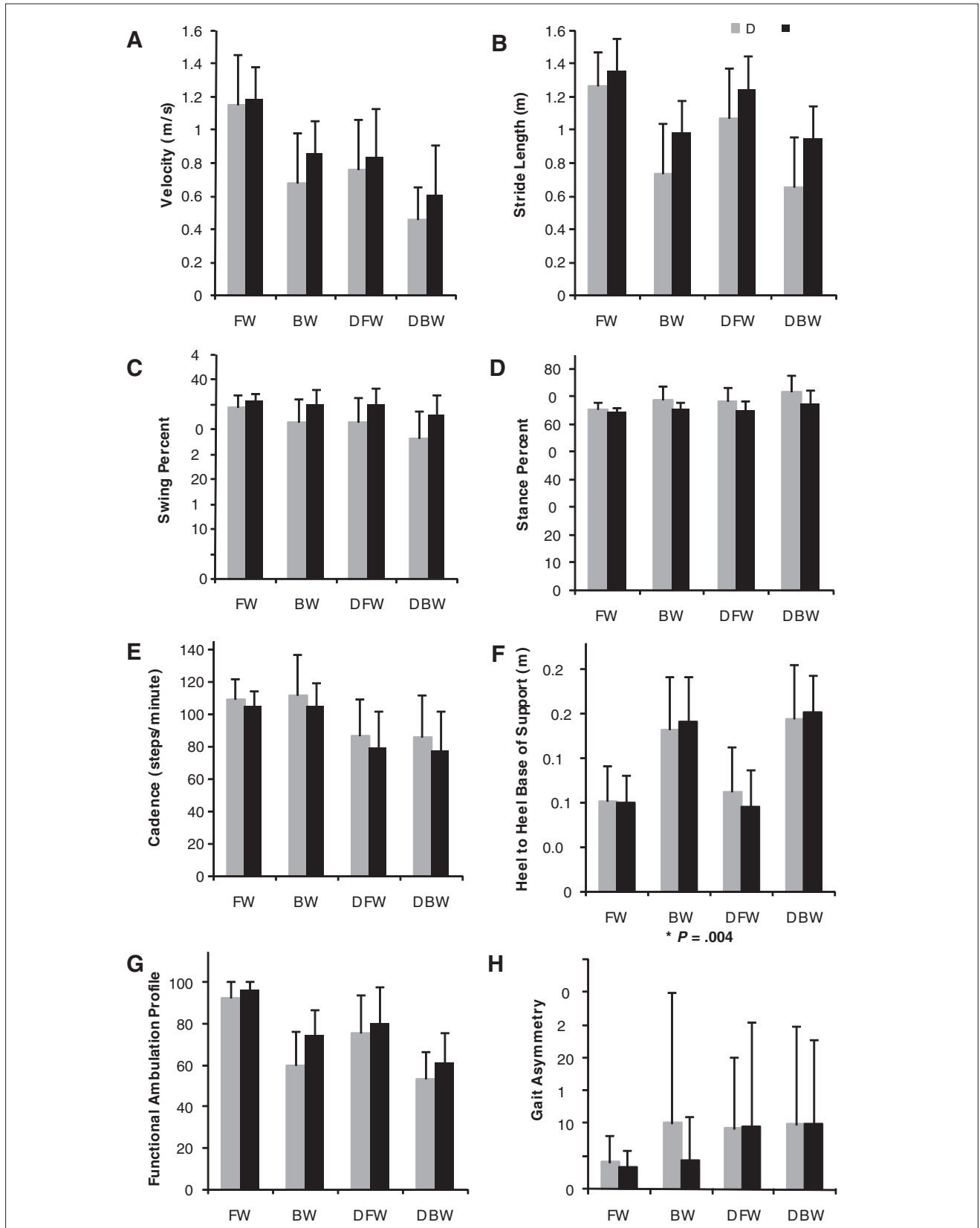
Figure 1. Walking velocity (A), stride length (B), swing percent (C), stance percent (D), cadence (E), base of support (F), functional ambulation profile scores (G), and gait asymmetry (H) of individuals with Parkinson disease (PD; light gray bars), and Controls (black bars) in forward walking (FW), backward walking (BW), dual task forward walking (DT), and dual task backward walking (DTB). Values are mean ± standard deviation. *Significant 3-way interaction between group, task, and direction.

Table 2. Main Effects and 2-Way Interactions[a]: Freezer Versus Nonfreezer

Main Effects	Velocity (m/s)	Stride Length (m)	Swing Percent	Stance Percent	Cadence (steps/min)	Base of Support (m)	Functional Ambulation Profile	Gait Asymmetry
Group								
Nonfreezer	**0.8 ± 0.4**	0.98 ± 0.36	**32.6 ± 4.2**	**67.4 ± 4.2**	100 ± 22	0.14 ± 0.06	**74 ± 20**	**7.2 ± 12**
Freezer	**0.7 ± 0.4**	0.86 ± 0.35	**30.0 ± 5.4**	**70.2 ± 5.7**	97 ± 29	0.16 ± 0.07	**66 ± 20**	**9.8 ± 1**
Task								
Simple	**0.9 ± 0.4**	**1.00 ± 0.37**	**33.0 ± 3.9**	**67.1 ± 4.2**	**110 ± 20**	**0.14 ± 0.06**	**77 ± 20**	7.1 ± 15
Dual	**0.6 ± 0.3**	**0.86 ± 0.34**	**30.0 ± 5.4**	**70.2 ± 5.5**	**86 ± 35**	**0.15 ± 0.07**	**65 ± 19**	9.6 ± 13
Direction								
Forward	**1.0 ± 0.3**	**1.16 ± 0.27**	**33.0 ± 4.0**	**67.0 ± 4.1**	98 ± 22	**0.11 ± 0.04**	**84 ± 16**	**6.6 ± 9**
Backward	**0.6 ± 0.3**	**0.69 ± 0.30**	**29.8 ± 5.3**	**70.3 ± 5.5**	99 ± 29	**0.19 ± 0.05**	**57 ± 15**	**10 ± 17**
Group × task								
Nonfreezer simple	1.0 ± 0.4	1.05 ± 0.33	33.8 ± 3.6	66.3 ± 3.5	110 ± 18	0.14 ± 0.06	79 ± 20	6.5 ± 13
Freezer simple	0.9 ± 0.4	0.93 ± 0.36	32.0 ± 4.0	68.2 ± 4.7	111 ± 20	0.15 ± 0.06	74 ± 21	7.8 ± 16
Nonfreezer dual	0.7 ± 0.3	0.92 ± 0.34	31.5 ± 4.5	68.6 ± 4.5	90 ± 22	0.14 ± 0.06	69 ± 20	7.8 ± 12
Freezer dual	0.5 ± 0.2	0.78 ± 0.33	27.9 ± 5.8	72.2 ± 6.0	82 ± 27	0.17 ± 0.07	59 ± 16	12 ± 14
Direction × task								
Simple forward	**1.2 ± 0.3**	**1.26 ± 0.24**	34.4 ± 2.4	65.5 ± 2.4	109 ± 13	0.10 ± 0.04	**93 ± 8.1**	4.1 ± 4
Dual forward	**0.8 ± 0.3**	**1.06 ± 0.30**	31.6 ± 4.7	68.5 ± 4.8	87 ± 23	0.11 ± 0.05	**76 ± 18**	9.2 ± 11
Simple backward	**0.7 ± 0.3**	**0.67 ± 0.30**	31.4 ± 4.5	68.8 ± 4.9	112 ± 25	0.18 ± 0.06	**60 ± 16**	10 ± 20
Dual backward	**0.5 ± 0.2**	**0.65 ± 0.27**	28.2 ± 5.5	71.9 ± 5.6	86 ± 26	0.20 ± 0.06	**53 ± 13**	10 ± 15
Group × direction								
Nonfreezer forward	**1.0 ± 0.3**	1.22 ± 0.32	34.2 ± 2.9	65.8 ± 2.9	100 ± 17	0.10 ± 0.04	88 ± 14	4.9 ± 5
Freezer forward	**0.9 ± 0.3**	1.09 ± 0.28	31.5 ± 4.7	68.5 ± 4.8	95 ± 27	0.12 ± 0.05	79 ± 18	8.8 ± 11
Nonfreezer backward	**0.6 ± 0.3**	0.75 ± 0.30	31.0 ± 4.7	69.1 ± 4.7	99 ± 27	0.18 ± 0.05	60 ± 16	9.5 ± 16
Freezer backward	**0.5 ± 0.3**	0.62 ± 0.26	28.4 ± 5.5	71.9 ± 6.1	99 ± 31	0.20 ± 0.06	53 ± 19	11 ± 19

[a] Values are mean ± standard deviation. Bold entries indicate significant results.

direction, significant 2-way direction × task and group × task interactions and significant 3-way interactions between group, task, and direction (Table 2). Only significant interactions are presented in the following paragraphs.

Main effects of group, direction, and task for freezer versus nonfreezer comparisons. With respect to group, Freezers had lesser swing percent (Figures 2A, 2B, and 2C), greater stance percent (Figure 2D), and lower FAP values (Figure 2G) than Nonfreezers. With respect to task, participants walked more slowly, with shorter strides, lesser swing percent, greater stance percent, lower FAP values, wider BOS, and lower cadence (Figure 2E) in dual task conditions as compared with simple conditions. With respect to direction, participants walked backward more slowly, with shorter strides, lesser swing percent, greater stance percent, lower FAP values, and wider BOS (Figure 2F) as compared with forward walking.

Interactions between task and direction in freezers versus nonfreezers. Participants walked more slowly with shorter strides, lower FAP values, and wider BOS in dual task forward as compared with simple forward walking. Participants walked more slowly with shorter strides, lower FAP values, and wider BOS in dual task backward as compared with simple backward walking. Participants walked more slowly in both simple and dual backward tasks as compared with

both simple and dual forward tasks (Figures 2A, 2B, 2F, and 2G).

Interactions between group, task, and direction in freezers versus nonfreezers. Freezers walked more slowly, with shorter stride lengths, and lesser FAP than Nonfreezers in all 4 conditions. Both groups walked fastest with the longest strides and highest FAP values in simple forward walking, and walked slowest, with the shortest strides and lowest FAP values in dual task backward walking. Additionally, both groups walked more slowly with shorter strides and lower FAP values in simple backward as compared with dual task forward walking (Figures 2A, 2B, and 2G).

Discussion

This is the first study to examine dual tasking while walking backward in people with PD and healthy older controls and the first to demonstrate differential effects of a secondary task on those with and without FOG. Healthy older controls show a similar pattern of impact of direction and task to those with PD. With respect to spatiotemporal gait parameters, those with PD were more impaired than Controls whereas Freezers were more impaired than Nonfreezers across all conditions.
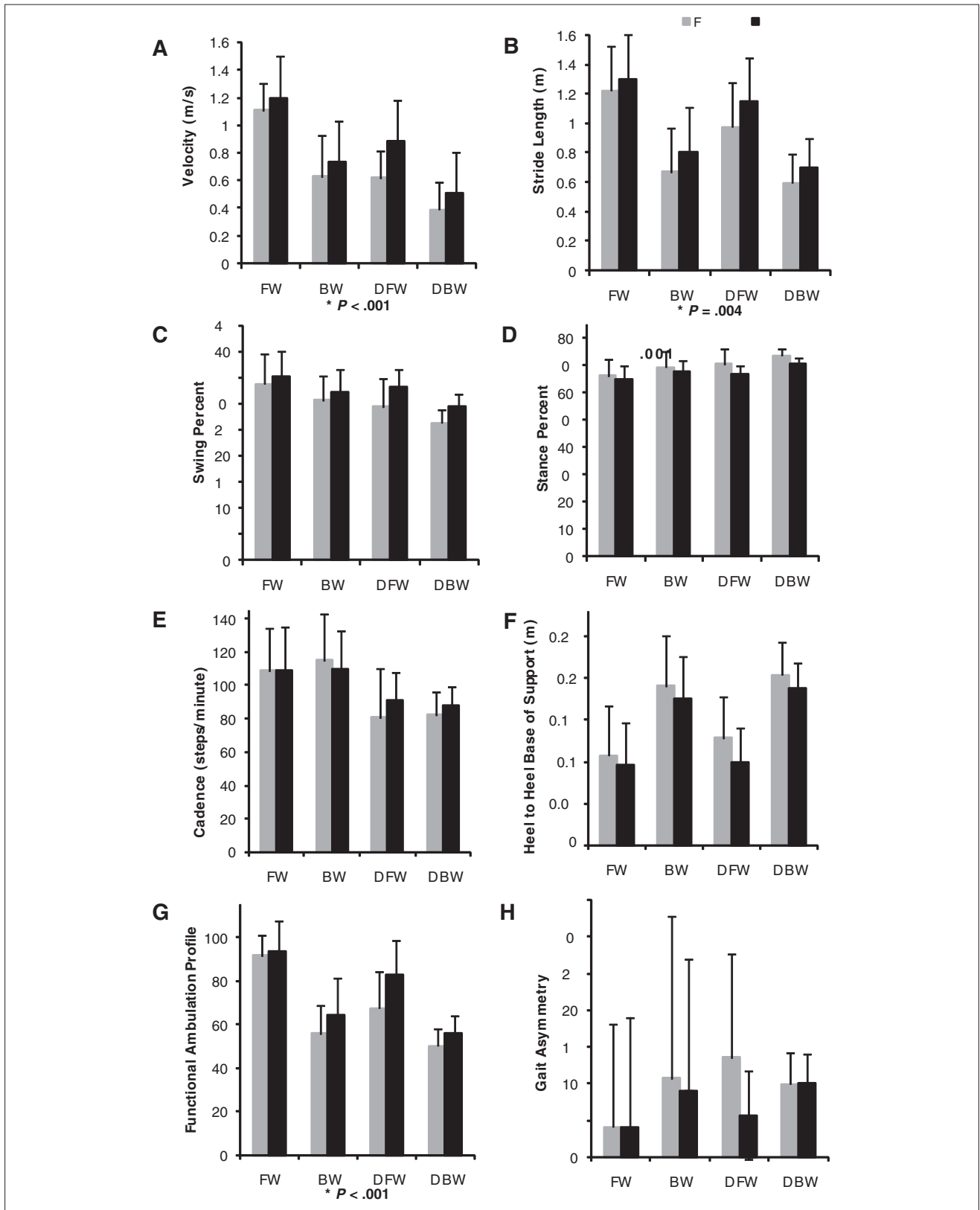
Figure 2. Walking velocity (A), stride length (B), swing percent (C), stance percent (D), cadence (E), base of support (F), functional ambulation profile scores (G), and gait asymmetry (H) of individuals with Parkinson's disease classified as Freezers (light gray bars), and Nonfreezers (black bars) in forward walking (FW), backward walking (BW), dual task forward walking (DT), and dual task backward walking (DTB).
Values are mean ± standard deviation. *Significant 3-way interaction between group, task, and direction.

Impact of Task

Dual tasking appeared to adversely impact all gait variables examined. With respect to gait variables, dual tasking affected cadence more than did backward direction and Freezers were more affected by both challenges, that is, backward direction and dual tasking, than Nonfreezers. Not only did individuals with PD walk more slowly while dual tasking, but they also gave answers at a slower rate than did Controls. Attention has profound effects on gait[33] and patients with PD may have limited attentional resources, defective central executive functioning, and less automaticity while performing in a dual task situation.[34] While walking and performing a difficult cognitive task, gait performance may deteriorate in those with PD because of equal treatment of all elements of a complex task.[3]

Impact of Direction

Those with PD were generally more affected by the backward direction than by the secondary task. In the present study, notable gait asymmetry, which has been linked to deprived attentional resources allocated to gait[30] was demonstrated in those with PD in the simple backward direction, an effect not seen in Controls. Secondary tasks can be either motor or cognitive and can affect the gait and motor performance of those with PD adversely.[9,34] Being less habitual, walking backward is likely a motor task that requires additional attentional resources. Those with PD are impaired while walking backward,[11] possibly because backward walking relies more heavily on proprioception than forward walking.[35] Proprioceptive disturbances in PD have been attributed to abnormal processing of proprioceptive signals in the basal ganglia.[36,37]

Gait Variability, Asymmetry, and Automaticity

In the present study, those with PD became more variable (as measured by the FAP) when performing backward walking or the secondary mental arithmetic task. Those with PD demonstrated gait asymmetry in all challenging conditions, that is, backward walking or dual task conditions, and Freezers demonstrated more gait asymmetry (albeit nonsignificantly) in dual tasking than did Nonfreezers. Healthy gait coordination, a relatively automatic process in controls, may require attentional control in those with PD; therefore, their gait is particularly affected during performance of secondary tasks.[38] Subjects with PD are increasingly variable in gait while performing a cognitive task,[33] and individuals with PD and elderly fallers demonstrate more gait asymmetry, exacerbated under dual task conditions.[30] Dual tasking has been linked to gait dysrhythmicity and asymmetry and may lower the threshold for FOG.[16] Automaticity is greatly impaired in those who experience FOG,[39] as their internal drivers of movement seem to be particularly affected by deficient basal ganglia function. Dual tasks activate similar brain regions in those with PD and controls in the task training and motor adaptation stages that precede automaticity; however, those with PD probably achieve automaticity with more difficulty, as during task training and motor adaptation, greater activity is found in the cerebellum, premotor area, parietal cortex, precuneus, and prefrontal cortex when compared with controls. Possibly, this compensates for basal ganglia dysfunction that impairs automatic movement.[40]

Implications

Competition for attention through challenging activities will increase gait difficulty in those with PD. A limitation of the present study is the lack of formal cognitive screening of participants; however, overall, this study demonstrates that those with PD are considerably more impaired than healthy controls in complex functional tasks that might be necessary to successfully complete ADLs. Therapeutic assessment should thus include evaluation of performance during complex functional activities.[41] Motor and cognitive domains have functional coupling, in that challenges in one domain result in compromised performance in the other. This is clearly illustrated by the performance of those with PD in both the mental and motor tasks, which appeared to be impaired as compared with the performance of healthy, age-matched controls. In fact, executive function and neurocognitive speed could be distinct clinical markers of disease progression in PD.[42] Potentially this could be evaluated while a person with PD performs multitasking involving motor and cognitive challenges, such as that provided by the dual task backward condition, which appeared to most adversely impact gait of all participants.

Clearly, new therapies are needed to address these deficits in complex motor and mental tasks. Deep brain stimulation, the premier surgical option for those with PD, appears not to benefit dual task performance[43] and the present study shows that dual tasking is impaired even when participants are on their prescribed medications. Therapeutic approaches may include multiple task training, which has been shown to increase gait velocity in those with PD.[44] Practice in situations that require divided attention can improve dual task ability.[34,45] In addition, those with PD appear to benefit from rhythmical cues during dual task situations. Cues may reduce attentional costs of walking by facilitating particular attentional allocation.[46] Gait variability of individuals with PD, which has been correlated with fall risk, disease duration, and severity, motor function, and cognitive function,[33] was reduced with cues.[47] Training with cues in multitask situations may be an effective form

of training and may reduce FOG.[29] FOG may be even more effectively addressed by adding a focus on training gait symmetry in the context of a cued dual task paradigm, as gait asymmetry may lower the threshold for FOG.[15] Training with backward walking under dual task conditions may be advantageous, as gait asymmetry clearly increased during backward walking in those with PD.

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Declaration of Conflicting Interests

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