# COMPARING FORWARD (FW) AND BACKWARD WALKING (BW) SPEEDS WITH AGE AND DISEASE SEVERITY IN PERSONS WITH PARKINSON DISEASE (PWP)

By

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## Abstract

Parkinson disease (PD) is a neurodegenerative disease with a worldwide prevalence of 6.2 million, expected to double by 2040. 90% of these individuals will fall and be seriously injured in their lifetime. Clinical tests are needed that can predict falls so that proactive fall prevention can be implemented. While there are several clinical measures shown to predict falls in persons with Parkinson disease (PWP) there are none that accurately represent the complex and multidirectional nature of everyday mobility that may lead to falls in PWP. Previous studies suggest that backward walking (BW) deficits may surpass forward walking (FW) deficits, be more related to disease severity, impacted earlier in disease, and indicative of everyday mobility problems in PWP. We summarize retrospective data from a physical therapy clinic that used the 3-meter BW test, previously introduced in healthy adults, in a group of PWP of varying disease severity. We describe the relationship of FW and BW gait speed across age, disease severity, and fall risk, as determined by a retrospective 6-month fall report. Our data suggests BW may predict fall risk across disease severity and supports a prospective study that combines BW with other tests to assess fall risk across disease severity.

## Introduction

Parkinson disease (PD) is a progressive neurodegenerative disease most commonly associated with aging, as the average age of diagnosis is 60. 10% of those diagnosed with PD are diagnosed before age 50 and are therefore considered young-onset[1]. By 2040, 12.9 million people are expected to be diagnosed with PD worldwide, which is more than double the 6.2 million cases recorded in 2010[2]. In the United States alone, estimates suggest that the PD population will total 1.2 million by 2030[2]. Falls are a common problem for people with Parkinson disease (PWP): 17% of newly diagnosed individuals have fallen prior to diagnosis[3] and 35-90% of PWP will fall at least once in their lifetime[4]. Of

those who fall, 76% require health care services and of those, 33% sustain a fracture[5].

Essential to fall prevention is postural stability, which becomes increasingly dysfunctional with age[6] (McElroy), is deficient in PWP with early and moderate disease progression[7,8], and is one of the PD symptoms that is unresponsive to medication[9]. Clinically, backward pull tests[10] and/or push-release tests in multiple directions[11] are performed to elicit protective stepping responses as a test for postural instability in PWP. Backward pull test scores reflect the number of steps required to catch one's balance and whether physical assistance is required to prevent a fall. The inability to catch oneself in the backward direction is a component used to rate disease severity on the Hoehn and Yahr (H&Y) rating scale[12]. By the time postural instability has been diagnosed, as evidenced by an inability to recover during a retropulsion test (H&Y 3), the PWP has probably already experienced a fall[3]. In fact, the best predictor of falls in PWP is a history of two or more falls in the previous six months[13,14].

Unfortunately, if fall prevention is the goal, knowledge about previous falls is not an effective preventative measure. Instead, the goal should be the ability to predict fall risk before a fall happens and be prepared to implement proactive fall prevention training programs. A variety of clinical tests for balance and mobility are able to predict fall risk reliably in elderly controls (EC) as well as in PWP[15-19]. Most of these tests involve walking forward, turning in place or around a marker, multidirectional stepping, functional mobility, or static and dynamic measures of balance. While these tests assess a wide breadth of balance and mobility markers, fall risk factors are complex and immense for both PWP and elderly controls[3,16]. Fall risk factors include generic age-related and PD-specific factors, such as peripheral neuropathy, arthritis, reduced executive function, and decreased axial motor flexibility, and no currently available measure separately evaluates all the components that can potentially contribute to falls[16]. Tests of everyday mobility that can better predict fall risk, which also better incorporate

real-world environmental complexity and cognitive resource requirements, have yet to be created and validated[3,16,20].

Laboratory-based and health-related community studies have suggested that, in elderly controls, kinematic measures of backward walking (BW) are more strongly associated with age[21] and more predictive of walking difficulties and falls in the elderly than forward walking (FW)[21-24]. In PWP, BW measures may provide additional insight: BW deficits may surpass FW deficits and be more correlated with disease severity[25]. BW may be controlled by separate neural systems that are potentially differentially affected in PD, when compared to elderly controls[26,27]. In PWP, BW training improved both FW and BW gait speed and translated to improved coordination during BW; FW training did not appear to have the same impact[28].

Recently, Carter et al.[29] have introduced a clinical 3-meter backward walk test (3MBW) as a novel measure of fall risk. Participants were older adults living in retirement communities, and were excluded if they had a history of neurological deficits or required an assistive device for walking. In addition to the 3MBW, participants were assessed using several clinical measures used to identify elderly fallers, including the Timed Up and Go (TUG) test, Four Square Step Test (4SST), and the 5-time sit-to-stand (5xSTS) test. Using receiver operating curve analysis to calculate optimal cutoff points for sensitivity and specificity for the 3MBW, Carter et al. concluded that the 3MBW was highly correlated with other widely used fall risk measures. Additionally, the 3MBW was outperformed the 4SST and 5xSTS, while performing similar to the TUG test, at differentiating fallers and non-fallers and predicting falls when applied to the compared to retrospective self-reported fall data for the year prior to the administration of the 3MBW.

The present study summarizes retrospective data gathered from a Parkinson disease-specialized physical therapy clinic which offers both PD-specific physical

therapy and group exercise programming, and which administered the 3MBW test to a group of PWP with varying disease severity. First, we characterize the differences between 3MBW trials, focusing on how 3MBW test scores may serve as predictors of everyday fall risk and the measure's potential translation to use in proactive intervention.Second, we examine the relationships between age and FW and BW, respectively. Third, we examine the relationships between disease severity and FW and BW. Penultimately, we discuss how well the 3MBW test is able to distinguish fallers from non-fallers in PWP, using additional 6-month retrospective self-reported fall history data. Finally, we compare the data collected in this study on BW gait speed in PWP to the fall risk cutoffs for the 3MBW determined by Carter et al. in their study on EC.

## Methods

### Study Design, Data Collection, and Database

The retrospective data presented here are a subset pulled from a larger ongoing medical record review and its corresponding database. At the time of publication, this database included a complete medical record review of all clients who had received an initial consultation from July 2013 through July 2018 (n=538). The larger review seeks to examine both adherence to and the potential long-term benefits of consistently attending a Parkinson disease-specialized clinic which offers both PD-specific physical therapy and group exercise programming. The data were gathered by physical therapists during the clinic's standard new client evaluation process, which includes a variety of measures, lasts approximately 90 minutes, and ultimately allows physical therapists to determine the appropriate plan of care and group exercise class placement. Those evaluated received no instructions regarding the administration of PD medication prior to their evaluation, but the therapists did record the most recent time the client reported taking their medication. Application for an IRB exemption is pending by a university institutional review board.

## Participant selection

The de-identified data included in the present study represent clients who (a) received an initial consultation from July 2013 through July 2018 and (b) received a second re-evaluation consultation one year later (footnote: within +/- 3 months). 176 clients met these criteria and were included for further analysis.

Table 1. Participant Demographic Information

| | Subgroups | Number of participants | Percentage of participants |
|---|---|---|---|
| Age[1] | 50 | 13 | 7.4 |
| | 60 | 45 | 25.7 |
| | 70 | 84 | 48.0 |
| | 80 | 33 | 18.9 |
| Sex | Male | 124 | 70.9 |
| | Female | 51 | 29.1 |
| Hoehn and Yahr | 1 | 62 | 35.4 |
| | 2 | 68 | 38.9 |
| | 3 | 27 | 15.4 |
| | 4 | 18 | 10.3 |
| Falls[2] | Yes | 67 | 40.4 |
| | No | 99 | 59.6 |

## Data selection

In addition to the 3MBW and 10MWT data under examination, previously collected demographic information (e.g., age, sex), clinical characteristics (e.g., whether the client had fallen in the last 6 months), and disease severity (H&Y) designation was included for analysis. Disease severity was based upon the

[1] Of the 176 total participants, 1 was age 40-49 and was excluded from the analysis.
[2] Of the 176 total participants, only 166 reported fall data.

Hoehn and Yahr Scale[12], a commonly used metric for describing the symptoms and progression of Parkinson disease. A PD-specialized physical therapist reviewed disease staging criteria, including bilateral motor involvement, postural instability, use of walking aids or a wheelchair, reported need for assistance with activities of daily living, and confinement to bed, to determine the H&Y stage for each client. In addition, clinical measures related to forward and backward walking were extracted for analysis and an explanation of the procedures for those data collection are described below.

**3-Meter Backward Walk Test (3MBW)**

For the 3-meter backward walk test, a distance of three meters was marked with tape on the floor. Participants were instructed to align their heels with the tape at one end and to walk backward "as fast and safe as possible" when signaled to go and to stop when they passed the second piece of tape 3 meters away (or when the therapist otherwise signaled them to stop). They were also instructed not to run, but were told they could look over their shoulders if they so desired. Therapists began timing as soon as the leading foot crossed the tape at the start of the 3 meter walkway and stopped timing when the leading foot crossed the tape at the end of the walkway. The time to complete the 3-meter distance was recorded in seconds. Participants completed two trials to allow for the examination of practice effects on performance, given the novelty of the task and its lack of validation as a measure for PWP.

**10-Meter Forward Walk Test (10MWT)**

For the 10-meter forward walk test, a distance of ten meters was marked with tape on the floor, with two additional markers two meters on either side of the start and finish lines. Using these lines as guides for beginning and ending the test allow time for participants to accelerate to full speed by the start line and to decelerate after crossing the finish line. Participants were instructed to complete the test under two conditions. In the forward walk normal speed condition (FW_NS), participants were instructed to align their toes with the tape at one end

and walk at a self-selected pace when signaled to go and to stop when they reached the fourth piece of tape (14 meters away from the first), or when the therapist signaled to stop. In the forward walk fast and safe condition (FW_FS), participants were instructed to walk as fast and safe as possible. Therapists began timing as soon as the leading foot passed the second piece of tape indicating the start of the 10-meter walkway and stopped timing when the leading foot crossed the third piece of tape indicating the end of the 10-meter walkway. The time to complete the 10 meter distance was recorded in seconds. Participants completed one trial of each FW condition, as previous studies have demonstrated excellent test-retest reliability for both normal speed (ICC=0.96) and fast and safe (ICC=0.97) conditions in PWP[15].

## Analysis

Demographic characteristics of participants and clinical data were summarized with descriptive statistics (means/SD) and frequency distributions (Table 1). For this and all other comparisons, a p-value of 0.05 was used. There were no outliers, as assessed by boxplot; data was normally distributed for each group, as assessed by Shapiro-Wilk test ($p>.05$); and there was homogeneity of variances, as assessed by Levene's test of homogeneity of variances for all forward and backward walking tests ($p>05$). In addition, the times to complete the backwards walking (BW) test, and the forwards walking (FW) test were recorded in seconds and converted to backward and forward gait speed for comparison to other established norms and cutoffs by dividing the distance covered by time it took to walk that distance.

For Aim 1, differences in gait speed between the first and second trial of BW was analyzed using paired samples t-test (Figure 1). For Aims 2 and 3 and 4, gait speeds during FW and BW were compared across decades (50-80 years; Figures 2 and 3), disease severity (H&Y Stages 1-4; Figures 4 and 5), and fall risk (reported fallers versus nonfallers) using one-way ANOVA. Multiple comparisons were performed when appropriate for the variable of interest. The BW gait speeds were compared to the dual cutoff times that Carter et al.[29] reported in elderly controls of greater than 4.5 seconds to capture 75% of reported nonfallers) and less than 3 seconds to capture 81% of reported fallers (Figure 6). For all figures, gait speed is reported with means and standard errors (SE).

## Results

For Aim 1, the first trial (T1) of BW was significantly slower than the second trial (T2) (p=.002) and is illustrated in Figure 1.

Figure 1. Comparing Trial 1 and Trial 2 of Backward Walking

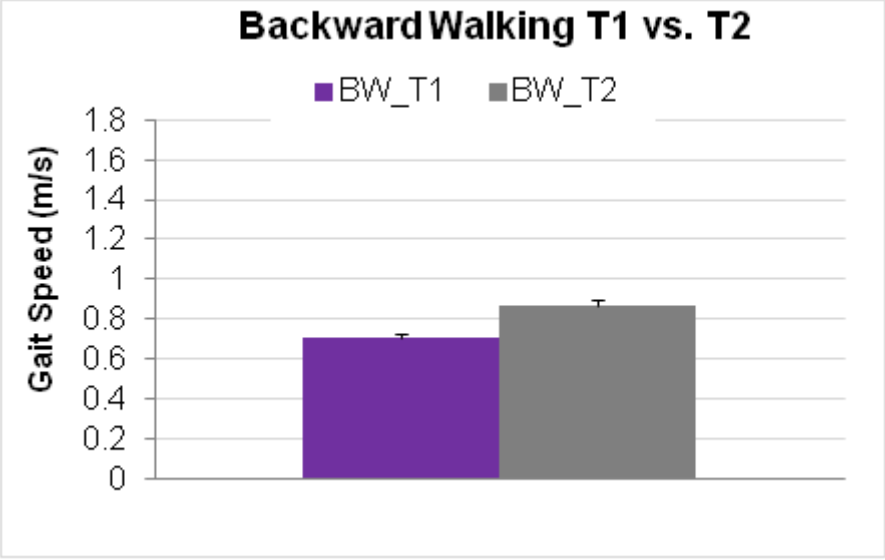


Figure 2. Forward Walking vs. Age

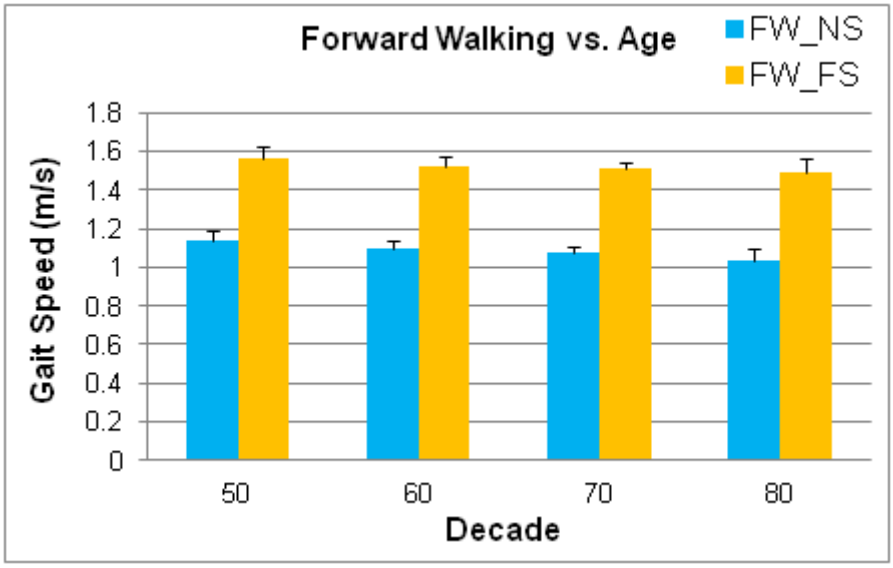
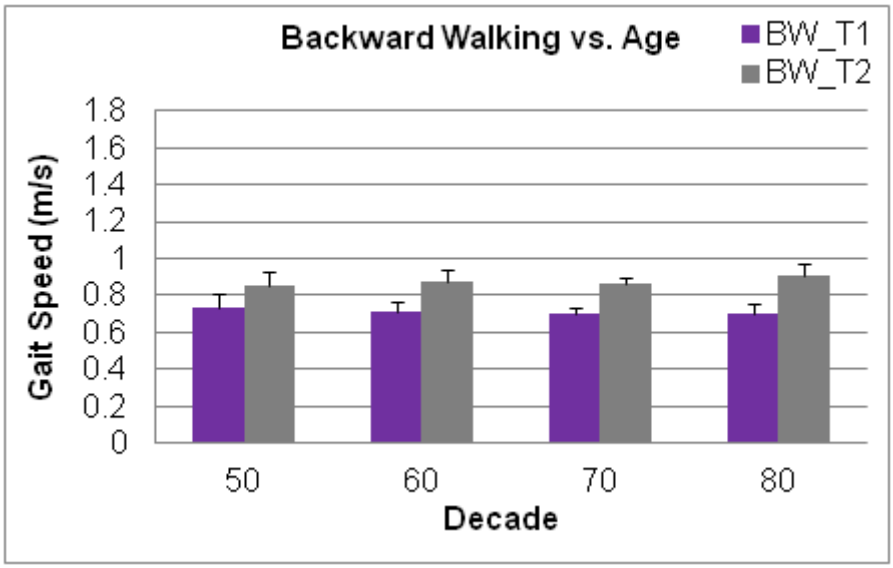



Figure 3. Backward Walking vs. Age




For Aim 2, both FW speed conditions decreased in speed across decades, but the differences were not significant (Figure 2; FW_NS, p=.535; FW_FS, p=.929). For both BW speed trials, there were no significant differences in speed across decades (Figure 3; BW_T1, p=.989; BW_T2, p=.900). Visually, the gait speed relationship between FW conditions appeared consistent (Figure 2). This was confirmed numerically as the mean variability of the FW_FS trial ranged from

26.9% to 30.9% faster than FW_NS across decades. In contrast, the gait speed relationship between BW trials was visually more variable (Figure 3). This was confirmed numerically as the mean variability of BW_T2 ranged from 14.12% to 23.1% faster than BW_T1, increasing with age.

Figure 4. Forward Walking vs. Disease Severity

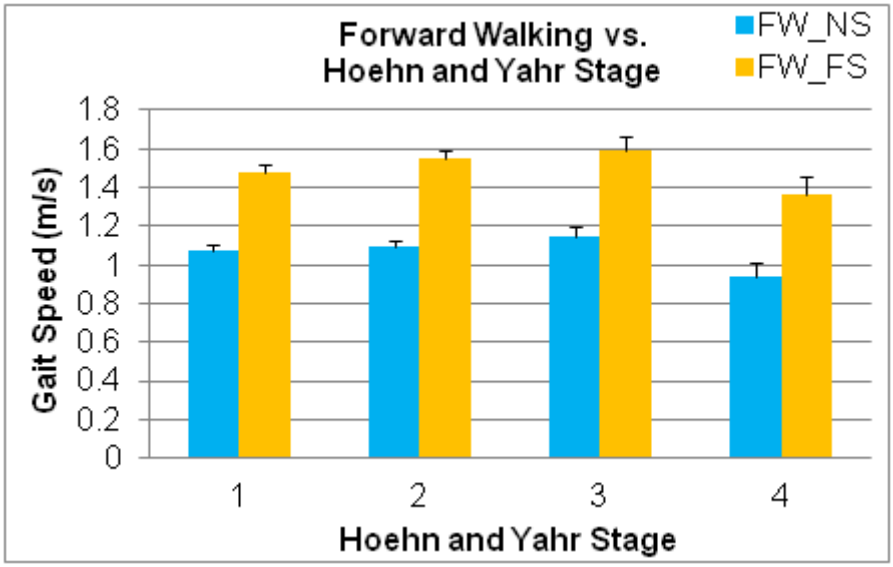
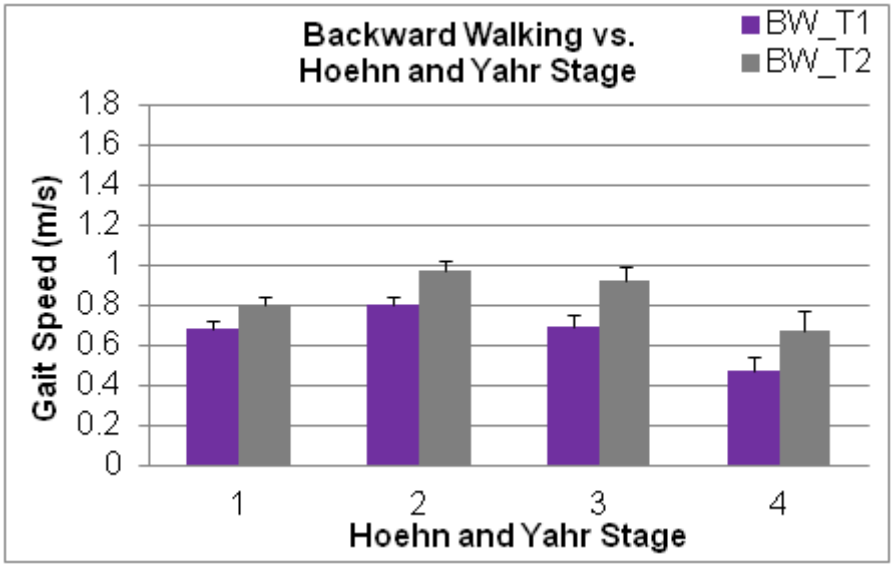



Figure 5. Backward Walking vs. Disease Severity



For Aim 3, FW was shown not to be statistically significant across disease severity for either speed condition (FW_NT, p = .066; FW_FS, p = .091). Unlike FW, both trials of BW showed statistically significant slowing with greater disease severity (BW_T1, p = .002; BW_T2, p = .006). BW_T1 was found to be significantly different between stages 2 and 4 (p = .001), and BW_T2 was found to be statistically different between stages 1 and 2 (p = .047) as well as between stages 2 and 4 (p = .001).

When viewing the gait speed relationship between FW conditions, variability was minimal (Figure 4). This was confirmed numerically as the mean variability of FW_FS ranged from only 27.3% to 31.1% faster than FW_NS across disease severity. In contrast, the gait speed relationship between BW trials was more visually variable across disease severity than FW (Figure 5) and more variable than BW across decades (Figure 3). This was confirmed numerically as the mean variability of BW_T2 ranged from 14.1% to 29.6% higher than BW_T1, increasing with disease severity.

Table 2. Fallers vs. Nonfallers

| | **Fallen in the last 6 months** | |
|---|---|---|
| | No (n=99) | Yes (n=67) |
| | Mean ±SD | Mean ±SD |
| Age | 71.32 ±7.90 | 74.42 ±7.14 |
| FW_NS_Speed | 1.09 ±.25 | 1.07 ±.31 |
| FW_FS_speed | 1.51 ±.35 | 1.53 ±.33 |

| | | |
|---|---|---|
| BW_T1_speed | .72 ±.33 | .70 ±.33 |
| BW_T2_speed | .89 ±.38 | .86 ±.34 |

For aim 4, gait speeds during FW and BW was compared between people who reported falling in the past year (fallers) and people who did not report falling (nonfallers). In total, 166 people answered the falls question, and 67 of those people were fallers (Table 1 and 2, missing data on n=10). Gait speed during FW and BW was not significant between the fallers and non-fallers (FW_NS; p = .62, FW_FS; p = .79, BW=_T1; p = .76, BW_T2; p = .59).

Table 3. Percentage of Fallers by Disease Severity

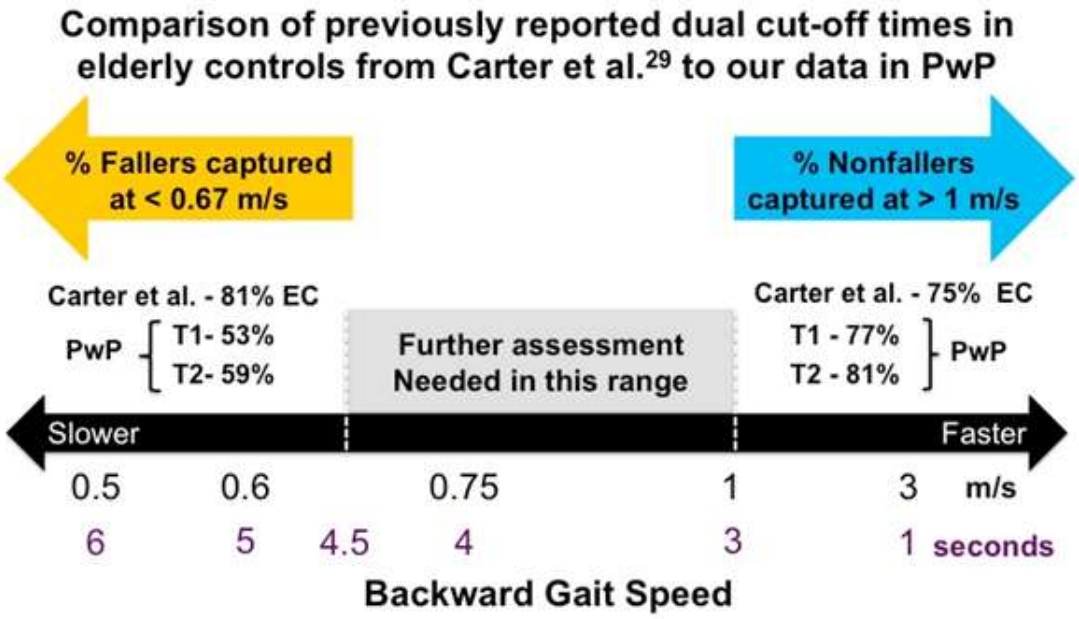
| H&Y Stage | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| FW_NS | 21 | 34 | 24 | 21 |
| FW_FS | 21 | 33 | 25 | 21 |
| BW_T1 | 20 | 34 | 25 | 21 |
| BW_T2 | 22 | 33 | 25 | 20 |

Age was significantly different between fallers and nonfallers (Table 2; p = .01). The average age (mean ±SD) for fallers was 74.42 ±7.14 and the average age for nonfallers was 71.32 ±7.9 (Table 2). The percentage of fallers was similarly distributed across disease severity for FW and BW conditions (Table 3). The highest probability of falls occurred for Stage 2, across all walking conditions (Table 3).

In Figure 6, data for BW gait speed for PWP from the present study were compared to the recommended cutoffs for healthy older adults collected by

Carter et al.[29] using their novel 3-meter backward walk test. The authors suggested that healthy older adults finishing the task in less than 3.0 seconds (> 1 m/s) were unlikely to have reported falling on a questionnaire (capturing 74% of nonfallers), whereas those finishing the task in more than 4.5 seconds (< 0.67 m/s) were very likely to have reported falling (capturing 81% of fallers). Using data reported by the present study in PWP, the cutoff of finishing in less than 3 seconds (> 1 m/s) captured 77% of nonfallers in T1 and 81% of nonfallers in T2, while the cutoff of finishing in more than 4.5 seconds (< 0.67 m/s) captured 53% of fallers in T1 and 59% of fallers in T2. This comparison suggests that for PWP, the cutoffs from healthy older adults may not be as accurate at capturing fallers and highlights that falls in PWP may be occurring more often at higher speeds (> .67 and < 1m/s) than in healthy older adults.

Figure 6. Summarizing Cut-offs




If T1 is worse it may be a better predictor of postural stability or fall risk in everyday situations and provide a better target for proactive intervention, as

previously shown for the training of the protective stepping response (Barjas, Jobges, Pai) and backward walking (Grobbelaar).

## Discussion

This retrospective study was the first to use the three-meter backward walk test, previously introduced for older adults by Carter et al. to characterize BW gait speed in across decades, disease severity, and describe its' accuracy to identify retrospective falls in a group of PWP.

In Aim 1, we showed that first-trial BW is significantly different from second-trial BW, a result similar to what has been shown for the first-trial effect in protective stepping in PWP[30]. Barajas and Peterson[30] showed that an acute bout of training the protective stepping response improved the first trial protective step. In fact perturbation training to elicit protective stepping in older adults has shown retention out to 12 months and a 50% reduction in falls[32]. Recently, Grobbelaar et al.[28], compared BW training to FW training in PWP and showed that while both interventions were effective to improve gait speed, only BW training improved timing, cadence, and stride length in both directions, while FW training only showed improvement in FW gait speed characteristics. These data altogether suggest that an individual's initial response to common perturbations due to reactive or goal-directed movements like BW that occur during everyday mobility may be worthy real-world indicators of postural stability that may respond to training as a means of proactive fall prevention.

In Aim 2, our results showed that neither FW nor BW speeds were related to age. These results are different from other studies in healthy older adults[19,21,23,29] or in PWP[11,24,33] that have shown a relationship between FW gait speed and age. One possible reason we did not see slower gait velocity with aging is that we separated our data across decades (i.e., 50, 60, 70, 80 years) while these other studies looked at broader age categories that captured more than one

decade[21,23] (i.e., young, middle, elderly), simply provided an average age[17,19,24,19,33], or separated age into quartiles[11]. For example, when compared to young and middle-aged adults, kinematics of FW gait in older adults showed reduced speed, amplitude, coordination[23] as well as increased variability in all aspects of FW gait[21]. Our lack of ability to find differences across age in the present study may have been due to performance aspects of being tested in PWP and limitations of clinical tests that rely on the recording of time without quantitative technology for motion analysis. In addition, findings may have been influenced by the lack of people in younger age groups (≤50 years) and the unequal distribution of ages across decades (Table 1).

For Aim 3, we showed that only BW speeds were significantly different across disease severity as measured by H&Y stages. This is similar to the results observed by Hackney and Earhart[25] in which they found that BW velocity, but not FW velocity, decreased with increased disease severity as measured by the Unified Parkinson Disease Rating Scale[10,25](UPDRS), another scale used to rate the severity of PD. Others have shown slowing of FW with increased disease severity[11,33], but had larger numbers of PWP and a larger range of disease severity. Hackney and Earhart[25] report that while PWP in their study were able to match the FW velocity of their EC, spatiotemporal features were affected. In contrast, during BW, deficits were present both velocity and coordination and were greater in PWP than EC[25]. These data showing greater deficits for BW when compared to FW highlight the potential risks associated with everyday mobility and support the construct of separate neural network control for FW and BW as has been shown by Choi and Bastian[26] using a split-belt treadmill to manipulate walking directions and gait patterns. As suggested by others[20,25], the existence of different control mechanisms for FW and BW explains the greater difficulties PWP have with turning and transitioning in complex environments and the ability of PWP to easily override a more automated FW gait with attention. This highlights the difficulty of using FW gait speed alone to predict falls in PWP

and may explain why our subjects did not show a relationship with disease severity in the FW direction using gait speed as the primary variable.

For Aim 4, we showed that while age was significantly different in fallers and nonfallers there was no significant difference in gait speed for FW or BW across fallers and nonfallers (Table 2). This highlights the finding that older age is a risk factor for falls, even in PWP[34]. However, there was an interesting trend in that for both FW and BW, there were fallers in all stages of H&Y, but the highest percentage of fallers was always in H&Y 2 (Table 3). This could be attributed to the finding that when people in the early stages of the disease, H&Y 1 and 2, begin to take their dopamine replacement medication they experience improved gait speed and mobility, but experience more falls after being on medication for a longer period of time[34]. This could be because they are walking faster, because it is easier, but putting themselves at a greater risk for falls because of existing postural instability, gait difficulties, or executive functioning deficits that are being hidden by the medicine[35].

When we placed the data from the present study on PWP into the cutoffs presented by Carter et al.[29] in EC, we underreported the fallers, while showing similar accuracy to predicting nonfallers. This is consistent with our finding that people fell across all H&Y stages; with the highest for FW or BW occurring early in the disease. Suggesting that for PWP using an upper and lower boundary may not be an adequate method to capture at risk individuals in the cutoff windows and especially not those persons not included in a cutoff. Since the dual cutoff model does not seem appropriate for PWP, another solution is to combine BW with other validated tests that may measure different constructs. That way, if they aren't accurately identified by one test, they may be with another[17]. Since Carter et al.[29] showed that the 3MBW was most highly correlated to the TUG test in EC, future studies in PWP may look to combine these two tests. The need for multiple tests can be attributed to the complexity of PD and all of its associated symptoms, bradykinesia, postural instability, resting tremor, and difficulties with

maintaining attention and focus as well as the side effects of medications, like dyskinesias.

## Future Directions

A major limitation is the retrospective nature of this study. Prospective studies are needed to determine the ability of BW to predict falls, as well as to compare the BW test with other validated fall risk measure (TUG, 10MWT, four square step test, five times sit to stand, or pull/push tests). Future studies should determine if there is a difference in sensitivity of BW T1 and T2 to different modes of practice (i.e. aerobics versus skill learning) or to individuals with different distribution of symptoms (i.e., tremor vs. PIGD; freezers and nonfreezers). It is also important to establish the reliability of the 3MBW test within and between raters, and across time and in different populations. It is important to include a broader and more equal range of ages and disease severity to capture younger individuals (<50) and those with greater disease severity (H&Y 4). And finally, it is important to determine the sensitivity of BW to detect short- and long-term improvements with rehabilitation or group exercise interventions that include multidirectional, and complex cognitive and motor training.

References


1. Parkinson’s Diagnosis Questions: The Michael J. Fox Foundation. The Michael J. Fox Foundation for Parkinson's Research | Parkinson's Disease. https://www.michaeljfox.org/understanding-parkinsons/i-have-got-what.php. Accessed April 29, 2019.
2. Dorsey ER, Sherer T, Okun MS, Bloem BR. The Emerging Evidence of the Parkinson Pandemic. Brundin P, Langston JW, Bloem BR, eds. *J Parkinsons Dis*. 2018;8(s1):S3-S8. doi:10.3233/JPD-181474
3. Voss TS, Elm JJ, Wielinski CL, et al; Falls Writing Group NINDS NET-PD Investigators. Fall frequency and risk assessment in early Parkinson’s disease. *Parkinsonism Relat Disord* 2012 Aug;18(7):837-41. doi: 10.1016/j.paarreldis.2012.04.004. Epub 2012 Apr 26.
4. Fasano A, Canning CG, Hausdorff JM, Lord S, Rochester L. Falls in Parkinson's disease: A complex and evolving picture. *Mov Disord* Nov;32(11):1524-1536. doi: 10.1002/mds.27195. Epub 2017 Oct 25.

5. Wielinski CL, Erickson-Davis C, Wichmann R, Walde-Douglas M, Parashos SA. Falls and injuries resulting from falls among patients with Parkinsons disease and other parkinsonian syndromes. *Movement Disorders*. 2005;20(4):410-415. doi:10.1002/mds.20347.
6. McElroy WE, Maki BE. Age-related changes in compensatory stepping in response to unpredictable perturbations. Journals of Gerontology Series A Biological Sciences and Medical Sciences 1996;51:M289–96. [15]
7. McVey MA, Stylianou AP, Luchies CW, et al. Early biomechanical markers of postural instability in Parkinson's disease. *Gait Posture* 2009;30:538-542.
8. Mcvey MA, Amundsen S, Barnds A, et al. The effect of moderate Parkinson's disease on compensatory backwards stepping. *Gait Posture*. 2013;38(4):800-805. doi:10.1016/j.gaitpost.2013.03.028.
9. de Kam, D., Nonnekes, J., Oude Nijhuis, L.B. et al. Dopaminegic medication does not improve stepping responses following backward and forward balance perturbations in patients with Parkinson's disease. *J Neurol* 2014;261:2330-2337. doi.org/10.1007/s00415-014-7496-3.
10. Goetz CG, Tilley BC, Shaftman SR, et al. Movement Disorder Society–sponsored revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): scale presen- tation and clinimetric testing results. Mov Disord. 2008;23:2129–2170.
11. Hass CJ, Bloem BR, Okun MS. Pushing or pulling to predict falls in Parkinson disease? *Nat Clin Pract Neurol*. 2008;4(10):530-531. doi:10.1038/ncpneuro0912
12. Hoehn MM, Yahr MD. Parkinsonism: onset, progression, and mortality. *Neurol*. 1967;17(5):427-427. doi:10.1212/wnl.17.5.427.
13. R.M.Pickering,Y.A.M.Grimbergen, U. Rigney et al., "A meta-analysis of six prospective studies of falling in Parkinson's disease," Movement Disorders, vol. 22, no. 13, pp. 1892–1900, 2007.
14. Duncan RP, Leddy AL, Cavanaugh JT, et al. Accuracy of fall prediction in parkinson disease: Six-month and 12-month prospective analyses. *Parkinsons Dis*. 2012;2012. doi:10.1155/2012/237673
15. Steffen T, Seney M. Test-retest reliability and minimal detectable change on balance and ambulation tests, the 36-item short-form health survey, and the unified Parkinson disease rating scale in people with parkinsonism. *Phys Ther*. 2008;88(6):733-746. doi:10.2522/ptj.20070214.
16. Bloem BR, Marinus J, Almeida Q, et al.; Movement Disorders Society Rating Scales Committee. Measurement instruments to assess posture, gait, and balance in Parkinson's disease: Critique and recommendations. *Mov Disord.* 2016 Sep;31(9):1342-55. doi: 10.1002/mds.26572. Epub 2016 Mar 4.
17. Dibble LE, Lange M. Predicting Falls In Individuals with Parkinson Disease. *Journal of Neurologic Physical Therapy*. 2006;30(2):60-67. doi:10.1097/01.npt.0000282569.70920.dc.'
18. Duncan RP, Earhart GM. Should one measure balance or gait to best predict falls among people with Parkinson disease? *Parkinsons Dis*. 2012;2012. doi:10.1155/2012/923493

19. Shumway-Cook A, Baldwin M, Polissar NL, Gruber W. Predicting the Probability for Falls in Community-Dwelling Older Adults. *Physical Therapy*. 1997;77(8):812-819. doi:10.1093/ptj/77.8.812.
20. Crenna P, Carpinella I, Rabuffetti M, et al. The association between impaired turning and normal straight walking in Parkinson's disease. *Gait Posture*. 2007;26(2):172-178. doi:10.1016/j.gaitpost.2007.04.010.
21. Fritz N, Worstell A, Kloos A, Siles A, White S, Kegelmeyer D. Backward walking measures are sensitive to age-related changes in mobility and balance. Gait & Posture. 2013;37(4):593-597. doi:10.1016/j.gaitpost.2012.09.022.
22. Husu P, Suni J, Pasanen M, Miilunpalo S. Health-related fitness tests as predictors of difficulties in long-distance walking among high-functioning older adults. *Aging Clin Exp Res* 2007;19:444-450.
23. Laufer Y. Effect of Age on Characteristics of Forward and Backward Gait at Preferred and Accelerated Walking Speed. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 2005;60(5):627-632. doi:10.1093/gerona/60.5.627.
24. Nemanich ST, Duncan RP, Dibble LE, et al. Predictors of gait speeds and the relationship of gait speeds to falls in men and women with Parkinson disease. *Parkinsons Dis*. 2013;2013:1-8. doi:10.1155/2013/141720.
25. Hackney ME, Earhart GM. The effects of a secondary task on forward and backward walking in Parkinson's disease. *Neurorehabil Neural Repair*. 2009;24(1):97-106. doi:10.1177/1545968309341061.
26. Choi JT, Bastian AJ. Adaptation reveals independent control networks for human walking. Nat Neurosci 2007;10(8):1055-1062.
27. Grasso R, Bianchi L, Lacquaniti F. Motor patterns for human gait: backward versus forward locomotion. *J Neurophysiol* 1998;80:543-551.
28. Grobbelaar R, Venter R, Welman KE. Backward compared to forward over ground gait retraining have additional benefits for gait in individuals with mild to moderate Parkinson's disease: A randomized controlled trial. *Gait Posture* 2017 Oct;58:294-299. doi:10.1016/j.gaitpost.2017.08.019. Epub 2017 Aug 18.
29. Carter V, Jain T, James J, Cornwall M, Aldrich A, Heer HDD. The 3-m backwards walk and retrospective falls. *J Geriatr Phys Ther*. 2017;00:1-7. doi:10.1519/jpt.0000000000000149.
30. Barajas JS, Peterson DS. First-trial protective step performance before and after short-term perturbation practice in people with Parkinson's disease. *J Neurol*. 2018;265(5):1138-1144.
31. Jobges M, Heuschkel G, Pretzel C, Illhardt C, Renner C, Hummelsheim H. Repetitive training of compensatory steps: a therapeutic approach for postural instability in Parkinson's disease. J Neurol Neurosurg Psychiatry 2004;75:1682–1687.
32. Pai YC, Bhatt T, Yang F, Wang E. Perturbation training can reduce community-dwelling older adults' annual fall risk: a randomized controlled trial. *J Gerontol A Biol Sci Med Sci*. 2014;69:1586–1594. doi:10.1007/s00415-018-8821-z.
33. Paker N, Bugdayci D, Goksenoglu G, Demircioğlu DT, Kesiktas N, Ince N. Gait speed and related factors in Parkinson's disease. *Journal of Physical Therapy Science*. 2015;27(12):3675-3679. doi:10.1589/jpts.27.3675.

34. Hiorth YH, Alves G, Larsen JP, Schulz J, Tysnes O-B, Pedersen KF. Long-term risk of falls in an incident Parkinson's disease cohort: the Norwegian ParkWest study. *Journal of Neurology*. 2016;264(2):364-372. doi:10.1007/s00415-016-8365-z.
35. Bryant MS, Rintala DH, Hou JG, Lai EC, Protas EJ. EFFECTS OF LEVADOPA ON FORWARD AND BACKWARD GAIT PATTERNS IN PERSONS WITH PARKINSON'S DISEASE. *Neuroreahbilitation*. July 2012:247-252. doi:10.3233/NRE-2011-0700.