The relationship between balance and gait characteristics in Parkinson disease: A cross-sectional study

Claire Gentile, SPT[1]; Camryn Sprouse, SPT [1]; Benjamin Killen PT, DPT [2]; Chelsea Duppen PT, DPT, PhD [2]; Michael D. Lewek PT, PhD [1,2]

Abstract:

PURPOSE: Parkinson disease is characterized by significant gait and balance deficits, leading to increased risk of falls and reduced quality of life. Gait and balance are likely interrelated, however, as walking requires sufficient balance to be able to maintain single limb support while advancing the swinging leg. Understanding the relationship between gait and balance is essential to develop targeted therapeutic interventions that enhance mobility and mitigate falls risk. Given the balance requirements associated with maintaining a stable gait pattern, the purpose of this study is to examine the potential relationship between measures of balance and spatiotemporal aspects of gait in people with Parkinson disease (PwPD) using a cross-sectional analysis. We hypothesize that gait and balance measures (along with measures of balance confidence) will be significantly correlated due to the overlapping impairments that influence gait and balance performance in PwPD.

METHODS: Cross-sectional (n= 56) data from previous studies of gait and balance in PwPD (Hoehn and Yahr stages I-III) were used for this secondary analysis. All measures were acquired prior to any intervention. Specific balance measures included the Mini-BESTest, Activities-specific Balance Confidence (ABC) Scale, single leg stance time, and Timed Up and Go (TUG). Specific measures of spatiotemporal aspects of gait included step length, gait speed, swing time and double support time. Pearson (r) and Spearman's (ρ) rank correlations were used to examine potential relationships between gait and balance measures.

RESULTS: The cross-sectional analysis revealed a significant positive correlation between mini-BESTest total score and comfortable gait speed ($r=.435$, $p = .004$) and minimum step length ($r=0.420$, $p = 0.005$). A significant negative correlation was found between mini-BESTest total score and minimum double limb support time ($r=-.550$, $p < .001$). A significant negative relationship between the Timed Up and Go test and comfortable gait speed ($r= -.764$, $p < .001$), minimum swing time in percentage of gait cycle ($r= -.630$, $p < .001$), and minimum step length ($r= -.744$, $p < .001$). Finally, a significant positive relationship was found between the Timed Up and go and minimum double limb support time as a percentage of the gait cycle ($r=.731$, $p < .001$).

CONCLUSION: These findings reveal significant relationships between gait and balance capacity measures in PwPD. It appears that individuals with greater balance demonstrate greater gait speed and step lengths. We can postulate that these greater step lengths are possible due to better balance. Conversely, it is possible that participants exhibit greater balance because they are used to walking at faster speeds and with longer steps, which presumably challenges balance more so than slower walking with smaller steps. Future studies should investigate potential causal relationships by implementing physical rehabilitation to affect these variables of gait and balance in PwPD.

Background:

Parkinson disease (PD) is a progressive neurodegenerative disease characterized by disabling non-motor and motor symptoms that contribute to deficits in gait and balance.[1] Because PD effects multiple neural pathways and brain networks, people with Parkinson disease (PwPD) present with classic motor symptoms (bradykinesia/akinesia, resting tremor, rigidity, and postural instability) and various “invisible” non-motor symptoms.[2-4] Clinical subtypes such as tremor dominant (TD) and postural instability gait disorder (PIGD) have been used to categorize PwPD according to clinical presentation. The PIGD subtype is thought to be associated with a more severe progression of disease, with earlier clinical signs of disruption in balance and gait than those with the TD subtype.[2] Given the importance of gait and balance measures in PwPD for clinical subtyping and functional status, it is important to understand the relationship between gait and balance measures to guide interventions.

Gait and balance are thought to be interconnected due to their mutual requirement for proper function. For example, walking with low step length variability requires less CNS activation for sagittal plane movements, minimizing the need for integrated balance control during gait. This allows walking balance to be maintained through lateral foot placement. However, in everyday environments, maintaining low gait variability is not practical for navigating varied terrains, crowded settings, and unexpected disturbances, which rely on more active CNS control and balance during walking.[5] Since balance is significantly influenced by foot placement in the sagittal plane, this may explain why individuals with balance deficits may use large step widths. Given the potential interaction between gait and balance, it is possible that those with balance deficits will be unable to maintain adequate single limb stance for sufficiently long steps. Furthermore, it is possible that individuals take smaller steps to increase double limb support for greater stability. Investigating the interaction between gait and balance across different populations is worthwhile to maintain safe ambulation in community settings.

With PD becoming more prevalent in older age, individuals with PD experience changes in gait and balance due to both the neurodegenerative process in the brain and the natural aging process.[1] As individuals age, there is a decline in the sensory system's ability to adapt to environmental changes and maintain balance.[6] Unipedal stance time specifically requires multiple sensory inputs, neuromuscular control, and sufficient lower extremity strength, all of which are affected by aging, causing significant declines in single leg balance.[7] Additionally, spatiotemporal aspects of gait change with age, resulting in slower gait speeds and increased gait variability, which elevates the risk of falls.[6] Furthermore, PD contributes its own motor symptoms that lead to common gait impairments such as decreased gait speed, reduced step lengths and arm swing, impaired rhythmicity, and freezing of gait.[8] Damage to the basal ganglia further results in rigidity, impaired proprioception, and difficulty initiating movements, leading to balance impairments such as increased postural sway and narrow step width/base of support.[9]

Current pharmacological interventions for PwPD are intended to restore normal dopamine levels, with levodopa being the leading option.[10] Although dopaminergic therapies may enhance gait speed and step length, they may also increase postural sway.[8, 11] Additionally, adverse effects of levodopa use can cause adverse effects such as dyskinesia, the on-off phenomenon with diminishing effectiveness of medication before next dosage, and reduced responsiveness over time necessitating in higher and more frequent doses as the disease progresses.[10, 12] These factors may alter both gait and balance, contributing to an increased risk of falls, subsequent injuries, decreased mobility due to injuries, lower quality of life, and potentially death.[13]

Currently, there remains a lack of evidence exploring the possible relationship between gait and balance measures in PwPD. Previous literature has found that balance outcome measures such as the Berg Balance Scale are correlated with step length and gait speed in people with brain injuries.[14] Similarly, there is a significant positive relationship between gait speed and balance measures in older adults living in long term care facilities.[15] However, this relationship has not been studied in PwPD. Given the high prevalence of both gait and balance impairments, the purpose of this study is to examine the potential relationship between measures of balance and spatiotemporal aspects of gait in PwPD using a cross-sectional analysis. Considering the multisensory interactions[16] and overlapping impairments that influence gait and balance performance, it is anticipated that there will be significant correlations between gait performance measures (step length, gait speed, swing time, and double support time) and balance measures (Mini-BESTest, TUG, single leg stance time, and Activities–Specific Balance (ABC) Scale).

Methods:

This cross-sectional study represents a secondary analysis from several published[17-19] and unpublished IRB approved studies to examine both continuous walking and gait initiation in PwPD. All studies collected data prior to any intervention and while participants were in the "on" phase of medication. Participants were included if they had a clinical diagnosis of idiopathic PD with mild to moderate severity (Hoehn and Yahr 1 – 3), as well as mild to moderate gait or balance impairment characterized by a rating of 1–2 on the Movement Disorders Society - Unified Parkinson's Disease Rating Scale (MDS-UPDRS) item 10.

Gait data were collected using a Zeno mat (Protokinetics) gait analysis system, which consisted of a 4x20 foot mat containing multiple pressure sensors. Participants were instructed to complete two passes across the mat at a comfortable gait speed and then two passes at a fast gait speed. The outcome measures collected via the Zeno include step length, comfortable gait speed, and percentages of the gait cycle for double limb stance, and single limb stance (i.e., swing phase). Data were extracted for each limb and the smaller value from both limbs was retained for analysis (e.g., minimum step length, minimum swing time, and minimum double support times). The Mini-BESTest was administered to evaluate dynamic balance by testing anticipatory reactions, reactive postural control, sensory orientation, and dynamic gait.[20] In addition to the total score, the following values were extracted from the mini-BESTest: single leg stance time and Timed Up and Go (TUG) time. The Timed up and Go is a balance test that measures the time required to rise from sitting, walk 3 meters at a comfortable pace, turn, return to the chair and sit down.[21] Scores below 11.5 seconds indicate a higher risk for falls.[22] The single leg stance time was performed for each limb separately and the smaller of the two values was used for analysis (SLS_{min}). Finally, the Activities-specific Balance Confidence Scale (ABC) is a self-reported measure used to assess a patient's subjective balance confidence, which is an important factor associated with recurrent falls in PwPD.[18]

SPSS was used (version 29, IBM) for all statistical analyses. Pearson correlation was used to analyze the relationship between gait (CGS, step length, double support time, and swing time) and balance (TUG, SLS_{min}). Spearman correlation analyses were used to assess potential relationships between gait measures and the remaining balance measures (mini-BESTest, ABC) measures. An adjusted alpha of .00125 (i.e., .05/4) was used and interpreted the strength of these relationships as either a small ($r = .1$ to $.3$), medium ($r = .3$ to $.5$), or a large ($r > .5$) effect size.

Results:

Forty-five participants were included for analysis with a diagnosis of PD stages I-III on the Hoehn and Yahr scale. Table 1 describes the demographic details of the participants. Using Spearman's correlation, a significant positive correlation was found between mini-BESTest total score and comfortable gait speed (r=.435, figure 1) and minimum step length (r=.420, figure 2). A significant negative correlation was found between mini-BESTest total score and minimum double limb support time (r=-.550, figure 3). Pearson's correlation revealed a significant negative relationship between the Timed Up and Go test and comfortable gait speed (r= -.764, figure 4), minimum swing time in percentage of gait cycle (r= -.630, figure 5), and minimum step length (r= -.744, figure 6). A significant positive relationship was found between the Timed Up and go and minimum double limb support time as a percentage of the gait cycle (r=.731, figure 7). See Table 2 and 3 for additional correlations between balance measures and spatiotemporal gait measures.

Table 1: Participant Demographics

Sex	Female: 17 / Male: 28
H&Y Stage* **	I: 8 / II: 26 / III: 6
Medication dose (mg)*** (mean ± SD)	522 ± 429.3
Chronicity of disease* (mean ± SD)	12.2 ± 6.1
UPDRS**** (mean ± SD)	24.8 ± 10.3
Weight (kg)** (mean ± SD)	74.1 ± 16.3
Height (in)** (mean ± SD)	67.7 ± 3.6
Age (yr) (mean ± SD)	67.3 ± 10

*Note: *: missing data for 2 participants, **: missing data for 3 participants, ***: missing data for 5 participants, ****: missing data for 8 participants*

Table 2: Spearman correlations between balance measures and spatiotemporal gait measures

ABC	*CGS*	r = .284; p = .179
	%Swing	r = .347; p = .096
	SLmin	r = .438; p = .032
	%DLS	r = -.313; p = .136
MB	*CGS*	r = .435; p = .004
	%Swing	r = .330; p = .030
	SLmin	r = .420; p = .005
	%DLS	r = -.550; p < .001

Note: Shaded cells indicate a significant relationship (p < .0125). ABC: Activities-specific Balance Confidence Scale; MB: MiniBEST total score; CGS: comfortable gait speed; %Swing: minimum swing time in percentage of gait cycle; SLmin: minimum step length; %DLS: minimum double limb support time in percentage of gait cycle

Table 3: Pearson correlations between balance measures and spatiotemporal gait measures

TUG	*CGS*	r = -.764; p < .001
	%Swing	r = -.630; p < .001
	SLmin	r = -.744; p < .001
	%DLS	r = .731; p < .001
SLSmin	*CGS*	r = .308; p = .045
	%Swing	r = .326; p = .033
	SLmin	r = .267; p = .083
	%DLS	r = -.375; p = .013

Note: Shaded cells indicate a significant relationship (p < .0125). TUG: Timed Up and Go; SLSmin: minimum single leg stance time; CGS: comfortable gait speed; %Swing: minimum swing time in percentage of gait cycle; SLmin: minimum step length; %DLS: minimum double limb support time in percentage of gait cycle

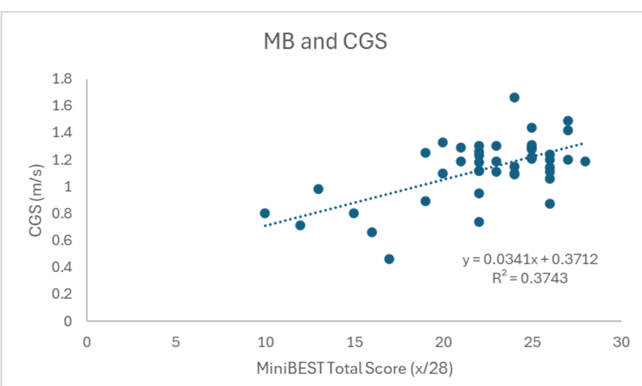

Figure 1: Spearman correlation between mini-BESTest and comfortable gait speed.

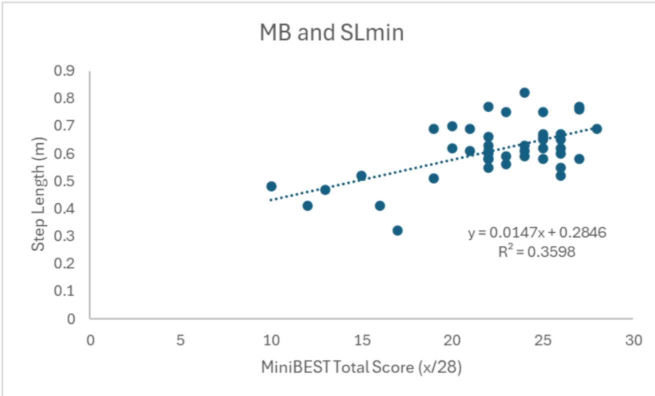

Figure 2: Spearman correlation between mini-BESTest and minimum step length

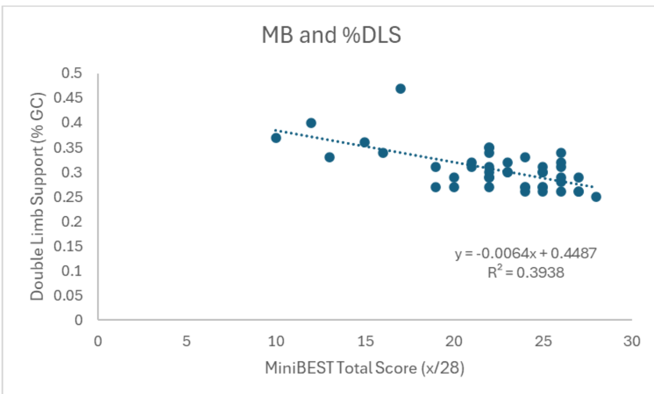

Figure 3: Spearman correlation between mini-BESTest and minimum double limb support time in percentage of gait cycle

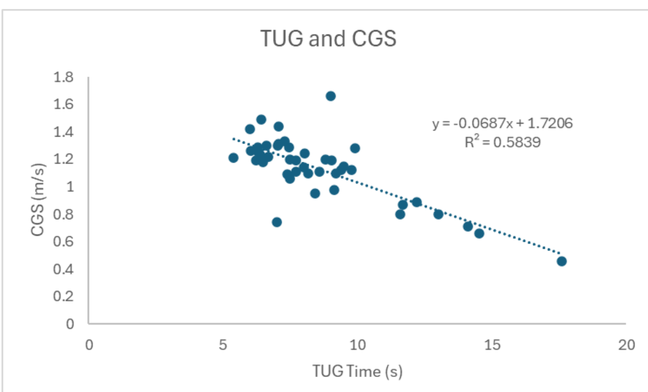

Figure 4: Pearson correlation between Timed Up and Go and comfortable gait speed

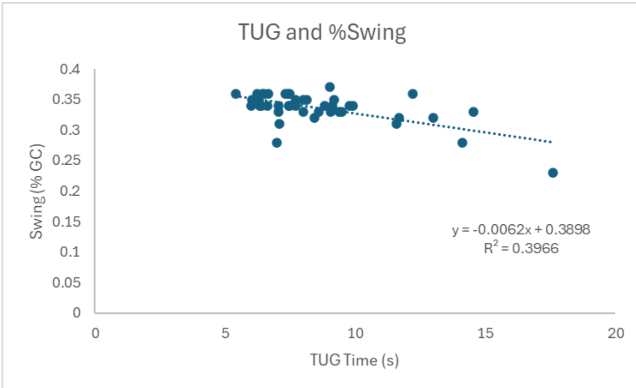

Figure 5: Pearson correlation between Timed Up and Go and minimum swing time in percentage of gait cycle

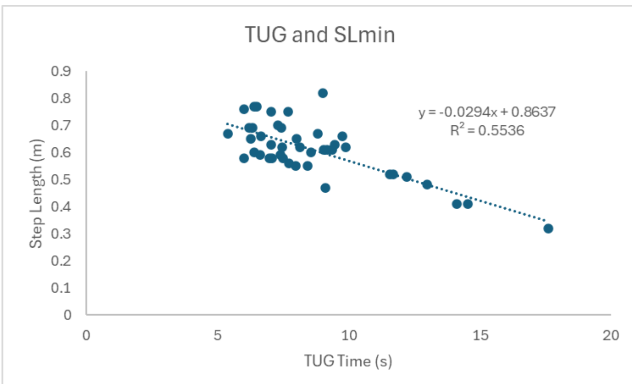

Figure 6: Pearson correlation between Timed Up and Go and minimum step length

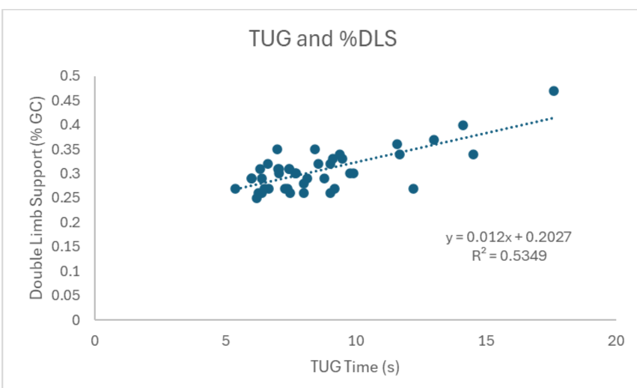

Figure 7: Pearson correlation between Timed Up and Go and minimum double limb support time in percentage of gait cycle

Discussion:

The purpose of this study was to examine the potential relationship between measures of balance and spatiotemporal aspects of gait in PwPD. Our hypothesis that gait and balance measures (along with measures of balance confidence) will be significantly correlated in PwPD was partially supported as some significant correlations were found. Balance measures, such as the TUG and Mini-BESTest, were broadly related to spatiotemporal measures of gait in PwPD. Specifically, the TUG was significantly related to comfortable gait speed, minimum swing time, minimum step length, and minimum double limb support time. The Mini-BESTest was significantly related to comfortable gait speed, minimum step length, and minimum double limb support time. Generally, these data suggest that we must pay attention to both balance and gait at the same time for PwPD. Although the TUG and Mini-BESTest are measures of balance, they both require the participant to ambulate during testing.[23] Because of this, it is not surprising that both of these balance measures are significantly correlated to spatiotemporal parameters of gait.

Interestingly, the ABC, a measure of one's perception of their balance abilities, was not significantly correlated with spatiotemporal aspects of gait. This implies that one's perception of balance may not correlate with actual balance performance. This concept is especially important to determine an individual's risk for falls. Objective measures are important to perform to fully evaluate one's risk for falls, as our results suggest that subjective report may not correlate with performance of gait. This conclusion builds on previous research that found a discordance between actual and perceived balance and correlates with individuals' history of falls.[24] This misjudgment can lead to situations where PwPD take risks leading to falls or avoid activities unnecessarily due to an exaggerated fear of falling; both scenarios which can negatively impact quality of life. It is essential that performance measures such as the TUG or Mini-BEST be used to understand balance and gait deficits in PwPD instead of relying on subjective measures and the individual's perception. Nevertheless, the ABC Scale may be important in addressing an individual's participation and safety.[25]

While single leg stance is required during the midstance phase of the gait cycle, the minimum duration that a PwPD can maintain static one-legged balance showed no correlation with spatiotemporal gait measures. This indicates that the ability to stand statically on one leg may not directly translate to dynamic balance during ambulation for PwPD. Gait involves intricate coordination among sensory, motor, and neural systems, which extends beyond isolated assessments of static postural control.[26] Consequently, outcome measures and interventions designed to evaluate and improve single-leg stance time might not necessarily enhance or accurately reflect gait parameters. This underscores the importance of incorporating balance assessments that include ambulation during testing and the necessity for targeted, multifaceted rehabilitation strategies that address both dynamic and static balance challenges in PwPD.

Gait and balance deficits are highly prevalent concerns among PwPD, yet gait and balance could represent distinct constructs that coexist simultaneously. Gait encompasses spatiotemporal parameters and dynamic movement patterns, while balance involves postural stability and ability to resist falls.[26] These differences suggest that gait and balance measure different aspects of functional mobility and an intervention targeting gait may not also improve balance and vice versa.

This correlational analysis has limitations, such as the inability to determine causation. Performance measures such as the TUG are helpful for evaluating functional mobility but are unable to establish causation; a better TUG score does not guarantee improved walking abilities. Incorporating additional tests could have provided a more nuanced understanding of balance and its relationship to gait, but the analysis remained constrained by the data at hand. Additionally, the subjects were mostly Hoehn & Yahr stage 2, implying that they had deficits bilaterally but did not yet have poor reactive balance responses. If more subjects were Hoehn & Yahr stage 3, the results may have looked different since this stage is associated with an increase in postural sway.[27] Since PD is a neurodegenerative disease, both balance and gait performance are expected to worsen over time with disease progression.[1] This study has demonstrated relationships between balance and spatiotemporal aspects of gait relatively early in the disease process, however these relationships may change in magnitude or direction with disease progression. Future studies should include PwPD with more advanced stages to build a more comprehensive picture of gait and balance performance in PwPD.

Conclusion:

To effectively assess gait and balance in PwPD, it is crucial to select measures that evaluate both constructs comprehensively. Outcome measures such as the Mini-BESTest or TUG are designed to capture aspects of gait and dynamic balance, making them more suitable than static measures such as single leg stance time. Additionally, while performance-based measures provide insights into physical capabilities, perceived balance does not always align with balance performance. This disconnect highlights the complexity of understanding balance confidence versus actual performance in PwPD.

Citations:

1. Hayes, M.T., *Parkinson's Disease and Parkinsonism.* Am J Med, 2019. **132**(7): p. 802-807.
2. Jankovic, J. and E.K. Tan, *Parkinson's disease: etiopathogenesis and treatment.* J Neurol Neurosurg Psychiatry, 2020. **91**(8): p. 795-808.
3. Li, Z., et al., *Abnormal Functional Brain Network in Parkinson's Disease and the Effect of Acute Deep Brain Stimulation.* Front Neurol, 2021. **12**: p. 715455.
4. Váradi, C., *Clinical Features of Parkinson's Disease: The Evolution of Critical Symptoms.* Biology (Basel), 2020. **9**(5).
5. Kuo, A.D. and J.M. Donelan, *Dynamic principles of gait and their clinical implications.* Phys Ther, 2010. **90**(2): p. 157-74.
6. Osoba, M.Y., et al., *Balance and gait in the elderly: A contemporary review.* Laryngoscope Investig Otolaryngol, 2019. **4**(1): p. 143-153.
7. Rezaei, A., et al., *Age-related changes in gait, balance, and strength parameters: A cross-sectional study.* PLoS One, 2024. **19**(10): p. e0310764.
8. Mirelman, A., et al., *Gait impairments in Parkinson's disease.* Lancet Neurol, 2019. **18**(7): p. 697-708.
9. Park, J.H., Y.J. Kang, and F.B. Horak, *What Is Wrong with Balance in Parkinson's Disease?* J Mov Disord, 2015. **8**(3): p. 109-14.
10. Pardo-Moreno, T., et al., *Current Treatments and New, Tentative Therapies for Parkinson's Disease.* Pharmaceutics, 2023. **15**(3).
11. Rocchi, L., L. Chiari, and F.B. Horak, *Effects of deep brain stimulation and levodopa on postural sway in Parkinson's disease.* J Neurol Neurosurg Psychiatry, 2002. **73**(3): p. 267-74.
12. Lipsmeier, F., et al., *Evaluation of smartphone-based testing to generate exploratory outcome measures in a phase 1 Parkinson's disease clinical trial.* Mov Disord, 2018. **33**(8): p. 1287-1297.
13. Carpenter, C.R., et al., *Older Adult Falls in Emergency Medicine: 2019 Update.* Clin Geriatr Med, 2019. **35**(2): p. 205-219.
14. Lee, B.J., et al., *Evaluation of balance functions using temporo-spatial gait analysis parameters in patients with brain lesions.* Scientific Reports, 2021. **11**(1): p. 2745.
15. N, G., *Relationship between Gait Speed and Balance Among Older Adults Residing in Long Term Care Settings.* Open Access Journal of Frailty Science, 2024. **2**: p. 1-5.
16. Roytman, S., et al., *Multisensory mechanisms of gait and balance in Parkinson's disease: an integrative review.* Neural Regen Res, 2025. **20**(1): p. 82-92.
17. Hayworth, E.M., et al., *Limb and joint kinetics during walking in individuals with Mild-Moderate Parkinson's disease.* J Biomech, 2024. **167**: p. 112076.
18. Almeida, L.R., et al., *Comparison of Self-report and Performance-Based Balance Measures for Predicting Recurrent Falls in People With Parkinson Disease: Cohort Study.* Phys Ther, 2016. **96**(7): p. 1074-84.
19. Duppen, C.P., et al., *Blending motor learning approaches for short-term adjustments to gait in people with Parkinson disease.* Exp Brain Res, 2024. **242**(12): p. 2853-2863.
20. Leddy, A.L., B.E. Crowner, and G.M. Earhart, *Utility of the Mini-BESTest, BESTest, and BESTest sections for balance assessments in individuals with Parkinson disease.* J Neurol Phys Ther, 2011. **35**(2): p. 90-7.

21. Dal Bello-Haas, V., et al., *Psychometric Properties of Activity, Self-Efficacy, and Quality-of-Life Measures in Individuals with Parkinson Disease.* Physiother Can, 2011. **63**(1): p. 47-57.
22. Nocera, J.R., et al., *Using the Timed Up & Go test in a clinical setting to predict falling in Parkinson's disease.* Arch Phys Med Rehabil, 2013. **94**(7): p. 1300-5.
23. Caronni, A., et al., *The Mini-BESTest scale and the TUG test turning duration have satisfactory criterion validity as balance measures: a longitudinal study with prospective falls reporting in neurological patients.* Gait & Posture, 2023. **105**: p. S10-S11.
24. Longhurst, J.K., et al., *Discordance Between Balance Ability and Perception Is Associated With Falls in Parkinson's Disease: A Coordinated Analysis.* Neurorehabilitation and Neural Repair, 2025. **39**(2): p. 114-125.
25. Schepens, S., A. Goldberg, and M. Wallace, *The short version of the Activities-specific Balance Confidence (ABC) scale: its validity, reliability, and relationship to balance impairment and falls in older adults.* Arch Gerontol Geriatr, 2010. **51**(1): p. 9-12.
26. MacKinnon, C.D., *Sensorimotor anatomy of gait, balance, and falls.* Handb Clin Neurol, 2018. **159**: p. 3-26.
27. Dallaire, M., et al., *Impact of frailty and sex-related differences on postural control and gait in older adults with Parkinson's Disease.* Experimental Gerontology, 2024. **186**: p. 112360.