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Backward Walking in Parkinson's Disease

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Abstract: We walk backward on a daily basis, such as when backing away from the kitchen sink or stepping back from a curb as a swiftly moving bus passes. This task may be particularly difficult for individuals with Parkinson's disease (PD) who often fall as a result of moving or being perturbed in the backward direction. The aim of this study was to assess backward walking (BW) in individuals with PD. Both forward walking (FW) and BW were assessed in 78 people with idiopathic PD (H&Y range: 0.5–3) in the ON state, and 74 age- and sex-matched controls. In FW, those with PD had significantly shorter strides, lower swing percents, higher stance percents, and lower functional ambulation profiles than controls. Both groups walked significantly slower and with a wider base of support during BW than FW. Additionally, in BW those with PD walked significantly slower with shorter strides, lower swing percents, and higher double support and stance percents, and lower functional ambulation profiles compared with controls. Those with mild to moderate PD have impaired FW and BW, but differences between those with and without PD are more pronounced in BW. © 2008 Movement Disorder Society

Key words: gait; backward; Parkinson's disease

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. Fall-related hip fractures in the United States cost ∼$192 million annually.[1,2] Seventy percent of patients experienced a fall within a 1-year period, with 50% of fallers experiencing a recurrent fall in the subsequent year.[3] A meta-analysis of fall rates revealed that in 3 months, half of a large cohort of those with PD experienced a fall. In fact, patients with no previous fall history had a 21% risk of falling in this same time period.[4] Many falls occur from backward perturbation or while moving backward.[4,5] Those with PD have difficulty modulating gait parameters according to task, and locomotion is a complex multidirectional activity; therefore, gait analysis should include functional locomotor tasks beyond straight walking.[6] No study has examined backward walking in PD.

We walk backward daily, such as when backing away from a sink or stepping back from a curb as a swiftly moving bus passes. Laufer et al.[7] noted that an elderly cohort walked slower backward than a younger group. BW was also characterized by lesser cadence, increased double support time, and shorter stride length and swing phase. Unable to increase stride length while walking backward, the elderly increased speed only by increasing cadence. Possibly, those with PD are further impaired while walking backward, as without visual cues it relies more heavily on proprioception than forward walking (FW).[8] Postural instability in PD may be related to proprioceptive disturbances attributed to abnormal processing of proprioceptive signals in the basal ganglia.[9,10] Those with PD excessively activate antagonist muscles when posturally perturbed, particularly in the lateral and backward directions.[11] Postural abnormalities are most noted in response to backward perturbations because counteracting muscle torques generate stiffening in the ankle and trunk. PD medication does little to improve pitch plane abnormalities,[12] and pronounced backward instability in PD is levo-

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dopa-resistant and not helped by subthalamic nucleus stimulation.[13] This study aimed to quantify BW in those with mild to moderate PD in comparison with a matched control group.

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

Participants were recruited from the St. Louis community through advertisement at support groups and community events and from a database that follows some 2,000 people with PD. Although some participants self-identified, most were directly recruited via telephone, and some were randomly asked to participate at a public site distant to the laboratory. Data files were coded for participant confidentiality.

Seventy-eight people with PD (mean age = 65.1 ± 9.5 years, Female: 28%) and 74 age- and sex-matched controls (mean age = 65.0 ± 10.0 years, Female: 23%) participated. Participants 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,"[14–16] demonstrated clear benefit from levodopa, were tested ON medications at a time of self-determined optimal performance, and could walk at least 3 m with or without an assistive device. Participants were evaluated using the Unified Parkinson's Disease Rating Scale Motor Subscale 3 (UPDRS)[17,18] and the Berg Balance Scale (BBS).[19] Fallers were those who reported one or more falls in the preceding 6 months. Freezing status was determined by the Freezing of Gait questionnaire (FOG).[20] Participants were considered freezers if they had a score >1 on Item 3 on the FOG, indicating freezing frequency of more than once per week.[21]

Kinematics

FW and BW were measured using a 5 m instrumented, computerized GAITRite walkway (CIR Systems, Inc., Havertown, PA). Participants were requested to walk at their normal pace forward to accustom themselves to the mat, and then backward, performing three trials of each direction. Participants were given adequate rest time and allowed to sit between trials. No participants reported fatigue, likely because of the short walking distance and limited number of trials. Results from trials of each direction were averaged. Primary variables of interest were gait velocity, stride length, cadence, heel to heel base of support (BOS), double support percent, swing and stance percent, and functional ambulation profile (FAP, a.k.a. Functional Ambulation Performance). The FAP is a valid and reliable numerical representation of gait performance[22] that distinguishes between people with and without PD.[23] FAP values quantify gait variability and comprise the linear relationship of step length/leg length ratio to step time when the velocity is normalized to leg length (see Appendix for more detail).

Statistical Analyses

Two-way repeated measures ANOVAs (two subject groups × two conditions) with Holms-Sidak post hoc tests determined statistical significance when comparing those with PD to controls. Pearson's product moment correlations determined relationships between disease severity or balance and FW or BW velocity. Independent *t*-tests determined significant differences between freezers and nonfreezers. Mann Whitney's rank sum tests were used for nonparametric data. The level of significance was set at $P = 0.05$.

RESULTS

The PD group's Hoehn and Yahr scores 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. Fifty percent of those with PD had a history of falls and 45% were freezers.

Gait Parameters of Forward and Backward Walking: Individuals with PD versus Age- and Sex-Matched Controls

Table 1 summarizes results. If significant interactions are presented, there are also significant main effects of condition and group.

Velocity

There were significant two-way interactions among group and condition for velocity (interaction: $F(1,150) = 22.352$, $P < 0.001$). In FW, the groups walked at similar velocities. In BW, those with PD walked slower than controls ($P < 0.001$). Both groups walked significantly slower during BW than FW ($P < 0.001$).

TABLE 1. *Spatiotemporal gait parameters of forward and backward walking*

	Forward walking		Backward walking	
	PD	Control	PD	Control
Velocity (m/s)	1.2 m/s ± 0.2[a]	1.2 ± 0.2[a]	0.7 m/s ± 0.2[b]	0.9 m/s ± 0.2
FAP	92.7 ± 1.1[a,b]	96.9 ± 1.1[a]	60.4 ± 1.1[b]	74.2 ± 1.1
Stride length (m)	1.3 ± 0.01[a,b]	1.4 ± 0.01[a]	0.7 ± 0.01[b]	1.0 ± 0.01
Base of support (m)	0.1 m ± 0.04	0.1 m ± 0.04	0.2 m ± 0.04	0.2 m ± 0.04
Cadence (steps/min)	109 ± 1.4	105 ± 1.4	112 ± 1.4	105 ± 1.4
Swing (%)	34.5 ± 0.3[a,b]	35.7 ± 0.3[a]	31.4 ± 0.3[b]	34.8 ± 0.3
Double support (%)	31.3 ± 0.8[a]	28.7± 0.8[a]	39.3 ± 0.8[b]	32.0 ± 0.8
Stance (%)	65.5 ± 0.3[a,b]	64.3 ± 0.3[a]	68.8 ± 0.3[b]	65.2 ± 0.3
Variability				
Stride length SD (m)	0.05 ± 0.006	0.05 ± 0.006	0.09 ± 0.006	0.09 ± 0.006
Swing % SD	2.1 ± 1.3	1.9 ± 1.4	7.4 ± 1.3	4.9 ± 1.4
Stance % SD	3.0 ± 0.7[a]	3.2 ± 0.7	8.0 ± 0.7[b]	5.0 ± 0.7

Values are means ± SE.
[a]Significant difference between forward walking and backward walking within group.
[b]Significant difference between groups within walking condition.

Stride Length

There were significant two-way interactions among group and condition for stride length (interaction: $F(1,150) = 28.232$, $P < 0.001$). Those with PD walked with a significantly shorter stride length than controls in FW ($P = 0.023$) and BW ($P < 0.001$). Both groups walked with significantly shorter strides during BW than FW ($P < 0.001$).

Swing Percent

There were significant two-way interactions among group and condition for swing percent (interaction: $F(1,150) = 18.818$, $P < 0.001$). Those with PD walked with lesser swing percent than controls in both FW ($P = 0.019$) and BW ($P < 0.001$). Lesser swing percent was noted in BW when compared with FW in both those with PD ($P < 0.001$) and controls ($P = 0.024$).

Stance Percent

There were significant two-way interactions among group and condition for stance percent (interaction: $F(1,150) = 20.223$, $P < 0.001$). Those with PD walked with greater stance percent than controls in FW ($P = 0.023$) and BW ($P < 0.001$). Greater stance percent was noted in BW when compared with FW in both those with PD ($P < 0.001$) and controls ($P = 0.014$).

Double Support Percent

There were significant two-way interactions between group and condition for double support percent (interaction: $F(1,150) = 8.847$, $P = 0.003$). In FW, the groups walked with a similar double support percentage ($P = 0.065$). In BW, those with PD walked with greater double support percentage than controls ($P < 0.001$). More double support percent during BW than FW was noted in both those with PD ($P < 0.001$) and controls ($P < 0.005$).

BOS

There were no significant two-way interactions between group and condition for BOS ($F(1,150) = 2.005$, $P = 0.159$), but there was a significant main effect of condition ($F(1,150) = 556.438$). Both groups walked with a significantly wider BOS during BW than FW ($P < 0.001$).

Cadence

There were no significant two-way interactions between group and condition for cadence ($F(1,150) = 0.942$, $P = 0.333$), but there was a significant main effect of group ($F(1,150) = 4.838$). Those with PD walked with a greater cadence than controls overall ($P = 0.029$) but were not different form controls within FW or BW alone.

FAP

There were significant two-way interactions among group and condition for FAP. (interaction: $F(1,150) = 18.433$, $P < 0.001$). Those with PD had significantly lower FAP values than controls in both FW ($P = 0.022$) and BW ($P < 0.001$). Both groups had significantly lower FAP values during BW than FW ($P < 0.001$).

TABLE 2. *Spatiotemporal gait parameters in freezers (n = 35) versus nonfreezers (n = 43)*

	Forward walking		Backward walking	
	Freezers	Nonfreezers	Freezers	Nonfreezers
Velocity (m/s)	1.1 ± 0.04	1.2 ± 0.04	0.61 ±0.05	0.73 ±0.05
FAP	91.4 ± 7.9	93.7 ± 8.2	55.8 ± 2.2[a]	64.1 ± 2.5
Stride length (m)	1.2 ± 0.03	1.3 ± 0.03	0.7 ± 0.04[a]	0.8 ± 0.05
Base of support (m)	0.1 ± 0.007	0.1 ± 0.005	0.2 ± 0.01	0.2 ± 0.01
Cadence (steps/min)	109 ± 2.4	109 ± 1.7	114 ± 4.7	110 ± 3.5
Swing (%)	33.7 ± 0.42[a]	35.2 ± 0.34	30.3 ± 0.8[a]	32.4 ± 0.6
Double support (%)	32.8 ± 0.84[a]	30.0 ± 0.70	41.2 ± 2.3	37.8 ± 11.6
Stance (%)	66.4 ± 0.42[a]	64.8 ± 0.34	70.0 ± 0.9[b]	67.7 ± 0.6
Variability				
Stride length SD (m)	0.06 ± 0.04	0.05 ± 0.04	0.1 ± 0.01	0.1 ± 0.01
Swing % SD	2.5 ± 0.2[b]	1.7 ± 0.1	8.6 ± 3.2[b]	6.4 ± 2.8
Stance % SD	3.7 ± 0.4[b]	2.5 ± 0.1	10.8 ± 3.0[b]	5.7 ± 0.5

Values are means ± SE. Independent *t*-tests were used to test for significant differences between groups.
[b]Significant difference between freezers and nonfreezers.
[a]Significant difference with Mann Whitney's Rank Sum test.

Variability of Gait Measures

There were significant two way interactions among group and condition for stance percent variability (F(1,150) = 0.554, P = 0.034). Controls and those with PD had similar amounts of stance percent variability in FW (P = 0.849). Controls had similar amounts of stance percent variability in BW and FW (P = 0.089). Those with PD had more stance percent variability in BW than controls (P = 0.006). In those with PD stance percent variability was greater in BW than in FW ($P < 0.001$).

There was a significant main effect of condition for other measures of variability but no significant interactions. BW was more variable than FW in stance percent (F(1,150) = 21.071), stride length (F(1,150) = 45.135), and swing percent (F(1,150) = 0.686, P = 0.002).

Correlations of UPDRS or BBS and Forward or Backward Velocity

As UPDRS scores increased, BW velocity decreased (r = −0.290, P = 0.010) but UPDRS was uncorrelated with FW velocity (r = −0.126, P = 0.272). As FW velocity increased, BW velocity increased (r = 0.766, $P < 0.001$). As BBS scores increased, both BW (r = 0.538) and FW (r = 0.486) velocity increased ($P < 0.001$). No significant relationships were found between duration of PD and FW or BW (r = 0.012, P = 0.917; r = −0.200, P = 0.079).

Comparison of Freezers and Nonfreezers

On the BBS, freezers (mean: 46.8 ± 0.85) scored significantly lower (P = 0.003), than nonfreezers (mean: 50.0 ± 0.61), and had PD for longer (Freezers: 10.5 ± 1.00, Nonfreezers: 6.4 ± 0.57, P = 0.002) but did not differ from nonfreezers in disease severity (UPDRS Freezers: 29.2 ± 1.63, Nonfreezers: 26.2 ± 1.33, P = 0.150). No one exhibited freezing during testing. Table 2 summarizes results for freezers vs. nonfreezers.

Forward Walking

Freezers and nonfreezers were similar in FW FAP (P = 0.097), velocity (P = 0.106), cadence (P = 0.768), stride length (P = 0.075), and BOS (P = 0.195). Freezers had significantly lower swing percent (P = 0.007) and significantly greater double support (P = 0.012) and stance percent (P = 0.007) than nonfreezers. Freezers and nonfreezers were similar in FW variability for stride length (P = 0.053). Freezers were more variable in stance (P = 0.008) and swing percent ($P < 0.001$).

Backward Walking

Freezers and nonfreezers were similar in BW velocity (P = 0.091), cadence (P = 0.422), double support percent (P = 0.065), and BOS (P = 0.321). In BW, freezers had significantly lower FAP scores (P = 0.027), stride length (P = 0.032), swing percent (P = 0.040), and significantly greater stance percent (P = 0.031) than nonfreezers. Freezers and nonfreezers were similar in BW variability of stride length (P = 0.325). Freezers were more variable in stance percent (P = 0.010) and swing percent (P = 0.013).

DISCUSSION

This is the first study to examine BW in people with PD. Previous work showed that healthy younger and older adults walk slower backward than forward but alter their cadence little for different walking directions.[24,7] The elderly show diminished stride length when walking backward.[7] Our PD group exhibited similar but more pronounced changes during BW compared with older controls. Prior work has also shown that BW is more variable than FW.[25] On the FAP measure, lower values indicate more variable stride to stride performance. Our results are thus in keeping with those of Winter et al., [25] suggesting that all participants were more variable walking backward than forward. Variability was most evident in stance percentages of the PD group compared with controls. Freezers had longer disease duration and were more balance impaired, which may explain their slightly poorer performance and greater variability than nonfreezers.

Curiously, our PD participants did not walk slower than controls in FW. Possibly our participants with PD experienced a testing effect and could achieve nearly normal magnitudes of speed through focused attention on gait as our participants knew their performance was being monitored.[26,6] Although our PD group walked at a similar velocity to controls, their stride length, swing and stance percents, and FAP values were impaired in FW compared with controls. This agrees with current research demonstrating that gait speed may be virtually intact, whereas other spatiotemporal features of FW are affected in even de novo PD.[27]

This study demonstrates that individuals with PD have BW deficits that surpass FW deficits. Similarly, individuals with PD with normal or mildly impaired FW demonstrate greater impairments when turning.[28,29] Crenna et al.[28,29] propose that neural systems that are separate from FW mechanisms, and more vulnerable to the effects of PD, likely mediate turning. This may parallel BW, as recent work suggests the presence of separate control systems for FW and BW.[30,31] If FW and BW are controlled by separate neural systems, these systems could be differentially affected by PD. This study suggests the BW system could be impacted earlier in the disease process.

Increased UPDRS values correlated with a decrease in BW velocity. Fall rates also increased with UPDRS values.[4] BW performance is predictive of walking difficulty in high-functioning older adults and might prove useful for those with PD.[32] Assessment of BW may be an important clinical tool, as BW impairments might be related to the propensity for BW falls. BW observation may be more illustrative of the degree to which the basal ganglia are impaired than is FW. In fact, the basal ganglia appear important for optimizing patterns of postural muscle activation for the proper motor pattern in task or environmental changes.[11] Finally, subthalamic nucleus stimulation does not improve levodopa-resistant postural instability.[13] Although deep brain implants have been effective on multiple Parkinson-related impairments, BW could be especially useful as a test for further improvements or declines in those with STN stimulation and postural instability.

BW could be a rehabilitative component. In fact, multidirectional gait and step training reduced fall incidence and improved gait in people with PD.[33] Training BW could provide more cardiovascular benefit than FW walking, as energy expenditure is higher during BW than during FW at matched speed.[34,35] Training BW improves cardiovascular fitness and BW efficiency in controls.[36,37] Future studies should examine relationships between BW performance, postural instability, and the effects of increasing task complexity, such as dual tasking, on BW versus FW. Research that explores rehabilitative possibilities, such as employing BW in gait and step training, is needed.

APPENDIX: CALCULATION OF FUNCTIONAL AMBULATION PROFILE[38]

The FAP Score in a healthy adult ranges from 95 to 100 points and is calculated from data collected by the GAITRitewalkway and the patient's physical measurements.

1. For each limb, step length is divided by leg length to produce the step length/leg length ratio (SL/LL), at the patient's preferred velocity. Velocity is divided by the patient's mean leg length to produce the mean normalized velocity expressed in leg lengths per second (LL/second).
2. For each limb, SL/LL ratio, step time and mean normalized velocity are then compared on a model of regression lines to determine their deviations from normal. This constitutes 44% of the total score.
3. Degree of asymmetry is calculated by subtracting the SL/LL ratios of each limb and then compared with normal, representing 8% of the total score.
4. Dynamic BOS represents 8% of the total score.
5. Use of assisting devices (orthoses, splints, etc.) represent 5% of the total score. Ambulatory aids (canes, crutches, or walkers) represent 5% of the total score.

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