The Effects of Performance-Based Overground Locomotor Training on Walking Turns Among Individuals with Parkinson's Disease

A Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

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DEDICATION

This dissertation is dedicated to my family; past, present, and future.

ACKNOWLEDGEMENTS

First, I want to thank God, without whom this journey would not be possible. I want to acknowledge and thank the Office of the Provost for funding through the Summer Research Fellowship and the Dissertation Completion Grant. I want to extend my sincerest gratitude and appreciation to my advisor, Dr. Andrew Guccione, for mentorship and guidance. Additionally, my appreciation is extended to the entire dissertation committee for their time and input into this project. A special thank you is owed to all study participants for volunteering their time and effort. Also, I want to thank the entire study team for their contribution to the project. To my wife, Brittany, I love you and thank you for supporting this journey. Your willingness to sacrifice and fill the void for our children Jordyn, Zoë, and Ava, is not taken lightly, and I am forever grateful. To my parents, Randy and Janet Pugh, I owe my life and thank them for their loving patience and dedication in supporting my growth. I must also thank my mentor of nearly 30 years, Dr. Joseph Dancy Jr, for continuously providing encouragement and advice. Finally, I must thank Thomasina Green, affectionately known as "Grandma," for planting her seed of knowledge, cultivating my curiosity with love, and inspiring me to blossom.

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LIST OF ABBREVIATIONS AND/OR SYMBOLS

Angle ..... θ
Anteroposterior ..... AP
Center of Mass ..... CoM
Comfortable Walking Speed ..... CWS
Control Group ..... HC
Difference ..... Δ
Dynamic Gait Index ..... DGI
Freezing of Gait ..... FoG
Inertial Measurement Unit ..... IMU
Left Limb Stride Length ..... SLL
Margin of Stability ..... MoS
Mediolateral ..... ML
Modified Cognitive Assessment ..... MoCA
Older Adults ..... OA
Overground Locomotor Training ..... OLT
Parkinson's Disease ..... PD
Peak Turn Velocity ..... PTV
People with Parkinson's Disease ..... PWPD
Quality of Life ..... QoL
Range of Motion ..... ROM
Right Limb Stride Length ..... SLR
Slower Walking Speed ..... SS
Straight Walk ..... W
Ten Minute Walk Test 10MWT
Walk and Turn ..... W&T

ABSTRACT

THE EFFECTS OF PERFORMANCE-BASED OVERGROUND LOCOMOTOR TRAINING ON WALKING TURNS AMONG INDIVIDUALS WITH PARKINSON'S DISEASE

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George Mason University, 2022

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PURPOSE: Individuals with Parkinson's disease (PD), a progressive neurodegenerative disorder, exhibit compromised postural stability along with impaired gait and balance, contributing to walking limitations, including difficulty performing turns while walking. Previous studies demonstrated that individuals with neurological impairment improve walking capacity following performance-based overground locomotor training (OLT), but the effect of OLT on turning remains unknown. This study aimed to understand the effect of twenty-four sessions of OLT on walking turns among individuals with mild- PD.

METHODS*:* Twelve participants with PD (7 Male / 5 Female; Age: 68.5±6.4 years; H&Y: 1-3) completed twenty-four 60-minute sessions of OLT, twice-weekly. Pre- and Post-assessments included the ten-minute walk test (10MWT) with the primary outcome measures including thoracolumbar rotation change in the vertical axis and peak turn velocity change in frontal (PTV_F) and transverse (PTV_T) planes.

RESULTS*:* Mean thoracolumbar rotation change was not significant following OLT (+0.23 ± 4.24°;95% CI: -4.30, 3.84; p= 0.454;Cohen's *d* = 0.05). Mean normalized thoracolumbar rotation change was also not significant (- 0.59 ± 5.52 (unitless);CI:[-12.05, 10.73]; Cohen's *d* = 0.10)p = 0.45; Cohen's *d* = 0.05). Mean PTV_F showed a moderate and significant increase following OLT (1.59 ± 2.18 °/s; 95%CI: 0.20, 2.98; p = 0.014; Cohen's *d* = 0.43). The effect of OLT on mean PTV_T was small and not significant (0.88 ± 3.18 °/s; 95%CI: -2.90, 1.14; p = 0.179; Cohen's *d* = 0.25).

CONCLUSION*:* This study provides preliminary evidence suggesting individuals with mild-PD moderately improved frontal plane dynamic postural stability during walking turns following performance-based overground locomotor training.

INTRODUCTION

Parkinson's disease (PD) is a progressive neurodegenerative disorder affecting more than 10 million people globally.[1] Gait and balance impairments develop in the early stages of PD, often before motor symptoms become prominent. [2,3] Walking and gait-dependent activities are among the earliest limitations to initiate individuals onto the path of disablement.[2] Even when the severity of the disease of any duration elicits only mild to moderate neuromuscular impairments, defined as Hoehn and Yahr (H&Y) stages I-III, altered stepping and posture coupling commonly leads to walking limitations.[4] Overall, roughly 77% of individuals with any stage of PD develop walking limitations that restrict community ambulation [5,6] and reduce their quality of life.[7]

Community ambulation requires transitions between gait subtasks (e.g., initiation, termination, and turning),[8] made difficult[3,9] by stereotypical PD gait characteristics (e.g., shortened stride length and reduced speed).[10,11] The performance of some gait subtasks for this population is well documented,[12–14] but investigations on turns while walking are scarce. Turning is a complex subtask accounting for nearly 50% of daily steps for unimpaired adults,[15] yet challenges nearly half of individuals with PD.[16] Turns while walking provokes freezing of gait (FoG),[17] increase the risk of serious injury from a fall,[18] and are described contributing to difficulty as barriers to community ambulation

from individuals with mild- PD.[19] Improving turns while walking may facilitate community ambulation for individuals with PD, thereby improving the quality of life.[19]

Performing turns while walking perturbs postural stability differently than straight-line walking. Postural stability during gait acquires, maintains, or re-establishes equilibrium to control momentum[20] and stabilize the body's center of mass (CoM).[21] When making turns, the body must decelerate, rotate, and step toward the desired trajectory,[21,22] requiring coordination between posture and stepping patterns[23–25] to create and control momentum.[20,26] For unimpaired adults, transitioning to turns occurs without incident. Healthy adults make anticipatory postural adjustments[4] that optimize turn performance when approaching planned turns.[27] Lastly, when rotating, unimpaired adults exhibit craniocaudal temporal sequencing,[3] creating intersegmental separation as the body realigns toward the new direction.

Individuals with PD exhibit different movement patterns while turning compared to unimpaired adults, reflecting disease-related motor impairments.[4,28] Figure 1 visualizes our conceptual framework describing the mediators and moderators of walking turns for this population. Following the onset of PD, impaired gait and balance characteristics[11] alter postural control during gait and contribute to modified stepping patterns, consequently contributing to difficulty performing turns.[3] Although not exhaustive, mediating factors that affect turning include intersegmental coordination and dynamic postural stability. Intersegmental coordination describes temporal and spatial relationships along the vertical axis of spinal segments.[16,29] Thoracolumbar rotation, measured by the intersegmental angular difference in the transverse plane, is reduced[29]

and less coordinated[29] while turning among people with PD, resulting in stereotypical "en bloc" turns.[16,29] The trunk plays a role in manipulating the CoM[30] for stability; however, this role becomes minimized[9] due to the flexed posture trunk [27] associated with PD. Stepping patterns also contribute to stability[4] by establishing the base of support within which to manipulate the CoM,[32,] but individuals with PD typically reduce this area[9] while turning[31] by exhibiting a narrow step width[32,33] and shortened stride length.[31,34]

Among other moderators of turns, our conceptual framework focuses on those resulting from PD-related motor symptoms, including disease severity,[2,35] gait velocity,[36] turn strategy,[32,37] and turn angle.[37,38] Disease severity, as rated using the H&Y, directly reflects the progression of motor symptoms influencing gait and posture.[6] and correlates with turn quantification.[37] Gait velocity slows with disease progression,[11] impacts thoracolumbar rotation[36] and the distance needed to complete turns.[32] Turn strategies influence stability by generating and controlling momentum through the asymmetric changes in direction and acceleration.[39] Individuals with PD typically select conservative trategies[16] to meet this unique challenge, using more steps, slower turn velocities,[16,32] and shortened stride lengths.[32] Lastly, people with PD have angle-specific turning impairments that challenge stability,[32,40] leading to similar compensatory behavior[24,31,33] as turn angles increase above 90°. In short, these mediating and moderating turning factors develop from gait and posture impairments and are promising intervention targets for people with PD.

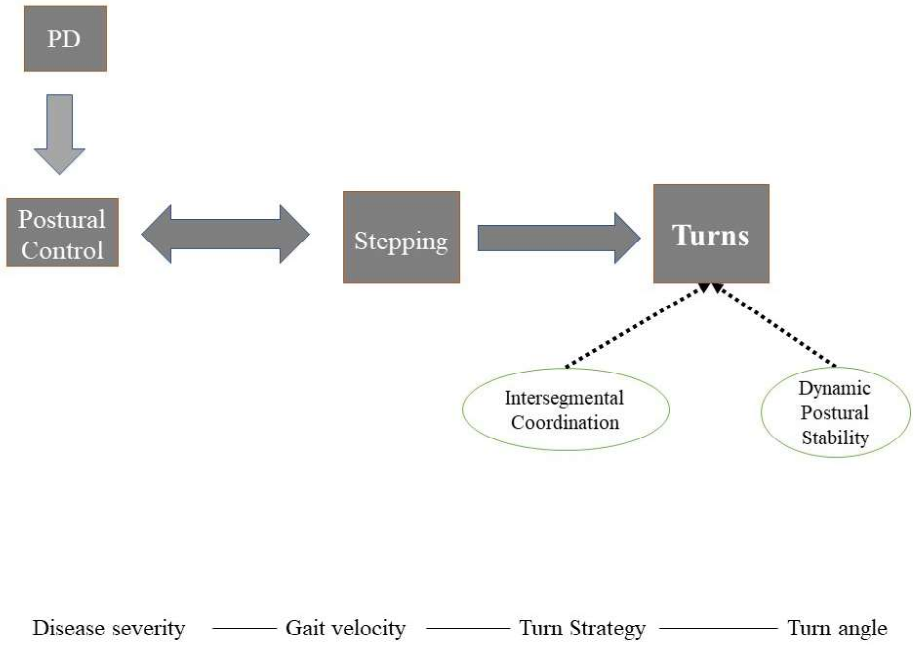

Figure 1 Conceptual framework describing turns while walking. In this framework, impaired postural control resulting from PD contributes to gait and balance impairments that contribute to difficulty performing turns while walking. The mediating factors affecting turns of focus for this study are circles and include intersegmental coordination and dynamic postural stability. The moderators are listed on the bottom line, including disease severity, gait velocity, turn strategy, and turn angle.

Various turning measurements quantify postural stability in the vertical (transverse plane) and anteroposterior (frontal plane) axes (Figure 2). However, particular interest areas include thoracolumbar rotation and peak angular turn velocity. Thoracolumbar rotation is often assessed using a clinical range of motion tests,[41] but despite its clinical relevance, assessing rotation during gait tasks better captures

participation in walking-related activities, as the coupling between segmental coordination and locomotion is foundational to maintaining dynamic postural control while turning.[42] Within the same context, peak turn velocity, also known as peak angular velocity, quantifies the highest level of dynamic postural control, the ability to respond to speed and directional challenges.[42] More specifically, peak turn velocities in the transverse (PTV_T) and frontal plans (PTV_F) quantify the dynamic postural stability at the anatomical landmark used for testing.[31]

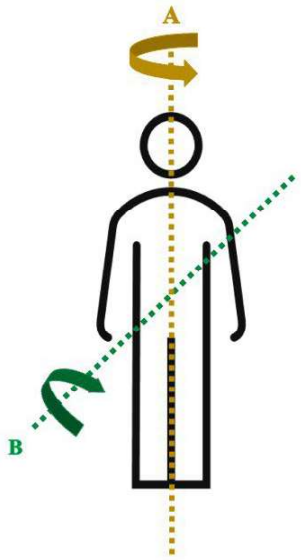

Figure 2 Visualizing rotation about the transverse plane/vertical axis (A) and frontal plane/anteroposterior axis (B).

Non-pharmacological treatments have addressed PD-related gait and posture impairments, including dance,[43] agility training,[44], and treadmill training.[45,46] Each showed improvements in global walking parameters such as distance and time. However, these interventions lacked the specificity of daily walking, which requires the resolution of constraints presented by the individual's biomechanics, the task, and the environment to produce coordinated locomotor patterns that progress the body.[7,24] Therefore, interventions addressing walking limitations should promote the exploration and development of movement solutions within the constraints experienced throughout daily life. For example, Bello et al., 2013, compared the effects of treadmill training and overground walking program among individuals with PD.[47] The outcome measures for this study included the turn segment of the TUG. Participants were randomly assigned to each group and walked the same amount of time, using 4-minute bouts, relative intensity, defined as their comfortable walking speed measured during baseline testing, and 15 sessions over five weeks. Surprisingly, only the treadmill group significantly decreased their turning duration and steps at follow-up testing. The lack of improvement demonstrated from the overground group may be related to the design of the training program, which has a couple of points of contention. First, the program did not incorporate progressive overload, as previously recommended.[48–50] Instead, participants were monitored to train at the gait speed measured during baseline assessment. Secondly, the program did not incorporate task-specific movements but focused on straight-ahead

walking. In conjunction, these missing training elements leave the findings of Bello et al. unconvincing.

Unlike traditional training, performance-based training may present a paradigm shift in the design of gait training programs. Overground locomotor training (OLT) in this study is based on a performance-based intervention model [46] to influence self-organization of movement solutions to address the constraints that impede daily walking by task-specific practice. The tasks included in the training program deconstructed the multiplanar movements of the gait cycle into a preset and progressively overloaded schedule of subtasks designed to maximize practice variability within a set timeframe under conditions of the moderate aerobic challenge. In contrast to impairment-based training where participants learn specific movement, OLT allows individuals to self-organize movement solutions using principles of motor learning,[50] as previously recommended for individuals with PD.[48,51]

Changes in turn measurements quantify some of the outcomes of locomotor training [52] and are categorized by objective performance-based or movement quality. Performance measurements quantify turning duration and step quantity during clinical tests such as the Timed Up and Go (TUG).[33,53] but only quantify movement quality with the addition of three-dimensional motion capture, [32,53,54] Despite the accuracy of motion capture systems, their environmental constraints (e.g., walkway $\leq$ 10 meters, testing in gait laboratory) and a single turn of clinical tests inadequately estimate changes that generalize beyond the clinic or gait laboratory.[33,53] In contrast, the Six-Minute Walk Test (6MWT) combines an extended walking path with multiple turns and is a gait assessment

tool for people with PD.[55,56] Studies that quantify turns during the 6MWT for this population did not include performance-based interventions but used agility t training[44] or lacked an intervention entirely.[57]

To our knowledge, no published study to date has examined changes in turns while walking overground following performance-based training, creating a knowledge gap in the mutability of turning impairments for people with PD. Understanding how these impairments change may address this barrier to community ambulation using a low-cost, non-pharmacological intervention. This pre-experimental pilot study addresses this knowledge gap with the overarching aim to understand changes in turns while walking among individuals with mild-PD following twenty-four sessions of performance-based OLT.

Specific Aims

Specific Aim 1: Quantify changes in intersegmental coordination while turning following OLT among individuals with PD, as measured by peak thoracolumbar rotation (°).

Hypothesis 1: Intersegmental coordination while turning will improve following OLT, as evidenced by increased peak thoracolumbar separation amplitude (°).

Specific Aim 2: Characterize changes in dynamic postural stability while turning following OLT among individuals with PD, as measured by PTV_T and PTV_F (°/s).

Hypothesis 2: Dynamic postural stability while turning will improve following OLT, as evidenced by increased PTV_T (°/s) and PTV_F (°/s) recorded at the sternum.

METHODS

Study Design

This pre-experimental pilot study was performed inside George Mason University Functional Performance Laboratory (Fairfax, VA). Participants completed baseline (pre-) and follow-up (post-) assessments before and following the twelve-week OLT intervention. OLT consisted of twenty-four sessions lasting 60 minutes performed twice weekly, with at least 48 hours between sessions. For inclusion in the final analysis, subjects were required to complete all training within 15 weeks of their baseline assessment and not miss more than three consecutive sessions.

Ethical Approval

This study was approved by George Mason University's Institutional Review Board (IRB) (#1374615-3) and registered on clinicaltrials.gov (NCT03864393). All prospective participants received written and verbal explanations of the study protocol and the associated risks and benefits of testing and training. In addition, each participant signed the written informed consent was signed before entering the study.

Study Sample

Participants were recruited using IRB-approved digital and print flyers displayed online and distributed to local Parkinson's support groups of the greater Washington D.C. area. Inclusion criteria included the following: aged 18-85 years; diagnosed with mild-PD (H&Y score ≤ 3); English speaking; able to ambulate without an assistive device. Exclusion criteria included the following: diagnosed with a neurological disease other than PD; medications affecting heart rate or metabolism; uncontrolled cardiovascular, pulmonary, neurological, or metabolic disease impacting exercise or where exercise is contraindicated; any medically diagnosed condition preventing moderate-intensity exercise; taking medications altering heart rate; Mini-Mental State Exam (MMSE) score < 24; pregnancy; legal blindness; concurrent participation in another exercise program.

Enrollment Procedure

The enrollment procedure occurred in the following order. First, individuals contacted the study coordinator via email or telephone to express interest in participating. Next, study eligibility was determined by scripted telephone interviews. Once all inclusion criteria were met, prospective participants visited the George Mason University Human Performance Laboratory (Fairfax, Virginia), where a team member reviewed the informed consent document. Next, participants were officially enrolled after voluntarily signing informed consent. Following official enrollment, additional screening included

medical history, current medications, and the Mini-Mental State Examination in determining cognitive function, per the exclusion criteria. Finally, a qualified investigator administered the H&Y assessment to determine PD severity according to the exclusion criteria.

Testing Day Procedure

Participants were asked to refrain from vigorous physical activity for at least 48 hours before the assessment and maintain their regular diet and medication schedule. Participants completed baseline (Pre) and follow-up (Post) assessments in the "ON" medication state, with assessments scheduled during similar times of day to standardize diurnal medication effects. A team member recorded each participant's height, weight, resting heart rate, and blood pressure before testing, which included overground gait analysis inside the laboratory and the 10MWT, separated by 20-30 minutes of seated rest. The testing sequence was randomized for every other enrolled participant (i.e., 1st, 3rd, 5th, etc.), with the alternating participant (i.e., 2nd, 4th, 6th, etc.) testing in the opposite order for testing balance across the sample. Thus, the testing sequence was consistent between subjects from pretest to post-test.

Inertial Measurement Instrumentation

Participants wore six portable inertial measurement units (APDM, Portland, OR), each containing a tri-axial accelerometer (range: ± 200g) and gyroscope (range: ± 200 °/s) that objectively measure the gait of individuals with PD.[37,58,59] The inertial measurement units (IMUs) were secured with Velcro straps over previously identified [60] anatomical landmarks (Figure 3), including the sternum, the dorsal aspects of the left and right wrists, approximately the fifth lumbar vertebrae, and the dorsal aspect of the left and right shoes and were adjusted to maintain individual gait patterns. Data were collected at a sampling rate of 128 Hz and logged internally for offline processing.

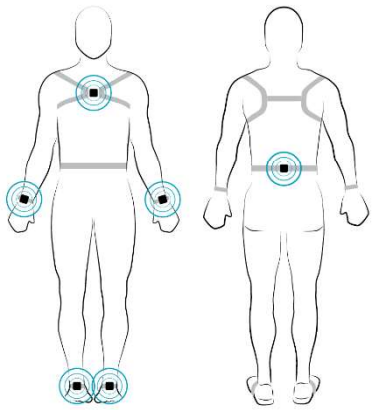

Figure 3 Schematic representation of sensor placement for the 10MWT, per APDM instructions. The placement locations include the sternum, the dorsal aspects of the left and right wrists, approximately the fifth lumbar vertebrae, and the dorsal aspect of the left and right feet.

Ten-Minute Walk Test Procedure

The ten-minute walk test (10MWT) is a task-specific gait assessment modified from the six-minute walk test, commonly used to assess walking limitations among individuals with PD.[52,55] The 10MWT increases the performance ceiling encountered with other assessments due to increased time, distance, and the number of turns.[56] The 10MWT was performed along a 60-meter corridor, indoors, and over a firm surface. After a brief familiarization, participants were instructed to complete as many laps as possible at their self-selected speed. Once the test commenced, participants received no further instructions or feedback. Participants walked at their preferred velocity and turning strategies during the test and remained unaware of time. One team member followed the participant for safety, while at least one other team member remained in the hallway for crowd control. Data were synchronized and logged in all sensors with event markers indicating the test "Start" and "End" of the 10MWT. Participants were instructed to stop, after ten minutes, without warning. IMUs were immediately removed and docked to upload raw data for offline processing.[57]

Intervention

Twenty-four overground locomotor training (OLT) sessions were performed for one hour, twice per week for twelve weeks. OLT is a performance-based motor learning program emphasizing self-exploration of movement solutions in an overground environment while full weight-bearing and free of assistive devices. OLT incorporates motor learning with locomotor training as recommended for individuals with PD[4] while

maintaining a moderate-aerobic intensity. The design of OLT is comparable to periodized training used in sports performance, where training goals occur in phases. Specific to OLT, 3, 4-week phases alternate between gait subtasks, including initiation, termination, steady-state, and turning. The complexity of the intra-session movement progressed from skill acquisition to rehearsal and integration. The complete list of training sessions is provided in Appendix C.

Data Analysis

Raw data were imported to Matlab 2021a (Mathworks, Natick, MA) for offline processing. Data were visually inspected and cropped to ensure the collection of the complete 10MWT. After assessing the frequency domain, raw gyroscope data were low-passed through a zero-phase, fourth-order Butterworth filter with a cutoff frequency of 1.6 Hz.[35] The vertical axis was re-aligned to the global vertical axis to improve tri-axial measurement accuracy before analysis.[58] A semi-automated [59] Matlab script was adapted from previously described methods [63] to identify turning segments. The lumbar vertical axis angle reached a difference of two standard deviations (SD) away from the mean angle during linear walking identified the turn onset and offset. Figure 4 illustrates the identified turning segments. Turns identified in Matlab were verified with handwritten documentation from each testing session. Visual inspection confirmed the proper identification of all turning segments before data were extracted for offline analysis. Incomplete turns were excluded from the analysis.

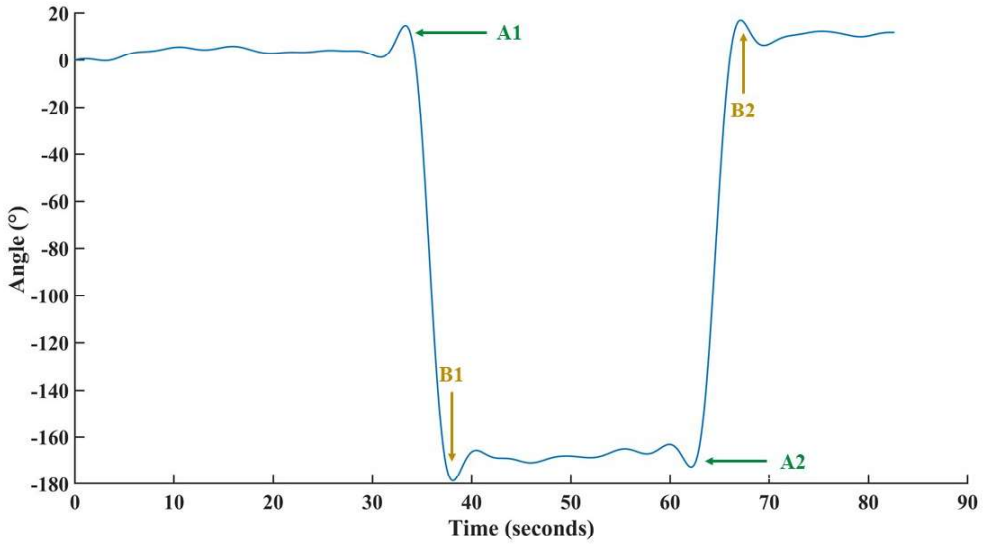

Figure 4 Visual representation of turning segment during the 10MWT, as identified using the transverse plane rotation angle of the lumbar sensor. "A1" represents the time point of turn onset, and "B1" represents the time point of turn offset. Likewise, "A2" and "B2" indicate the same onset and offset time points for the second turn.

Primary Outcome Measures

Thoracolumbar Rotation Change

The relative sternum and lumbar angles were calculated using cumulative trapezoidal integration[64] of filtered gyroscope signals at each turn. The angle is

considered relative because the integration of each turn segment causes the first data point to start at 0°. Thoracolumbar rotation (°) was defined as the peak angular difference between the sternum and lumbar signals, was calculated by subtracting the lumbar angular position from the sternum angular position. Figure 5 displays an example of thoracolumbar rotation, as measured by the peak angular difference between the sternum and lumbar segments.

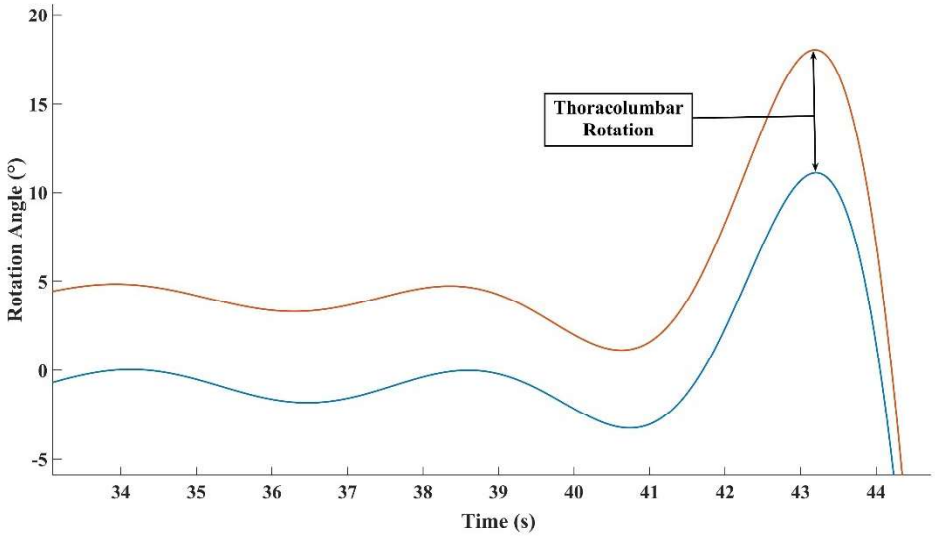

Figure 5 Thoracolumbar rotation, measured by the peak angular difference between the lumbar (blue) and sternum (orange) sensors.

The sign of thoracolumbar rotation denotes clockwise (-) and counterclockwise (+) turning directions. Therefore, the absolute value of rotation angles was used to calculate thoracolumbar rotation to avoid miscalculations. The final measurement represents the angular separation of the sternum relative to the lumbar segment. Positive values indicated greater sternum rotation, while negative values indicated greater lumbar rotation.[60]

Equation 1

$$\text{Thoracolumbar rotation } \theta = |\theta\text{sternum}| - |\theta\text{ lumbar}|$$

Because thoracolumbar rotation is speed-dependent,[36] we normalized (unitless) to the mean linear gait velocity of the 3 seconds leading into each turn.[61] This value is not intended to interpret positive or negative change but provide a comparison parameter that informs compensatory behavior. For example, increased normalized values may reflect more rotation or slower velocity. Alternatively, reductions in the measure can decrease

with reduced thoracolumbar rotation or increased linear velocity while approaching the turn. The gait velocity (m/s) was calculated using the cumulative trapezoidal integration function on the AP lumbar accelerometer (acc_y) for three seconds (dt) leading into each turn, as displayed in Equation 2.[64,66] Equation 3 provides the final step for calculating normalized thoracolumbar rotation.

Equation 2

$$\text{Gait velocity} = \int_0^n \text{acc(y)}\ \text{dt}$$

Equation 3

$$\text{Normalized Thoracolumbar rotation} = \frac{\theta}{\text{Gait velocity}}$$

Peak Turn Velocity

The peak turn velocities (°/s) were identified in the vertical (PTV_T) and anteroposterior (PTV_F) axes for each turn in the lumbar and sternum sensors. Figure 6 visualizes PTV_T peak turn velocities during the 10MWT.

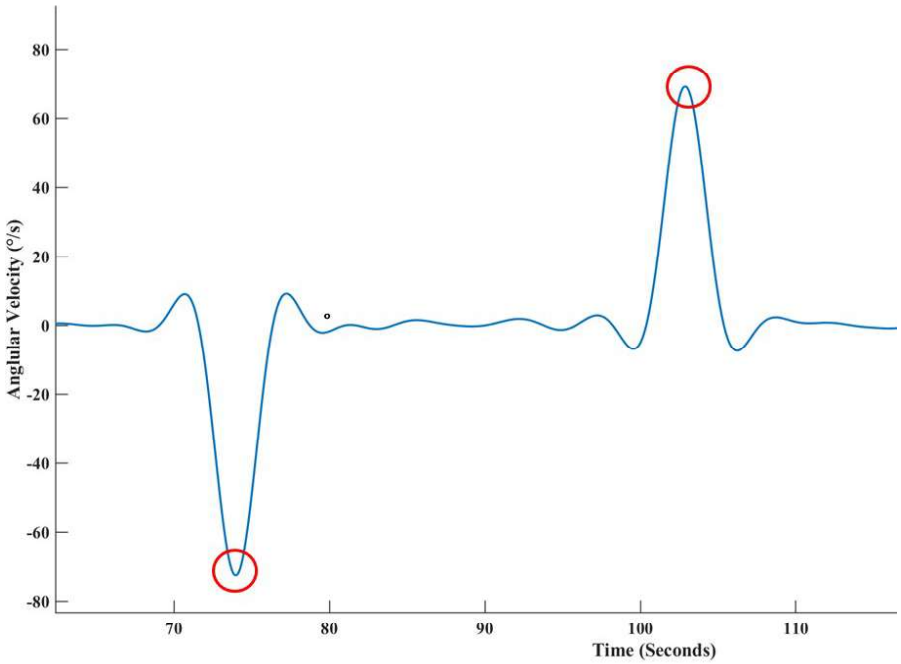

Figure 6 Visualization of angular velocities in the transverse plane during the 10MWT. The RED circles identify the peak angular velocity of separate turns.

Secondary Outcome Measures

Turn duration (s) was calculated as the difference between turn onset and offset. Next, turning steps for each foot were calculated using previously described methods.[62] Briefly, foot-mounted accelerometer signals were band passed through a fourth-order Butterworth filter with 0.9Hz and 2.5 Hz cutoff frequencies. Next, the previously

identified turning segments were extracted from the filtered signal, and turning steps were identified via the 95th percentile threshold. The filtered signals were then double integrated[63] and labeled in a two-dimensional coordinate system containing mediolateral (x) and anteroposterior (y) coordinates to obtain each foot's position, as described in Equation 4. Finally, stride lengths were calculated as the positional difference between ipsilateral steps.

Equation 4 Foot Position = $\sqrt{\boldsymbol{Position(x)^2 + Position(y)^2}}$

Statistical Analysis

Statistical analysis was performed using Stata 15.1 (College Station, TX). The descriptive statistics for participants included in the final analysis are presented as means ± standard deviations (SD).[64] Visual inspection of histogram plots and Shapiro-Wilk tests confirmed normal distribution. One-tailed paired *t*-tests compared the mean differences between baseline (pre) and follow-up (post) assessments for the primary outcomes to test the hypothesis that thoracolumbar rotation and PTV will increase the following OLT. Two-tailed t-tests were performed on the secondary outcome measures to test whether turning stride length, turn duration, and turning steps will change post-OLT. The

significance level for all tests was $\alpha = 0.05$. The effect of OLT on all outcome measures was estimated using Cohen's *d*.

RESULTS

We screened twenty-seven individuals for inclusion and enrolled 17 participants following the informed consent. One participant who enrolled was excluded due to uncontrolled hypertension during baseline testing. Three participants voluntarily withdrew from the study due to excessive fatigue (n = 1), dissatisfaction with training (n = 1), and a chronic knee condition (n = 1) exacerbated during training. One participant reported chest discomfort during the first training session and was referred to the treating cardiologist. After evaluation, the participant was cleared to resume training and completed the study without further incident. One participant who completed the follow-up assessment was removed from the final analysis after informing a team member of increasing dopaminergic medication during the intervention. In total, twelve participants were included in the final analysis. Figure 7 provides a detailed visualization of the study flow.

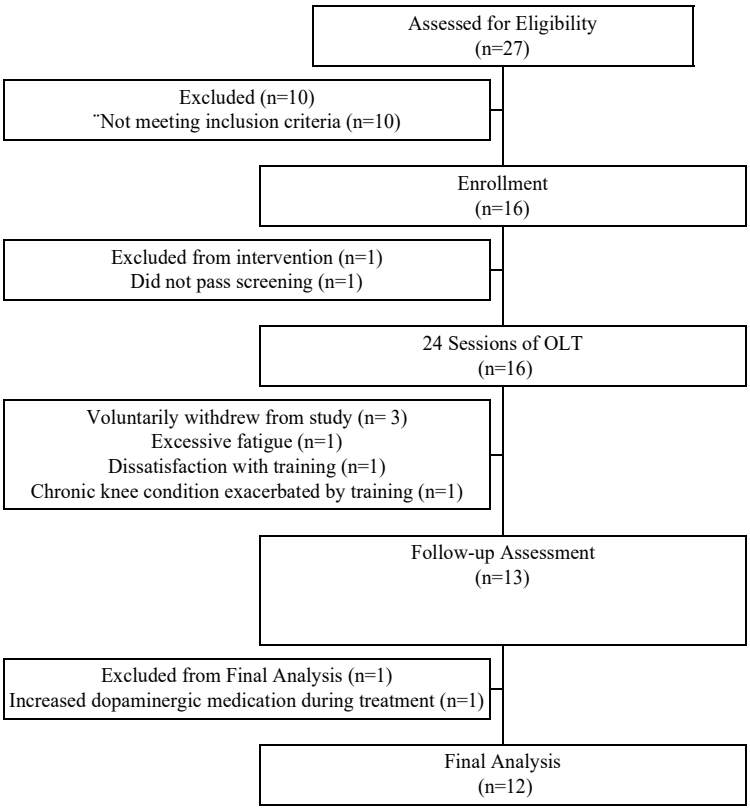

Figure 7 Schematic representation of the study flow from Assessment for eligibility, Study Enrollment, Intervention, Follow-up Assessment, And Final Analysis.

At baseline, participant characteristics included: 7 male / 5 female; Age: 68.5 ± 6.35 years; Height:166.93 ± 9.01 cm; Weight: 67.37 ± 11.47 kg; The Hoehn &Yahr scores: 1-3; Affected Side: 8 Right / 4 Left. Descriptive characteristics for each participant are provided in Table 1.

Table 1 Descriptive statistics of participants' characteristics are reported in mean ± standard deviation except for Gender, which is reported as the number of men and women, H&Y, reported as the score range, and the Affected Side, reported as the sum of left and right sides.

Participant	Age(years)	Gender	Height(cm)	Weight(kg)	H&Y	Affected Side
1	71	M	176.5	74.7	1	R
2	71	M	176.5	79.4	1.5	R
3	76	F	174.0	61.8	1	R
4	64	M	180.5	76.3	1	L
5	75	M	168.5	77.0	2	R
6	55	F	150.0	51.7	2	R
7	70	F	156.75	46.0	2	R
8	74	M	161.5	74.8	3	R
9	65	M	164.3	65.8	2	L
10	65	F	160.9	55.6	2	R
11	62	M	169.0	79.4	2	L
12	74	F	164.7	65.9	2	L
N=12	68.4±6.3	7M/5F	166.6±8.7	66.3±11.6	1-3	8R/4L

Abbreviations: M, Male; F, Female; H&Y, Hoehn and Yahr; R, Right; L, Left.

Primary Outcomes

Thoracolumbar Rotation

Visual inspection of histogram plot and Shapiro-Wilk test confirmed normal distribution of mean thoracolumbar rotation change following OLT, compared to right-skewed and unequal baseline values. A paired t-test revealed no significant change during post-assessment (mean change: +0.35 ± 4.68°; CI: [-2.63, 3.32]; p = 0.40; Cohen's *d* = -0.08). Figure 8 provides a visualization of the observed changes. Shapiro-Wilk indicated that mean normalized rotation changes were normally distributed. A paired t-test indicated that normalized rotation decreased slightly, though not statistically significant following OLT (mean change: - 0.18 ± 5.75;CI:[-3.83, 3.47]; p = 0.54; Cohen's *d* = -0.03). Figure 9 provides a visualization of the observed changes (Table 2).

Table 2 Results of Pre and Post-tests presented as mean ± standard deviation, 95% Confidence Interval (CI), p-value, and Cohen's *d* effect size.

Variable	Pre	Post	Change	95% CI	p-value	Cohen's *d*
Peak Rotation(°)	4.48±1.37	4.83±1.30	+0.35±4.68	-2.63, 3.32	0.401	-0.08
Normalized Rotation(unitless)	5.55±5.68	5.37±5.47	-0.18±5.75	-3.83, 3.47	0.542	-0.03

PTV_F (°/s)	5.70±3.47	7.29±3.79	+1.59±2.19	0.20, 2.98	0.014	0.43
PTV_T (°/s)	69.74±4.20	70.63±2.79	+0.88±3.18	-1.14, 2.90	0.276*	0.25

Abbreviations: PTV_T, Peak transverse plane angular turn velocity; PTV_F, Peak frontal plane angular velocity; N, normalized; PTV, Peak turn velocity. P-values ≤ 0.05 are bolded. "*" Indicates Welch's correction for unequal variances.

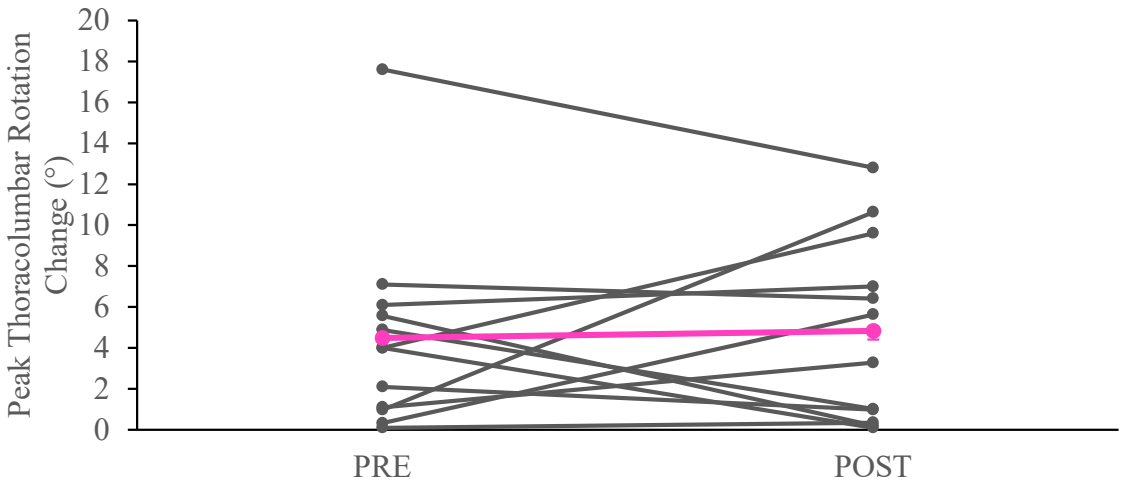

Figure 8 Mean change in thoracolumbar rotation for each participant following OLT from baseline (PRE) to follow-up (POST). All participants are "Black," and the group mean ± SD is "**Pink.**"

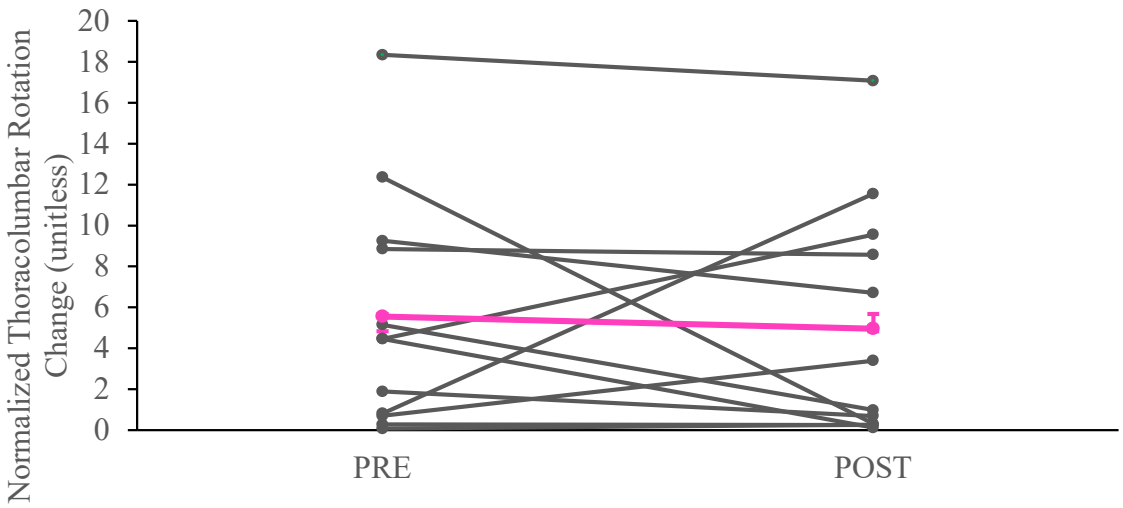

Figure 9 Mean change in normalized thoracolumbar rotation from baseline (PRE) to follow-up assessment (POST). All participants are "Black," and the group mean ± SD is "**Pink.**"

Peak Turn Velocity

At follow-up, Shapiro-Wilk results indicated that PTV_F change was normally distributed, compared to baseline values that were skewed rightward. Paired t-tests revealed PTV_F significantly increased 27.89% following OLT (mean change = 1.59 ± 2.18°/s; CI: [0.20, 2.98]; p = 0.014; Cohen's *d* = 0.43). The results are visualized in Figure 10. Histogram plots of PTV_T at baseline skewed leftward. Shapiro-Wilk revealed that PTV_T was not normally distributed. Paired t-test showed a slight, but not statistically

significant increase post-OLT (mean change: 0.88 ± 3.18 °/s; CI: [-2.90, 1.14]; p = 0.276; Cohen's *d* = 0.25). The results are visualized in Figure 11.

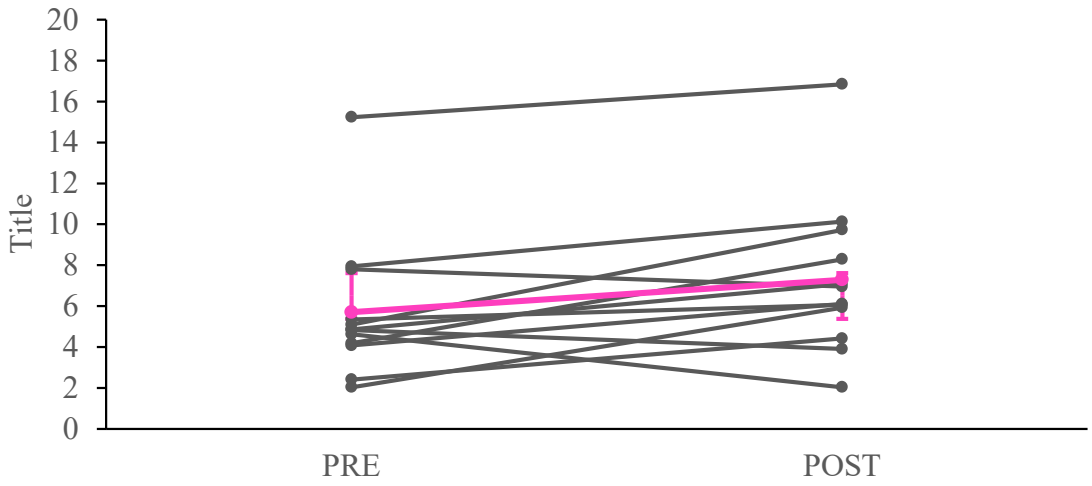

Figure 10 Mean PTV_F change following OLT at the sternum. These values represent angular velocity changes of the sternum along the anteroposterior axis or the frontal plane. Again, all participants are "Black," and the group mean ± SD is "**Pink.**"

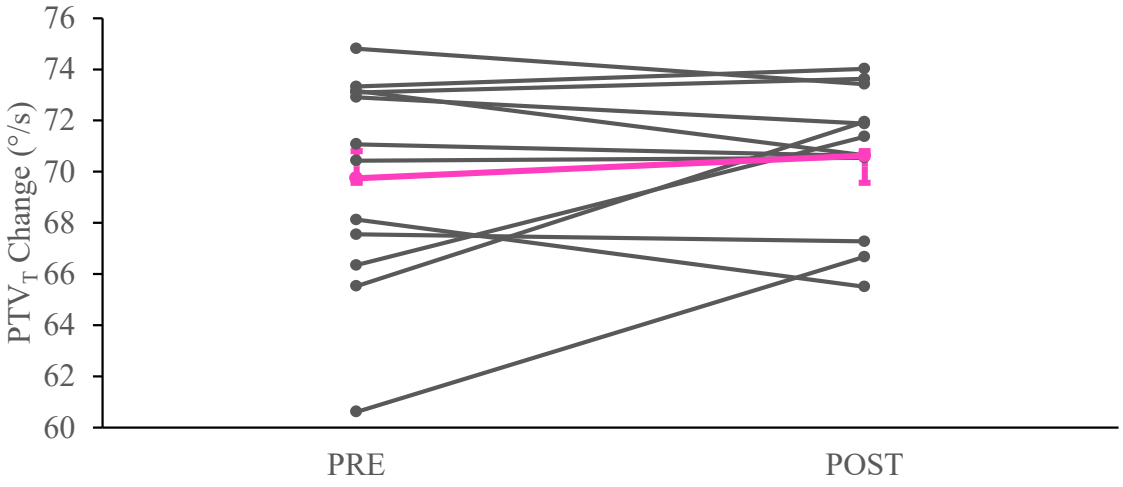

Figure 11 Mean PTV_T change following OLT at the sternum. The value represents a change in angular velocity at the sternum along the vertical axis or transverse plane. Again, all participants are "Black," and the group mean ± SD is "**Pink.**"

Secondary Outcome Measures

Participants completed significantly more turns during the follow-up assessment (mean change: 1.5±1.51**, CI =** -1.18, 3.18, $p < 0.01$, Cohen's $d = 0.39$). The turn duration increased (mean change = 0.07 ± 0.53 (s), CI = [-0.26, 0.41], $p = 0.32$, Cohen's $d = -0.19$) post-OLT. The turning stride length amplitude change was significant and high for the left (mean change = - 1.87±1.94 cm, CI = [-3.11, -0.63], $p = 0.006$, Cohen's $d = 0.67$) and right limb (mean change = - 1.99 ± 1.16 cm, CI = [-3.19, -0.78], $p = 0.004$, Cohen's d =

0.70). Bilateral turning steps showed a moderate, but not significant increase (mean change = 0.45 ± 1.07 steps, CI = [-0.23, 1.13], p = 0.08, Cohen's *d* = 0.43). Results are presented in Table 3.

Table 3 Statistical analysis of secondary outcome variables presented as mean ± standard deviation, 95% Confidence Interval, p-value, and Cohen's d effect size.

Variable	Pre Mean±SD	Post Mean±SD	Change Mean±SD	95% CI	p-value	Cohen's *d*
Turns (N)	14.25±2.63	15.75±2.38	1.5±1.51	-1.18, 3.18	**< 0.01**	0.39
Duration (s)	5.04±0.21	5.12±0.49	0.07±0.53	-0.26, 0.41	0.32	0.19
Stride Length L (cm)	26.55±2.80	24.68±2.78	-1.87±1.94	-3.11,-0.63	0.057*	0.67
Stride Length R (cm)	26.84±2.77	24.86±2.90	-1.99±1.16	-3.19,-0.78	**0.049***	0.70
B Turn Steps	6.48±0.91	6.94±1.15	0.45±1.07	-0.23, 1.13	0.08	0.43

Abbreviations: L, left; R, right; B, Bilateral; CI, 95% Confidence Interval. P-values < 0.05 are **bolded**.

DISCUSSION

Our study examined the effect of twenty-four sessions of performance-based OLT on peak thoracolumbar rotation and peak angular turn velocity among individuals with mild-PD. We did not observe effects on peak rotation following OLT; however, moderate and small effects were observed for PTV_F and PTV_T, evidenced by Cohen's $d = 0.43$ and Cohen's $d = 0.25$, respectively. These results display a trend toward improved intersegmental coordination, and moderate improvements in dynamic postural stability during walking turns after performance-based OLT.

Peak Thoracolumbar Rotation

Peak thoracolumbar rotation reflects intersegmental coordination and contributes to the stereotypical "en bloc" turning.[61,65–67] Despite its recognition as an indicator of turning difficulty among individuals with PD,[16] to date, no published study has measured thoracolumbar rotation change following performance-based overground locomotor training. Due to task-specific practice incorporated into the training, participants were hypothesized to increase thoracolumbar rotation significantly. Although participants did not significantly increase thoracolumbar rotation following OLT ($p = 0.40$), the results show a slightly increasing trend that participants modified thoracolumbar movement patterns following performance-based overground locomotor training ($+ 0.35 \pm 4.68°$).

This finding agrees with Stożek et al., 2016,[41] who found that individuals with PD improve thoracic rotation following 28 sessions of rehabilitation. However, unlike our current study, Stożek and colleagues[41] implemented a traditional, impairment-based style intervention focused on balance, postural stability, and range of motion. Moreover, participants performed range of motion (ROM) tests while seated with their legs secured for additional stability. While external support provides additional stability, it may not accurately reflect the available range of motion used during turning tasks.

Other studies have also measured peak intersegmental separation during walking turns using different instrumentation but without overground locomotor training. For instance, Crenna et al., 2007[16] measured peak cervical-thoracic separation using three-dimensional motion capture and found that individuals with PD displayed a median peak cervical-thoracic separation of 7.2° compared to the mean peak rotation observed in our study post-OLT, 4.83 ± 1.30°. Different measurement sites likely explain the different values, as our study measured the thoracolumbar difference, whereas Crenna and colleagues measured the cervical-thoracic difference.[16]

Intersegmental coordination is also speed-dependent,[61] and rotational amplitudes correlate with gait velocity. We account for this relationship using previously described methods to calculate normalized thoracolumbar rotation.[61] Since we expected greater peak thoracolumbar rotation post- OLT, we hypothesized that participants would increase normalized rotation during the follow-up assessment. Surprisingly, normalized values displayed a small, non-significant decrease.

This finding agrees with previous work [36,68] describing an inverse relationship between intersegmental coordination and pre-turn gait velocity and has two possible explanations based on Equation 3. First, smaller rotation amplitudes can reduce normalized rotation values without pre-turn gait velocity changes. This shift represents rotation without intersegmental separation. The second possible explanation involves the inverse, where rotation amplitude does not change and pre-turn velocity increases. This potential explanation would represent a shift toward a more challenging movement pattern following OLT due to the increased burden on postural stability from faster gait velocity. Due to the non-significant peak rotation change, it is plausible that pre-turn gait velocity increased following OLT. If true, this suggests that participants adapted movement strategies following OLT that are different from typically observed in this population.[61]

Peak Turn Velocity

Peak turn velocity quantifies dynamic postural stability to control perturbations experienced while turning. Individuals with PD usually display slower peak turn velocities in the frontal[31,69] and transverse planes[32,38,53] compared to other unimpaired older adults, which are considered manifestations of impaired dynamic postural control within those planes of motion. Our study observed moderate and significant PTV_F change following OLT ($p = 0.014$; Cohen's $d = 0.43$), while PTV_T change was small and not statistically significant ($p = 0.276$, Cohen's $d = 0.25$.

To date, the literature does not examine PTV_F change following overground locomotor training in any population. However, some studies quantify PTV_F among individuals with PD. The mean PTV_F calculated at follow-up (7.29 °/s) was slower than Visser et al., 2017 [31] (31 °/s), a difference likely explained by distinct testing methodologies. Visser and colleagues measured three trials where participants performed four separate 180° turns along a 6-meter walkway. In contrast, participants in our study walked for ten consecutive minutes along a 60-meter hallway. Though clinically relevant, shorter walkways such as those used in the Timed Up and Go (TUG) alter movement patterns and inaccurately reflect turns performed during community ambulation.[70]

A small (Cohen's $d = 0.25$) but statistically non-significant PTV_T increase was measured post-OLT ($p = 0.276$). Although we have not found clinical trials that measured PTV_T change, some observational studies exist. For example, Bertoli et al., 2017[38] compared PTV_T between individuals with PD across different levels of FoG and found that individuals who experienced FoG displayed slower mean PTV_T (104.51 °/s) than individuals without FoG (131.48 °/s). Another study by Koop and colleagues[53] found that participants withdrawn from anti-parkinsonian medication displayed slower PTV_T than after taking their prescribed dosage, 172.73 °/s and 163.66 °/s, respectively. In comparison, the mean PTV_T observed post-OLT (70.63 °/s) was slower than reported in both studies. Again, this difference is likely attributed to distinct testing methods, as Bertoli and colleagues had participants turn 180° after walking 7 meters, and Koop et al. segmented the turn from the TUG where participants walked 3 meters before turning.

Overall, our results suggest that participants adapted frontal plane thoracic movement, which according to previous studies,[8,26,71] counters the mediolateral perturbation experienced while turning. Thus, the observed PTV_F increase likely represents an adapted movement that improves frontal plane postural stability while turning.

Turning Stride Length

Foot placement during gait activities contributes to postural stability. Consequently, adjusting the stride length amplitude reflects dynamic postural stability strategies.[24] Following OLT, participants in our study significantly reduced the stride length amplitude of their right limb while turning ($p = 0.04$). This finding agrees with previous studies that found individuals with PD turned with shorter stride lengths.[24,26,71]

The most logical explanation for reducing right limb stride length is the turning direction. During walking turns, the inside limb, on the side of the turning direction, is primarily responsible for stability and generally displays shorter stride lengths than the outer limb.[26] Therefore, if participants turn rightward more often, we would observe shorter right limb stride lengths during post-assessments.

The participants' more affected limb also influences turning stride length. For example, the location of the more affected side concerning the turn direction could explain why additional rightward turns could result in shorter mean stride lengths. In our study, eight out of twelve participants reported their right limb as more affected, placing their more affected limb on the inside during rightward turns. For example, Park and

colleagues,[67] examined the turning characteristics among people with PD and found that participants reduced the stride length of the inside limb significantly more when turning in the same direction as the more affected limb. Therefore, it is plausible that the shortened stride length results from participants performing more turns toward their more affected side.

Traditional Turn Performance Measures

Traditional measures of turn performance are prevalent in clinical turn assessments yet cannot detect changes in postural stability. According to the literature, individuals with PD display movement patterns that worsen turn performance as measured by increased turn duration and step quantity.[24,34,72,73] However, participants in our study changed their movement patterns without significant changes to traditional parameters of turn performance.

Turn duration remained unchanged ($p = 0.32$) and lasted about 5 seconds during baseline and follow-up assessments. Both mean turn durations were about 1.5 times longer than previous studies [16,31,35] that observed individuals with mild-PD completing 180° turns under 3 seconds. This disparity may be attributed to variations in assessment design and calculation methods. Regarding assessment design, earlier studies[32,53] segmented clinical assessments, such as the TUG, to quantify turn performance. Unlike traditional clinically oriented gait assessments with walkways lengths between there and 10 meters, participants in our study performed the 10MWT along a 60-meter hallway. While the extended path allows participants to make anticipatory adjustments that

improve postural stability while turning, extended walking paths may also result in longer turn durations due to our methods that determine turn on- and offset, agreeing with Conradsson and colleagues that rotation begins sooner during pre-planned turns.[68]

The step quantity change was moderate (Cohen's $d = 0.43$), though not statistically significant ($p = 0.08$). The turning step quantities measured at baseline (6.48 ±0.91 steps) and follow-up (6.94±1.15 steps) were greater than previous studies ranging between 4 and 5 steps.[35,65] This difference is likely attributed to different testing methods. Participants performed turning trials along a 7-meter walkway in the provided examples, limiting the available space to adjust the stepping pattern and turn trajectory. Although we did not measure turn strategies, the trend toward more turning steps may result from turn strategy changes, as previous reported.[74,75]

LIMITATIONS

First, our study lacks cranial or cervical rotations measurement, limiting spinal segment coordination interpretation. Although cranial and cervical rotations typically occur before thoracic and lumbar segments,[29,61,71], our conclusions are limited to thoracolumbar coordination. Secondly, we did not measure turn strategy (step vs. spin vs. combination), known to influence turn duration, step quantity, and postural stability.[32,75] The step strategy correlates with reduced fall risk and is the least demanding strategy for postural stability.[39,75] The spin strategy is more challenging and requires better motor performance, as evidenced by higher ratings on the Unified Parkinson's Disease Rating Scale motor examination (UPDRS-III).[74] Moreover, the same study found that individuals voluntarily changed their turn strategy from step to spin after taking anti-parkinsonian medication.[74] Therefore, without identifying the participants' selected turn strategy pre- and post-OLT, we cannot determine the influence of OLT on turning strategy changes and, therefore, motor performance changes. Lastly, our study is limited due to data analysis methods assuming linear relationships despite OLT promoting non-linear changes in movement behavior.

SUMMARY AND CONCLUSION

Our study provides preliminary evidence suggesting that participants moderately improved frontal plane dynamic postural stability while turning after performance-based OLT by adapting thoracic movement patterns that likely attenuate the perturbed mediolateral stability experienced while turning. Future studies in a larger dataset should also investigate whether age and disease severity affect outcomes. In conclusion, our findings suggest performance-based overground locomotor training promotes individual movement pattern changes that improve dynamic postural stability when performing walking turns.

APPENDIX A

Signed Proposal

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DEPARTMENT OF REHABILITATION SCIENCE DISSERTATION COMMITTEE AND PROPOSAL APPROVAL FORM

STUDENT: RANDY J. PUGH

PROPOSAL TITLE:

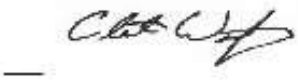
THE IMPACT OF OVERGROUND LOCOMOTOR TRAINING ON TURNS IN PEOPLE WITH PARKINSON'S DISEASE

Proposed Committee:

Rosemary D. Higgins, MD, Chair

Andrew A. Guccione, PT, Ph.D, DPT, FAPTA, Co-Chair

Hua Min, Ph.D, Committee Member



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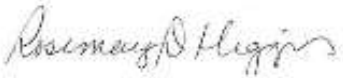


Rosemary D. Higgins, MD, Interim Department Chair

Date: April 23, 2021

Spring Semester 2021
George Mason University
Fairfax, VA

The Impact of Overground Locomotor Training on Turns in People with Parkinson's Disease

Jamil Pugh
April 2021

I. Abstract

Research Question: Among people with mild- to moderate-Parkinson's disease (PD), what is the impact of 12 weeks of overground locomotor training (OLT) on turns?

Design: Pre-experimental, pilot study

Setting: George Mason Department of Rehabilitation Science Human Performance Laboratory

Apparatus: Inertial Measurement Units

Participants: People with Mild-Moderate Parkinson's disease (N=12)

Intervention: Twenty-four sessions of overground locomotor training (1-hr/session, 2x/week x 12 weeks)

Outcome measures: Change in axial rotation, Change in peak turn velocity

II. General Intro

Specific Aims

Parkinson's disease (PD) is a progressive neurodegenerative disorder affecting more than 10 million people globally. A recent study[76] estimated the annual direct healthcare expenses in the United States reached $25.4 billion. Roughly 77% of people with PD develop gait and postural impairments that limit walking and restrict community ambulation. Early walking limitations include difficulty transitioning between gait subtasks. Changing direction (i.e., turning) is a complex subtask accounting for 50% of daily steps and challenges half of individuals with PD. Improving turns while walking may enable individuals with PD to increase community ambulation and slow the disabling process.

Turning elicits motor behaviors that are not observed during straight-line walking. Turning requires mediolateral stability to safely transition from steady-state gait and couples stepping, trunk posture, and axial rotation to control internal perturbations. Stereotypical gait and posture characteristics of individuals with PD reduce axial rotation and contribute to conservative turning strategies (e.g., "en bloc" turning, reduced angular turn velocity). Axial rotation is reduced in people with PD and influences the transition into walking turns. Hence, it is plausible that interventions addressing gait and posture will also change turn performance.

Traditionally, interventions addressing walking limitations measure changes in spatiotemporal gait variables. However, turn parameters provide a higher ceiling to measure changes following an intervention. Although previous studies measured differences in turn performance among people with PD, none examined axial rotation changes while turning. Therefore, the proposed study will answer the Question: What is the impact of 12-week overground locomotor training (OLT) on turns among people with mild- to moderate-PD?

Aim 1: Quantify the change in turns following OLT, evidenced by axial rotation.
Hypothesis 1: Following OLT, subjects will increase axial rotation during turns.
Aim 2: Characterize changes in trunk posture following OLT, evidenced by peak turn velocities (°/s).
Hypothesis 2: Following OLT, subjects will increase peak turn velocities (PTV).

Currently, no studies examine changes in axial rotation following overground locomotor training among individuals with PD. If successful, this study will provide evidence towards walking limitations' mutability following a low-cost, non-pharmacological intervention.

II. Rationale and Importance

Research Problem

Parkinson's disease (PD) is a progressive neurodegenerative disorder causing gait and balance impairments in more than 77% of people living with the disease.[5,6] Stereotypical gait characteristics (e.g., reduced stride length, narrow step width, and slowness of movement)[10,11] decrease the available area for postural equilibrium when transitioning between gait subtasks.[3,9] Turning is a complex subtask accounting for 50% of daily steps, yet roughly 50% of people with PD have difficulty turning.[15] Improving turns will slow the disabling process associated with walking limitations.

Turning reveals limitations in dynamic stability unapparent during straight-line walking due to linear and rotational components.[68] Turns require negative acceleration of the center of mass (CoM), axial rotation, and stepping toward the new direction of travel.[39] During walking turns, the body's CoM travels away from the axis of rotation, creating an internal perturbation, which must be controlled to continue the step cycle and remain upright.[26] Conservative turning strategies among people with PD are considered manifestations of reduced axial rotation and mediolateral instability. Therefore, turn

parameters are useful outcome measures following gait interventions to assess change or individuals with PD.
Studies that analyze turns among people with PD insufficiently describe turning behavior using a shortened walkway or a single turn.[33,53] Alternatively, incorporating inertial measurement units (IMUs) with longer distances and multiple turns improve the analysis.[70] The proposed study will examine this approach. Figure 1 displays the study's theoretical framework.

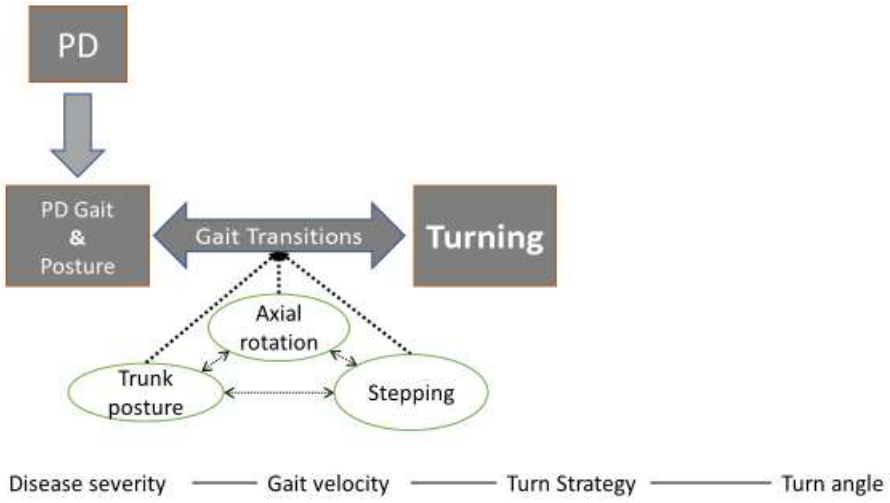


Figure 12 Theoretical framework displaying factors contributing to turns.

Literature Review and Critique
Reduced turn performance is an early motor symptom sensitive to disease progression in people with mild PD.[65,77] A 2012 systematic review identified **postural instability** as the prominent gait impairment limiting activity in people with PD.[17] Postural stability relies on appropriate segmental coordination while changing direction [42] and turning perturbs stability by provoking pelvis displacement.[78] This review briefly examines the current knowledge of turning among individuals with PD.

PD-related gait and posture characteristics (e.g., reduced stride length, narrow step width, slower gait velocity) limit turn performance.[9] Reductions in stride length and velocity make turning less efficient by increasing the number of turning steps, extending the turn

duration, and increasing the turning arc.[6,24] Follow-up analyses reveal a significant interaction between trunk rotation and the amount of turning steps. [25] Similarly, subjects who complete turns more efficiently, evidenced by turn duration and number of steps, also demonstrate higher peak angular velocity in the vertical and longitudinal axes.[31,32,35,53,65]

Reduced walking velocity affects axial coordination and rotation, causing a negligible **spatial difference between head and pelvis rotation, otherwise known as "en bloc" turns**.[16,36] Additionally, axial muscle hypertonicity reduces segmental coordination [29] and axial range of motion,[37] causing people with PD to **initiate turns sooner**.[68]

Preserving mediolateral stability takes precedence in completing turns [71] and plays a significant role in turn strategy [71,78], including step, spin, and mixed.[52,74] Anticipatory Postural adjustments (APAs) also contribute to dynamic stability and turn performance. [8,27,79] However, people with PD either lack or have diminished APAs due to insufficient temporal coupling and gait challenges.[27]

To date, studies examining turns in people with PD compare turns between age-matched healthy controls[31,65], between medication status,[53], or those with or without freezing of gait.[35] They commonly utilize three-dimensional motion analysis, known to produce different movement behavior compared to outside the laboratory.[53] Few studies were measuring change in turns following locomotor interventions among people with PD. The proposed dissertation will address this gap in the literature.

Scope and boundaries

The following topics are outside the scope of the proposed study:

- Kinetic data including momentum, impulse, ground reaction force, the center of pressure.
- A single foot sensor cannot measure margins of stability (MoS). Instead, the MoS is defined using the foot's anatomical landmarks (e.g., lateral malleolus, calcaneus, metatarsals) unavailable with an IMU sensor.
- Muscle activation patterns or strength cannot be measured due to a lack of electromyography instrumentation.

III. Research Plan

Study Design

A pre-experimental pilot study where participants served as their control using pre-intervention measurements. This design provides evidence of treatment efficacy and is appropriate for determining individual changes in motor behavior.[80] Data were extracted from a parent study, POSSabilities, which was halted during the COVID pandemic (Mason IRB # 1374615).

Setting

Testing and training were collected in the George Mason Rehabilitation Science Performance Laboratory prior to the COVID pandemic.

Target Population

People with Mild- to Moderate Idiopathic Parkinson's disease living in the Northern Virginia, Washington D.C. Metropolitan area. An online search found eight support groups within 20 miles of Fairfax, VA, the proposed study's location.

Recruitment

Pre-approved print and digital flyers were displayed online and distributed to local Parkinson's support groups in the greater Washington D.C. area for participants. Scripted telephone screenings determined study eligibility.

Participant Selection

Eligibility for study participation was determined using previously described inclusion/exclusion criteria described as follows: [14,45,81]

Inclusion:

- Community-dwelling adults with clinically diagnosed idiopathic Parkinson's disease
- 18-85 years
- Hoehn and Yahr score I – III (mild-moderate severity)
- Ability to independently ambulate without assistive device
- Ability to speak English

Exclusion:

- Mini-Mental State Exam (MMSE) ≤ 24
- Untreated visual impairments
- Uncontrolled cardiac, pulmonary, neurologic, or metabolic disease contraindicating or impacting the ability to exercise
- Legal blindness
- Pregnancy
- Concurrent participation in another structured exercise program

Consent Procedures

Before baseline testing, eligible participants were consent in a private room inside the Functional Performance Laboratory. A research team member read the Institutional Review Board approved rationale, procedures, human subjects' rights, and ability to terminate participation. If accepted, the official consent form was signed and secured with the faculty per the IRB application.

Power and Sample Size

With twelve subjects and $\alpha = 0.05$, OLT must show a moderately-large effect (0.75) on turns for a one-tailed paired t-test to have 80% power.

Intervention Description

Overground locomotor training (OLT) was performed for 60 minutes twice per week for 12 weeks at 60% of the age-predicted maximum heart rate. Heart rate was monitored throughout each training session with efforts to maintain the target heart rate zone. A pedometer attached to the right ankle tracked the number of steps taken during each training session.

Training included multi-directional stepping strategies, progressing difficulty weekly. An outline of the OLT program is provided in the appendix. The OLT program was fully documented and used to train team members. Plans of action to troubleshoot potential problems were also included.

Apparatus and Instrumentation

Data were collected using portable inertial measurement units (IMU) previously validated for gait analysis of people with PD.[82,83] Each IMU contains a tri-axial accelerometer, gyroscope, and magnetometer and were comfortably secured over previously described anatomical landmarks, including both wrists, and the dorsal aspects of each foot, the sternum, and approximately the fourth lumbar vertebra.[35,65] Figure 2 shows an example of IMU placement.

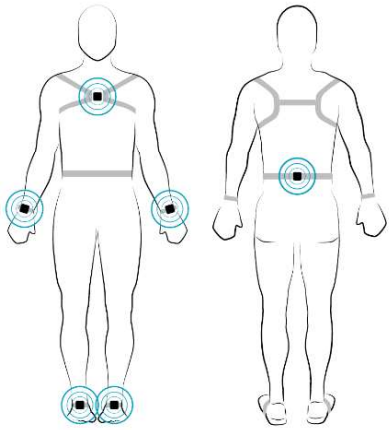


Figure 13 Sensor placement for 10MWT, as provided by the software.

Data Collection Procedures

A 10-minute walk test (10MWT) was performed overground, along a 60-meter corridor, indoors, and over a firm surface. Participants were instructed to “walk as far as you safely can” and “walk as many laps as safely possible in ten minutes.” Following a countdown,

participants completed as many laps as possible at their self-selected pace without knowing the time. Participants did not receive cues on performance or turn strategy, as previously recommended.[52] A member of the research team trailed the participant for safety, and at least one other team member controlled hallway traffic. Following each assessment, sensors were docked, and raw data were extracted for offline processing.

Data Analysis

Before analysis, the data will be visually inspected to confirm the collection of the entire trial. Raw data will be re-aligned along the vertical axis to the global vertical axis for each IMU for accurate measurements.[58] Each sensor's raw accelerometer and gyroscope data will be analyzed using a custom MATLAB script, based on previously validated algorithms analyzing turns in people with PD. [35,38,65,84(p)] Turning and straight walking segments will be extracted and analyzed separately.

Turn onset and offset will be determined using vertical gyroscope data from the lumbar sensor, per previously identified methods displayed in Figure 3.[65]. Briefly, vertical angular velocity will be integrated to obtain the absolute turn angle. Next, turns are identified using spikes in absolute vertical rotation two standard deviations (SD) above the mean of straight segments. Finally, the turn duration is defined as the time difference between turn offset and onset.

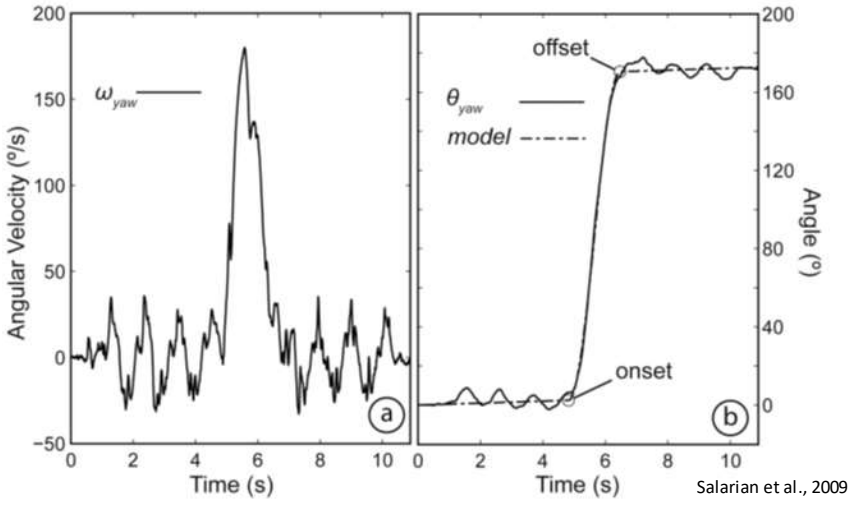


Figure 14 Example of gyroscope data graph for visual inspection of turn identification (Salarian et al., 2009).

Primary Measures

Aim 1: Quantify the change in turns following OLT, evidenced by axial rotation.
Hypothesis 1: Following OLT, subjects will increase axial rotation during turns.
Rationale: Axial rotation reflects PD-related motor symptoms that limit turning.

Axial rotation: Calculated by integrating angular velocity in the trunk and lumbar sensors' vertical axis and measured as the difference between the trunk and waist angles at turn onset. Axial rotation will be reported as mean ± SD for each participant, pre-, and post-intervention.

Aim 2: Characterize changes in trunk posture following OLT, evidenced by peak turn velocities (°/s).
Hypothesis 2: Following OLT, subjects will increase peak turn velocities (PTV).
Rationale: PTV represents control over internal perturbations.

Peak turn velocity (PTV): Identified as the maximum angular velocity in the vertical and longitudinal axes. These measures are referred to as yaw and roll, respectively. PTV will be normalized for the average gait velocity and reported as mean ± SD.

Secondary Measures:

Step characteristics: The mean ± standard deviation of spatiotemporal gait measures will be calculated using the vertical accelerometer data from each foot sensor. Step time is defined as the time difference between heel strike and toe-off from the same foot. Stride length is defined as the anteroposterior distance between steps of each foot. Step width will be calculated as the mediolateral difference between consecutive contralateral steps.

Gait velocity (m/s): The waist accelerometer will be integrated against time in the anteroposterior axis to provide velocity (m/s). The mean ± SD of straight segments will be calculated for each test.

Statistical Analysis

All data will be reported as mean ± standard deviations for each participant and group. Outliers of more than two standard deviations from the group mean will be analyzed and reported separately. After checking normality assumptions, pre-and post-intervention changes in axial rotation and PTV will be analyzed using paired t-tests. The effect of OLT on axial rotation and PTV changes will be determined using Cohen's *d*. Pearson's correlation will measure the relationship between change in axial rotation and change in turn duration.

APPENDIX B

Literature Review

Dynamic postural stability is central to safe ambulation. Individuals with Parkinson's disease (PD) experience walking limitations during the early stages of PD[65,77] that develop from postural instability.[17] Postural stability relies on coordinated movement patterns changing direction[42] and turning perturbs mediolateral stability.[78] This review examines the current knowledge of walking turns among individuals with PD.

PD Gait and Balance

PD-related gait and balance characteristics (e.g., reduced stride length, narrow step width, slower gait velocity).[9] contribute to postural control deficits throughout the turning process. Stack and colleagues[33] recorded individuals with PD (n=10; 6F; 74 ±7 years.; H&Y: 1–5) and healthy adults (n=14;13F; 74 ± 8 years; 67 ± 12 kg) performing the standing start 180° turn test and found that individuals.

Huxham et al., 2008[24] found that reduced stride length and velocity increases affect turn efficiency by requiring more steps, extending the turn duration, and increasing the turning trajectory.[24] Follow-up analyses revealed a significant interaction between trunk rotation and the number of turning steps.[25] Similarly, subjects who complete turns more

efficiently, evidenced by turn duration and the number of steps, also demonstrate higher peak angular velocity in the vertical and mediolateral axes.[31,32,35,53,65]

Stepping / locomotor foot. Stepping patterns

Stepping patterns contribute to dynamic postural stability while changing direction. Orendurff et al., 2006[26] explored how turning is accomplished by investigating the lower extremity kinematic changes while walking a circular path and found that participants reduced the stride length of the inside leg, an important aspect of turning. Similarly, Huxham et al., 2008a[24] measured participant turning steps at self-selected speed using three-dimensional motion capture. Results found that individuals with PD turned less efficiently by reducing stride length and increasing the quantity of turning steps compensates for mediolateral stability. The study did not measure axial rotation.

Stepping pattern adjustments are central to Stride length reductions during turns are integral to turning; however, people with PD display excessive SL reductions compared to unimpaired adults. Huxham et al., [24]

Intersegmental Coordination

Intersegmental coordination allows for independent movement between spinal segments, representing a challenge for people with PD. Patla et al., 1999[71] examined walking turns in unimpaired adults and was an early study establishing the cephalon-caudal, or top-down" temporal sequencing of spinal segments during walking turns. Unlike unimpaired adults, intersegmental coordination is a challenge for people with PD.

Huxham et al., 2008[25] examined axial coordination during turning in PD and unimpaired adults. Coordination among unimpaired adults displayed a top-down intersegmental sequencing toward the turning direction. People with PD turned with linked trunk and pelvis increased with turning magnitude. The results suggest that more rotation in unimpaired adults occurred during the turn, indicating a later turn onset. Over time, similar patterns were observed when examining rotation. Unimpaired adults prepared for the turn with the head rotating before the pelvis, unlike people with PD, who turned with locked spinal segments rotating in the same direction.

Limited intersegmental coordination observed in people with PD (PwPD) have various influencing factors. First, gait velocity influences intersegmental coordination reducing the spatial difference between cranio-pelvic separation during rotation, otherwise known as "en bloc" turning.[16,36] In 2017, Forsell and colleagues[36] examined the effect of walking speed on intersegmental coordination among 17 unimpaired older adults (10 Male / 7 Female; 72 ± 6 years; 76.1 ± 8.8 kg; 176 ± 9 cm). Participants walked along a 9-meter pathway before turning at an intersection designated by 2 stations. Before each trial, a visual cue indicated turning direction (straight, or 180° turns left, or 180° turns right). Then, participants were instructed to perform walking turns in the indicated direction without stopping, taking the closest path to the target during two separate sessions, self-selected comfortable speed (CWS) and slower speed (SS), to mimic the velocity of PwPD. SS walking velocity was monitored using a handheld stopwatch and corrected as needed. Participants randomly completed 5 trials for each direction during both sessions. The outcome variables included step length, head and pelvis angular

rotation, and cranio-pelvic separation. The study found that unimpaired older adults perform turns while walking in a top-down movement pattern where the head rotates faster and with greater angular amplitude than the pelvis at turn onset before the pelvis catches up in both angles and velocity at the end of the turn. The study also found that slower pre-turn gait velocity reduces intersegmental coordination in unimpaired older adults, as measured by cranio-pelvic separation.

Crenna and colleagues[16] used three-dimensional motion capture to analyze intersegmental coordination during turns while walking among individuals with PD (n=14); Age (years): 67.1 ± 6.5; H&Y: 1.8 ± 0.4) and age-matched unimpaired adults (n=15; Age (years): 67.7 ± 2.7; Height (cm):165.2 ± 8.6; Weight (kg): 65.7 ± 9.2).[16] Participants randomly performed two walking trials, including Straight (W) and Walk and Turn (W&T) in the "ON" medication state. In W trials, participants walked 6m at self-selected speed, and for W&T, participants walked at least 2m toward a vertical rod, then turned 90° leftward. All turning trials were left turns and right foot on the ground. Stride length was plotted against stride frequency for all participants from the W trial. As expected, Median gait velocity, measured as a percentage of body height, was significantly ($p < 0.05$) faster for unimpaired adults (81.8 (70.0–99.0)) compared to people with PD (72.8 (63.5–85.7)) but displayed similar Median cranio-pelvis separation 4.8 (1.6-9.9) and 2.2 (0.7-6.8), respectively. However, Mann–Whitney U-tests revealed that unimpaired adults displayed significantly greater median cranio-thoracic rotation amplitude ($p < 0.01$) than people with PD while performing the W&T trial 17.7° vs. 7.2°, respectively. Additionally, the median amount of turning steps for PwPD (2.5 (1.7–3.5))

were significantly higher ($p < 0.01$) compared to unimpaired adults (3.3 (2.8–3.9)). The results suggest that although axial coordination correlates with gait velocity, the turn performance difference between unimpaired adults and people with PD is affected by more than reduced intersegmental rotation amplitude.

Spildooren et al., 2013 investigated the relationship between impaired cranio-pelvis rotation while performing turns and FoG among people with PD with (+FoG n=13) and without FoG (-FOG; n=14) along with 14 unimpaired adults. While walking, participants turned 180° leftward and rightward, in random order, both with and without a dual-task. The study found that peak cranio-thoracic separation followed the same temporospatial pattern, with unimpaired adults displaying larger amplitude than +FoG and -FoG (35.4 vs. 25.7 vs. 27.3 °), respectively. Likewise, mean angular turn velocity was greater among unimpaired adults (95.4 °/s) compared to individuals with PD + FoG (25.7 °/s) and - FoG (60.6 °/s), demonstrating that smaller amplitudes of cranio-thoracic separation occur at slower velocities. Additionally, people with PD+FoG display slower peak angular velocities, suggesting that intersegmental rotation worsens with motor symptoms like FoG.

The muscular tonicity of spinal segments also influences intersegmental coordination while walking. Paraspinal muscle hypertonicity reduces intersegmental coordination [29] and range of motion.[37] Cole 2017[29] investigated trunk muscle activation deficits among PwPD and determined influences on spinal segment stability and found that increased muscle coactivation limited intersegmental coordination.

Franzén and colleagues[37] sought to determine if increased cervical tone limits gait and balance during turns while walking among people with PDPwPD withdrawn from medication (OFF) and under the influence of their prescribed medication (ON). Participants performed muscle tone assessments for the cervical, thoracic, and pelvic segments, along with functional performance assessments that included the TUG in both medication states. For comparison, unimpaired age-matched adults performed all assessments once. The results found that 180° turns among unimpaired adults lasted 1.0 ± 0.3) seconds, PD-OFF 1.6 (0.4), and PD-ON: 1.3 0.3) seconds. When comparing unimpaired adults vs. OFF, PD-OFF completed turns significant; y ($p< 0.01$) slower than unimpaired adults, and OFF was significantly slower ($p<0.05$) than ON. The results suggest that although participants ON L-dopa complete 180° turns significantly faster than OFF, participants with PD initiated compensatory movement patterns, such as starting the turn sooner, resulting in more time to perform turns while walking than unimpaired adults. This finding agrees with previous work by Conraddsson et al., 2017.[68]

Dynamic Postural Stability

Dynamic postural stability involves the manipulation of body segments to remain upright and can be quantified through peak turn velocity of the thoracic and pelvic segments. To date, studies examining turn velocity in people with PD compare turns with age-matched unimpaired controls,[31,65] between medication status, [53] or those with or without FoG. [35]

Mellone et al., 2016[32] sought to determine if people with PD (12 Male; Age: 67(8) years) have speed- and angle-specific dynamic stability impairments during turns using three-dimensional motion capture. Participants performed 12 trials walking at different velocities and turning angles. The results found that as turn speed increased, the CoM of people with PD spent more time outside the MoS than unimpaired, age-matched adults, suggesting that people with PD display movement patterns that compensate for reduced stability.

Visser et al., 2007[31] calculated PTV differences between PwPD and age-matched unimpaired adults and found the mean peak transverse and frontal plane turn velocities for PwPD, 137.7 ± 31.3 °/s and 31 ± 6.1 °/s, respectively, were significantly slower ($p < 0.05$) than those observed in the unimpaired adults, 178.3 ± 33°/s and 40.4 ± 8.9 °/s respectively. These results suggest that PTVT and PTVF can discriminate

e between neurologically impaired and unimpaired adults.

Bertoli et al., 2019[35] aimed to quantify and compare the kinematic of turning 180° between people with PD both with and without freezing of gait. Twenty-four participants with Fog (PD+FoG) (19M/5F; Age (years): 69.2 ± 7.1) and eighteen participants without FoG (PD-FoG) (14M/4F; Age (years): 70.3 ± 6.8) were recruited from a university Parkinson's Center for the study. While wearing three IMUs located on dorsal aspects of both feet and the fifth lumbar vertebra region. Among the tasks performed, participants walked a 7-meter pathway for two minutes and performed 180° turns at a comfortable speed. Results Mean turn duration among -FoG (2.55(0.58)) was significantly ($p < 0.01$) different compared to +FoG (3.2(0.75)) as well as the number of turning steps (5.24

(1.18) vs. 6.41(1.31)), and peak turn velocity (143.87 (26.18) vs. 106.77 ± 26.61) (°/s)), respectively. anteroposterior (AP) and mediolateral (ML) jerk scores did not show significant differences between PD-FoG and PD+FoG, suggesting no difference in movement smoothness between the groups. Overall, the study's finding suggests participants with FoG displayed longer turn duration, took more steps, and performed turns with slower lumbar peak turn velocity. As measured by AP and ML Jerk scores, movement smoothness was not significantly different between individuals with and without FoG during turns while walking.

Turn Strategy

Turn strategies represent compensatory movement patterns. Preserving mediolateral stability takes precedence in completing turns [71] and contributes to turning strategy.[71,78] Common turn strategies include step, spin, and mixed.[52,74] Anticipatory Postural adjustments (APAs) also contribute to dynamic stability and turn performance. [8,27,79] People with PD lack or have diminished APAs due to insufficient temporal coupling and gait challenges.[27]

Gavriliuc et al., 2019[74] investigated turning strategies in people with PD using video recordings to identify step, spin, and mixed turning strategies. Step strategies identified as taking three or more steps without pivoting spin strategy involved turning on one or both feet and in a single movement. Mixed strategy performed in 1-3 steps and represented a transition point in motor ability between step and spin turns. At baseline OFF, significantly ($p<0.001$) more participants preferred stepping strategy (n = 149) compared

to spin and mixed strategies, n = 18 and n = 4, respectively. During the ON-state at baseline, participants significantly ($p < 0.001$) changed turn strategy to spin(n = 40) and mixed (n = 27) compared to stepping (n = 103). These findings suggest that individuals with PD ON medication perform more demanding turn strategies, as evidenced by the change in turn strategy after taking medication. Further analysis found that individuals with lower UPDRS-III scores were observed in participants who continued the stepping strategy during follow-up assessment. Since UPDRS-III is commonly used to stratify functional movement ability, this finding may suggest that turning strategy may complement traditional parameters of turn performance when quantifying gait and posture changes among PwPD.

Interventional Studies

Intervention studies measuring the turn changes in people with PD are scarce. However, Interventional studies addressing gait and balance among individuals with PD are more common. Moreover, turns are commonly assessed using the TUG[53] using three-dimensional motion analysis. Despite the sensitivity of three-dimensional motion capture to movement, the literature cites movement pattern differences in the real world compared to the gait laboratory.[85]

Stożek et al., 2016 [41] recruited participants from a Movement Disorders Clinic to assess the effects of rehabilitation on balance, gait, motor performance, and thoracolumbar rotation among individuals with PD. Participants were randomly assigned to either the Rehabilitation group (n=30; 13M / 17F Age (years): 64.0 ± 9.9 ;) or the

Control group (n=31; 16M/15F Age (years): 67.0 ± 11.3;). The Rehabilitation protocol involved 28 twice-weekly small group sessions lasting 2 hours and included the following: relaxation, breathing, range of motion (ROM), thoracic rotation, postural reeducation, gait training, dance, weight shifting, and attentional strategy. The control group continued their prescribed medication dosage and was offered rehabilitation after 4 weeks. Assessments were performed "ON" at baseline, follow-up, and one-month follow-up. The study found that the quantity of turning steps decreased significantly immediately after four weeks of rehabilitation (p=0.001). Similarly, thoracolumbar rotation improved significantly in both directions for the rehabilitation group compared to participants in the control group. However, inferences from these findings are limited. First, the rehabilitation intervention combines vastly different interventions, limiting one's ability to identify which intervention style contributed to improvements. Secondly, the ROM measurements were taken while participants were seated and not while performing walking tasks. Although these measurements were obtained via traditional methods, these findings may not equate to improvements while performing walking activities. Nonetheless, these findings demonstrate that dynamic stability and thoracolumbar rotation improvements, as evidenced by fewer turning steps and increased ROM, respectively, are possible following an intervention

Tollár et al., 2019 [56] performed a randomized control trial that compared the effects of agility exergaming, upright stationary cycling, and medication only on gait mobility among people with PD. Each intervention consisted of 1-hour training sessions performed five times per week over five weeks and at 80% of the age-predicted

maximum heart rate. Assessments were performed at baseline, directly following the intervention, and four weeks after the conclusion of training with outcome variables that included changes in the Dynamic Gait Index (DGI) and 6MWT distance. This study found significant differences in DGI score changes among the exergaming, cycling, and control groups, 0.7±1.77, 0.3±0.98, –0.5±1.31, respectively. The study also found that 6MWT distance changes were significant across the exergaming, cycling, and control groups, 129.6±68.90 m, 141.6±51.53 m, –16.3±81.61 m, respectively. These results suggest two points. First, walking capacity improves independent of the training method but emphasizes the importance of exercise at moderate-high aerobic intensity. Second, participants make significantly greater improvements in gait adaptability after training, as evidenced by the DGI score increase. These results suggest the importance of incorporating full weight-bearing and aerobic training into rehabilitative interventions to improve dynamic postural stability.

Summary

In closing, the challenge of turning offers both a unique challenge and a sensitive assessment of motor abilities for individuals with PD. Shortened stride length, narrowed step width, reduced segmental coordination, increased turn duration, and steps.

Table 4 Review of turn-based literature focusing on individuals with PD.

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
Mellone et al., 2016[32]	Determine if PwPD have speed- and angle-specific dynamic stability impairments during turns	HC (n=19) -Age: 67(8) -Gender: 7F/12M PD (n=12) -Age: 66.3(6) yrs. -Gender: 4F/8M -H&Y: 2-3	Observational cohort Participants performed 12 walking trials over walked path marked on the floor at slow (S), preferred (P), and fast (F)	NA	Presented as Slow/Preferred/Fast **Mean turn duration (s)** HC: 1.5±0.02/1.4±0.01/1.5±0.01 PD: 1.6±0.01/1.5±0.12/1.6±0.01 **CoM Trajectory (m)** HC: 7.5±1.2/17.3±0.9/15.2±1.1 PD: 16.3±1.0/16.3±1.1/14.3±1.2 **DS (%GC)** HC: 18.0±8.3/16.6±4.4/16.3±3.6 PD: 16.2±5.4/15.9±3.1/18.0±3.6	PwPD actively reduces turn speed, and increases turn distance. PwPD do not exhibit different dynamic stability vs. HC, evidenced by & GC with CoM outside the BOS. Slow turning speed and larger turn angles are compensatory behavior to prevent dynamic postural instability
Bello et al., 2013[47]	Explore the effects of two training programs, walking on a treadmill and walking overground, in PD patients.	PD (N=22): 13M/9F **TT (n=11)** Age(years): 59.45(11.32 Height(m): 1.66(0.08 Disease duration (years): 2.82(3.28 H&Y: 2.27(0.41 UPDRS:18.64(7.99 **OG (n=11)** Age(years): 58.00(9.38 Height(m): 1.65(0.06 Disease duration (years):4.95(2.59 H&Y: 2.05 22.09(0.52 UPDRS: 22.09(9.44	Participants were randomly assigned to TT or OG and evaluated pre- and post-training. TT evaluated once more since SL increased significantly Gait assessed at preferred (PWS) and maximal speeds (FWS) Overground walking test: 4-min at preferred speed and 10m at max speed and TUG at safe and comfortable speed static posturography	15 sessions 3x/week four 4-minute-long bouts at a self-selected speed measured during baseline testing intensity was maintained to self-selected speed from the initial assessment. An additional 4-minute bout was added weekly. TT wore safety harnesses and held handrails continuously. OG	Mean Values presented as Pre/Post **UPDRS-III** OG: 22.09 ±2.84 / 18.2 ±2.01 TT: 18.64 ±2.4 /21.27 ±2.72 **Time to turn (s)**: OG: 2.62 ±0.16 / 2.57 ± 0.19 TT: 3.23±0.44 /2.76 ±0.27 **Knee Extensor Strength (N)** **Affected Leg:** OG: 650 ±106 / 578 ±72 TT: 817 ±138 / 804 ±129 **Non-Affected Leg** OG: 649 ±83 / 573 ±62 TT: 863 ±141 / 841 ±136 **Preferred Walking Speed (m/s):**	Incongruent evidence that TT training effect on balance offers better results than OG. Although overground walking bouts were performed, the training was limited to straight, forward walking. There were no differences between groups in HY status, but UPDRS-III scores decreased post-

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
				Bouts performed indoors 60m hallway and 10m wide using auditory cueing to maintain walking speed	OG: 1.33± 0.07 / 1.39 ± 0.08* TT (T0/T1/T2): 1.26 ± 0.09/ 1.36 ± 0.09*/ 1.37 ± 0.11* **Preferred Walking SL (m):** OG: 1.35 ±0.05 /1.38 ± 0.05 TT (T0/T1/T2): 1.27± 0.08 /1.33 ± 0.07* /1.33 ± 0.08	training in OG, while TT increased.
Forsell et al., 2017[36]	Investigate the influence of walking speed on axial coordination during turns while walking among healthy elderly adults	Healthy older adults (N = 17) 10M/7F Age (years): 72 ± 6 Weight (kg): 76.1 ± 8.8 Height (cm): 176 ± 9	Participants walked non-stop, over a 9-meter walkway 4.65 turned at the designated intersection in the direction of the visual cue (straight, left, or right 180° turns) given before each trial. Taking the closest path to the target during two separate sessions, self-selected comfortable speed (CWS) and slower speed (SS), to mimic the velocity of PwPD. SS walking velocity was monitored using a handheld stopwatch and corrected as needed. Participants randomly completed five trials for each direction during both sessions.	NA	Results presented by testing session: CWS/SS. Values are presented as Median, IQR **Walk velocity (m/s)** Pre-turn*: 1.12 ,0.20 / 0.93, 0.14 During turn*: 0.67, 0.17 / 0.57 0.14 **Step length (m)*:** 0.58, 0.05 / 0.54, 0.07 **Step time (s)*:** 0.62, 0.07 / 0.69, 0.07 **Turning radius (m):** 0.70 vs. 0.68 **Cranio-pelvic separation (°)*:** 28.4 / 24.4	In healthy older adults, the head rotates faster than the pelvis at onset, and the pattern inverses at turn offset. Cranio-pelvic separation measures slower velocity minimizes axial coordination in healthy older adults.
Cole et al., 2017[29]	Investigate trunk muscle activation deficits among PwPD and determine influences on spinal segment stability	**PD:(n=79)** 51M Age(years): 68.1±0.9 Height(cm): 168.2±1.0 Mass(kg): 74.3±1.8 Disease Duration(years): 6.1±.5	Cross-sectional with 12-month Prospective follow-up Using 3D motion capture, participants walked barefoot at self-paced velocity across a 9-meter walkway wearing surface	NA	Results are presented as: -Mean (SE) -PD/PD fall/PD non fall/HC /HC+fall/HC-fall Trunk flexion angle (°) 5.70 (0.94)/6.52 (1.30)/4.43 (1.30)/1.57 (0.57)/2.12 (0.98)/1.27 (0.71	Impaired neuromuscular activation, evidenced by higher coactivation levels among thoracic musculature, limits intersegmental

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
		H&Y: 1.9±0.1 **HC: (n=82)** 50M Age(years): 69.6± 0.8 Height(cm): 138.9±1.0 Mass(kg): 79.8±2.4	EMG on the thoracic erector spinae (TES), lumbar multifidus (LMF), and external obliques (EO). Four trials were performed wat a sampling rate of 150 Hz		Peak Thoracic erector spinae (%MVIC) 31.48 (1.68)/33.61 (2.32)/28.24 (2.25)/23.58 (1.28)//21.52 (2.27)/24.71 (1.53) Peak Lumbar multifidus (%MVIC) 39.49 (1.51)/41.39 (1.84)/36.50 (2.53)/34.09 (1.41)/29.91 (2.25)/36.37 (1.74) Peak External oblique (%MVIC) 26.01 (1.50)'27.84 (2.07)/23.40 (2.07)/22.95 (1.30)/20.91 (2.03)/24.04 (1.66)	coordination while walking and contributes to segments moving as one unit.
Spildooren et al., 2013[61]	Investigate the relationship between impaired cranio-pelvic rotation during turning and FoG.	**HC (n=14)** Age (years): 65.2 ± 6.8 Leg length(cm): 90.1 ± 4.9 MMSE 29.1 ± 1.3 **PD-FoG (n=14)** Age (years): 66.7 ± 7.4 Leg length (cm): 88.9 ± 6.5 MMSE 28.7 ± 1.2 Disease duration (years): 7.8 ± 4.8 H & Y 2.4 ± 0.3 UPDRS-III 34.4 ± 9.9 **PD+FoG (n=13)** Age (years): 68.1 ± 7.5 Leg Length(cm): 88.5 ± 4.5 MMSE 27.7 ± 1.2 Disease duration (years): 9.0 ± 5.0 H & Y 2.5 ± 0.5	Participants performed trials in a gait lab with 3-dimensional motion capture and walked 5m toward two retroreflective markers placed 0.5 m apart on the floor to standardize the turning arc without limiting available turning space. Participants turned 180 ° around the markers leftward and rightward, in random order, with and without a DT. Participants with PD performed the test OFF medication state. All trials were performed 3 times each.	NA	Results presented as HC/+FoG/-FoG Max turn velocity (°/s)**: 95.4 / 74.1 / 60.6 Max Cranio-pelvic Separation (°)**: 35.4 /25.7 / 27.3 Additional speed-dependent trials (reduced gait speed) Max Cranio-pelvic Separation (°)**: HC**: 34.8 / 24.9 +FoG:24.9 / 25.7	The separation between the head and trunk reduced with slower velocity. Peak angular velocity is slower among PwPD, whom experience FoG. Axial rotation worsens with PD and further declines as freezing develops.

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
Salarian et al., 2009[65]	Analyzed and compared 180° turn performance between PwPD (untreated) and age-matched HC	UPDRS-III 38.7 ± 14.2 HC (n=14) -Gender: 3M -Age: 61.1±7.9 years PD (n=12): -Age: 60.2 ± 8.9 years -Gender: 6M -H&Y:1- 2.5 -UPDRS III: 20.3 ± 9.8 -No history of PD medication	A longitudinal study lasting 18 months. Participants performed 3 walking trials along a 7-meter walkway while wearing portable IMU sensors (sternum and B shanks) every 6 months	NA	Turn Duration (s):* HC: 1.79±0.27 PD: 2.18±0.43 # Steps: HC: 3.50±0.52 PD: 4.08±1.00 PTV (°/s) HC:172.44±30.13 PD:162.3±30.85	During the early stages of PD, traditional turn duration is already significantly more extended than HC Transverse plane PTV is slower but not significantly
Gavriliuc et al., 2019[74]	Investigate turning strategies in people with PD and characterize those using various strategies. Analyze the effect of L-Dopa and subthalamic nucleus deep brain stimulation on turning strategies.	PD (n = 171) (Spinners/Mixed/Steppers) -Age: 59.1±8.4/59.7 ±9.3/60.6±8.1 Gender (F:M): 3:15/ 0:4/ 50:99 -Disease duration: 10.2±5.1/12.0±1.7/13.5±5.4 -UPDRS III: 31.8±8.9/45.7±5.2/39.3±11.8	Participants performed 180° turns pre-and post-STN-DBS using the self-selected turn strategy, OFF and ON medication. Trials were on video recording, with a blinded rater Baseline: OFF: L-dopa for 12 hours or Dopamine agonists for 72h "ON": 60 minutes after 1.5 times usual medication dosage Follow-up : 3-12 months post-surgery and ON	STN-DBS	OFF: Spin: n=18 (10.5%) Step: n=149 (87.1%) Mixed: n = 4 (2.3%) ON: Spin: n=40 (23.5%). Step: n= 103 (66%) Mixed: n=27 (15.9%) Lower UPDRS-III scores were observed in participants continuing the step strategy at follow-up (15.5 ± 6.8 vs. 19 ± 14)*	Turn strategy correlates with UPDRS III and PIGD More participants performed step strategy when OFF, suggesting a less demanding strategy. The turning strategy may complement turning parameters when quantifying gait and posture.
Huxham et al., 2008a[24]	Examine turning step adjustments among people with PD	**PD (n= 10)** -Age: 72.9 ±3.3 -Height (cm): 165.0 ±8.9 -Weight: (kg): 70.3 ±11.7 -H&Y: 2-3 -Disease Duration (years): 7.4 ±5.1 •HC (n= 10): -Age (years): 71.3 ±2.4 -Height (cm): 168.2 ±7.7 -Weight (kg): 71.6 ±10.9	Using three-dimensional motion analysis, participants walked at self-selected speed and turned three times each at 0°, 60°, 120° in randomized order.	NA	ST = 60°; LT= 120° **Stride Length (mm)** Displayed as pre-turn/Step1/Step2/Step3/Step4 **PD** ST: 991 (200) / 923 (180) /783 (174) /896 (221) /897 (242) LT: 914 (214) /690 (186) /682 (166) /620 (261) **HC** ST: 1333 (102) /1250 (85) /1105 (81) /1259 (113)/ 1232 (105)	Reduction in stride length is an integral component of turning, but people with PD display excessive reduction in SL Unimpaired adults begin to turn with

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
					LT: 1250 (96) / 954 (85) /994 (145)/ 1043 (194) •Turn efficiency (# steps to reach turning angle) **Stride Direction (deg)** **PD** ST: 0 (2) / 1 (5) / 16 (12) 38 (15) /51 (13) LT: 0 (4) /10 (11)/ 43 (28)/ 77 (32) **HC** ST: 0 (2) / -1 (3) /20 (9) /45 (9) /57 (4) LT: -1 (3) /16 (11) /65 (20) /104 (15)	preparatory steps away from turning direction, suggesting APA counter-rotation.
Huxham et al., 2008b[25]	Examine the contribution of intersegmental rotation to turns among PwPD	HC (n= 10) Age: 71.3±2.4 Height (cm): 168.2(7.7 Weight (kg): 71.6±10.9 MMSE: 29.3±1.0 PD (n=10) 8M/2F Age: 72.9±3.3 Height (cm): 165.0±8.9 Weight (kg): 70.3±11.7 MMSE (*/30): 27.7±1.8: H&Y: 2.3±0.3 UPDRS-III: 14.2±5.6 Disease Duration (year): 7.4±5.1	Controlled experiment Participants performed turning trials while walking at a self-selected speed. Using visual cues, turns were performed 3 times each at 0°,60°, and 120° in randomized order. In addition, 3-dimensional motion capture was used to quantify movement. Turns were performed with left foot landing and rotating rightward. Data were collected at the first turning step, 3 footfalls each entering and exiting the turn.	NA	Results show the differences between PwPD and HC during 120° turn trials, by step and time. Values are calculated as HC – PD). Therefore, negative values reflect larger values for PwPD for the measurement. Mean(SD) **1st Step** Cranial: HC: 2 (7) PD: 6 (7) Thoracic: HC: -8 (4) PD:-1(6) Pelvis: HC: -3 (5) PD: 0 (4) **3rd Step** Cranial: HC: 34 (21) PD: 36 (18) Thoracic: HC: 9 (12) PD: 18 (11) Pelvis: HC: 13 (12) PD: 16 (10)	Individuals with PD begin turns sooner with larger thoracic rotation than HC, who displayed greater cranial rotation at the first step. HC prepared for the turn with the head rotating before the pelvis, unalike PwPD who remained locked in the same direction.

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
					6th Step Cranial: HC: 128 (8) PD: 117 (12) Thoracic HC: 120 (8) PD: 105 (20) Pelvis: HC: 119 (8) PD:101 (21) **1.5s before** Cranial: HC: 2 (6) PD: 5 (8) Thoracic: HC: 7 (4) PD: 1 (5) Pelvis: HC: 6 (4) PD: 2 (3) **During** Cranial: HC: 54 (23) PD: 55 (14) Thoracic: HC: 24 (12) PD: 31 (10) Pelvis: HC:24 (12) PD: 28 (9) **1.5s after** Cranial: HC: 129 (7) PD: 121 (13) Thoracic: HC: 123 (6) PD: 113 (17) Pelvis: HC: 125 (6) PD: 110 (16)	
Park et al., 2020[67]	Investigate turn characteristics of the affected limb between PwPD with and without FoG and HC	**+FoG/-FoG/HC** -Gender: 7M/8M/6M -Age (years) 66.67±4.38/ 68.83±6.00/ 68.25±3.47 -Height (cm): 158.83± 9.08/ 157.73±7.22/ 160.30±9.29 -Weight (kg): 57.88±8.97/ 61.07±8.43/ 61.53±9.54	Tested "ON" 2-3 hours before the test 2 sessions 1st: Informed consent, UPDRS, HY, NFoGQ, and MMSE 2nd: 5-minute warmup, 5-minute rest, turning tasks modified from TUG, 3xea with 3D motion capture:	NA	Results presented as (PD/HC) Total Steps IMA*: 9.17±2.59/ 7.39±1.52 OMA: 9.96±2.53/ 9.11±2.14 Duration (s) IMA**: 4.34±1.18/ 3.25±0.66 OMA*:	Poor intersegmental coordination and slower and smaller axial rotations contribute to en bloc turns. Potentially contribute to disequilibrium while turning.

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
			360°, 540° at fastest self-selected speed max speed		4.67±2.03/ 3.42±0.70	
		-Disease duration (years): 9.83±4.26/ 5.96±1.83/ NA				
		-H&Y: 2.55± 0.27/ 2.38±0.31			Step width (m) IMA: 0.13±0.08/ 0.17±0.08	
		-Left Side More Affected: 11/ 8/ All R-handed			OMA**: 0.09±0.04/ 0.15±0.07	
					Inner step length (m) IMA**: 0.40±0.07/ 0.47±0.05	
					OMA**: 0.41±0.06/ 0.49±0.05	
					Outer step length (m) IMA**: 0.40±0.07/ 0.49±0.06	
					OMA**: 0.40±0.07/ 0.49±0.04	
Conradsson et al., 2018[40]	Investigate mediolateral stability during pre-and unplanned walking turns between PwPD and HC	PD(n= 19): 12M/7W Age(yrs.):72 (4) BMI: 25.0 (3.2) Disease duration (yrs.): 5.2 (4.2) HC(n= 19): 12M/7F Age(yrs.):72 (6) BMI: 24.7 (2.6)	RCT Participants walked straight or walked and turned 180° planned and unplanned trials with visual cues 9m walking •Self-selected •Turn 180° R or L •Pre- and unplanned •15 trials per subject Five trials each of straight, right, and left turns •Both sessions on the same day •HC performed tasks at the same speed as PD using a hand-held stopwatch	NA	PwPD initiated turns 12° and 16% narrower step width vs. HC 22% to 38% smaller pelvis lateral displacement during the widening turning steps	Turning stability compromised in PD during narrower crossover steps Impaired scaling flat. Pelvis displacement and step width regulation •HC maintained large ML difference across wide and narrow turning stability in PD was a robust finding—independent of

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
						turning strategy steps A scaling deficit in movement amplitude for individuals with PD
Conradsson et al., 2017[68]	Determine whether dopaminergic medication improves preplanned and unplanned turns in PwPD compared to HC	•PD(n=19): 12M/7F Age:72 (4) yrs. Weight:74.7 (10.7) kg Height: 172.9 (6.4) cm; Disease duration (y) 5.2 (4.2) **HC (n=17):** 10M/7F Age(yrs.):72 (5) Weight(kg): 76.1(8.8) Height(cm): 175.8 (8.8) UPDRS III: *: 44.8 (7.2) 35.0 (7.5)	Assessed "OFF" then ON within the same day •HC: Two sessions (i)comfortable walking speed (ii) speed-matched participants with PD. •Pre and unplanned turning conditions in randomized order Planned: Visual cue provided direction before star Unplanned: Begin walking straight with visa; the cue is given t	NA	Vales are mean (95% CI) and presented as PD-OFF/PD-ON/ES/HC **Body rotation (°)**77 (68–86) /80 (72–88)/0.30/99 (92–105) **Distance (m)** 1.47 (1.37–1.57)/1.55 (1.46–1.63)/0.75/1.82 (1.74–1.89) **Trajectory (m)** 0.61 (0.57–0.66)/0.59 (0.55–0.64)/0.29 0.60 (0.56–0.63) **Velocity (m/s)** 0.46 (0.40–0.52)/0.47 (0.43–0.50)/0.08/0.45 (0.40–0.49) • mean straight walking velocity improved by 0.07 m/s when “ON” medication intake along with a 0.03 m increase in step length	PwPD turns sooner began than HC, regardless of medication state. Individual turn strategy remained unchanged between participants after taking medication Step turns occur with widened BoS. Preplanned turns were initiated prior to the intersection; unplanned turns were initiated after crossing the intersection point mean turn velocity higher in preplanned turns Slower unplanned turn led to more considerable turn degree at final step vs. preplanned (100–113) compared to preplanned turns (77–99) (P<0.0

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
						Mean turn velocity higher in preplanned turns
Visser et al., 2007[31]	Quantify trunk rotations during turning tasks in PwPD	**PD (n=24):** 4M / 20F -Age(yrs.): 58.3 ± 10.1 -UPDRS-III: 38.8 ± 12.9. **HC(n=25):** 10M/15F Age(yrs.): 57.6±6.8 UPDRS-III: 38.8 ± 12.9	Observational Cohort Tested "ON" Participants perform four different turning tasks, three times each while wearing 2 angular velocity transducers on their sternum and lower back Participants walked 6m at their self-selected comfortable speed then turned 180° turns to the left and right. Tasks included self-paced "normal," as fast as possible, cued, and DT continuously answered simple questions. Participants were not instructed on the turning strategy.	NA	**Difference:** Duration (s)*: 0.6 (0.39,0.80) PTV yaw (°/s)*: 40.6 (59.1, 22.1) PTV roll (°/s)*: 9.4 (13.8, 5.0) Peak walking yaw(°/s): 5.7 (14.3, 2.9) Peak walking roll(°/s)*: 5.1 (9.8, 0.51) **PD:** Duration(s): 2.7 ± 0.39 PTV yaw (°/s): 137.7 ± 31.3 PTV roll (°/s): 31 ± 6.1 Peak walking yaw(°/s): 56.9 ± 10.7 Peak walking roll(°/s): 28.7± 7.1 **HC:** Duration(s): 2.1 ± 0.33 PTV yaw (°/s): 178.3 ± 33 PTV roll (°/s): 62.6 ± 18.1 Peak walking yaw(°/s):	Turn performance improves during planned for PwPD Peak velocities demonstrate differences in turn task. Postural control displayed in turning task to discriminate Measuring PTV as the outcome of interventions aimed to improve gait and balance

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
					56.9 ± 10.7 Peak walking roll(°/s): 33.8 ± 8.8	
Stack et al., 2018[33]	Explore wearable sensors compared to video analysis by an expert clinician to detect instability.	**N=24** **PD(n=10)** : 6F Age:74 (7) years. H&Y: 1–5 **HC(n=14)**: 13F Age:74 ± 8 years Height: 1.6 ± 0.1m Mass: 67 ± 12kg	Simultaneously wore IMU while being video recorded during multiple functional gait trials.	NA	Results presented as Video/Sensor **Duration(s):** 3.0 (1.9)/2.9 (2.0) **Steps:** 5.1 (3.3)/5.2 (3.4)	Wearable sensors can detect turn duration and steps similarly to video analysis PwPD
Franzén et al.,2009[37]	Test the hypothesis that neck tone is the most related to Impaired turn performance and balance in PwPD. To test this hypothesis, we correlated axial postural the tone in the neck, trunk, and pelvis segments was measured objectively using Twister with measures of balance and mobility in both subjects with PD and age-matched control subjects.	**PD (n=15)** 15M H&Y: 2.5 Age (yrs.): (63±8 years) Height (cm) 176 Weight (kg): 81 Affected Side: 8R/6L/1B **HC:** Age: 64 Height: 174 Weight (kg): 79	Participants performed morning assessments in the OFF (at least 12h), and the assessment included axial tone assessments of the cervical, thoracic and pelvic tone assessments, then six different functional performance assessments that included: Figure 8, Supine roll, TUG, BBS, Functional reach test, Standing 360 turn in place. The morning assessment concluded with UPDRS-III. Next, participants took their regular morning medication dosage, waited 1 hour, then repeated all assessments. Control subjects performed all assessments once,	Usual medication dosage	**TUG 180° turn duration(s):** HC: 1.0 (0.3) PD-OFF: 1.6 (0.4) PD-ON: 1.3 (0.3) HC vs. OFF** OFF vs. ON*	Although participants complete 180° turns significantly faster while on L-dopa medication than when OFF, participants with PD perform turns while walking slower than HC.
Koop et al., 2018[53]	Determine the sensitivity of mobile devices to	PD (n=30): 12 F/18 M Age (years): 61.9 ± 9.0	Participants performed 2 TUG trials over carpeted hallway randomized over	Medication	Results are presented as Mean (SD, ICC [LB,UB] OFF/ON	Average angular velocity increased with medication

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
	measure biomechanical metrics.	Disease duration(years): 4.0 ± 3.0 H&Y: ≤ 2.5: n=25	2 separate days while wearing iPads over the lumbar spine to approximate whole-body CoM Auditory cues provided start signal		Average Velocity (°/s) *: 90.94 (15.20), 0.83 [0.67 0.91] / 98.19 (20.24), 0.85 [0.71 0.93] Peak Velocity (°/s): 163.66 (41.25), 0.84 [0.69 0.92] / 172.73 (39.71) 0.80 [0.62 0.90] 0.14	status, but not peak angular velocity (vertical axis)
Song et al., 2012[39]	Characterize the postural control differences between PwPD and HC during a step turning activity.	PD (n=15) Age (years): 62 (9.1) Height (m): 1.68 (0.07) Weight (kg): 68.9 (12.1) Disease Duration (months): 18.2 ± 13.9 H&Y: 1.9 ± 0.3 UPDRS III: 21.2 ± 6.7 UPDRS-III: 0.1 ± 0.4 UPDRS postural stability: 0.3 ± 0.5 HC (n=10) Age (years): 60 (8.5) Height (m): 1.72 (0.09) Weight (kg): 74.8 (17.2)	Using 3D motion analysis and force plates, participants walked 4 m straight at self-selected speed and turned 90° toward their dominant leg (defined as kicking leg) after reaching the designated location for 10 trials	NA	Results are presented as PD/HC Approach gait velocity (m/s): 1.35 (0.14) / 1.46 (0.14) Peak COP-COG distance (m): Phase 1**: 0.13± 0.03 / 0.17 ± 0.03 Phase 2*: 0.21 ± 0.05 / 0.27 ± 0.04	PwPD likely adapts turning behavior to reduce postural demand while turning by reducing velocity, though the difference is not statistically significant. The scaling strategy reduces the moment arm and, consequently, the muscular force required to complete the turn.
Crenna et al., 2007[16]	Analyze turning in individuals with mild idiopathic-PD	**PD (n=7):** 5M/2F Age: 67.1 (6.5) Height (cm): 165.6(10.7 Weight (kg):66.9(9.0 UPDRS:14.7±3.9 H&Y: 1.8±0.4 **HC (n=15):** 8M/7F Age: 67.7 (2.7) Height (cm):165.2±8.6 Weight(kg):65.7±9.2	Using 8-camera 3-dimensional motion analysis, participants randomly performed two walking trials eight times each, Straight (W) and Walked and Turned (W&T) in "ON" state. In W trials, participants walked 6m at self-selected speed, and for W&T, participants walked at least 2m toward a vertical rod, then turned 90° leftward for all turning trials.	NA	Results are presented as HC / PD Median (Min-Max) **Gait speed (%BH/s)*** 81.8 (70.0–99.0) / 72.8 (63.5–85.7) **Peak head–trunk rotation (°)** W: 4.8 (1.6-9.9) / 2.2 (0.7-6.8) W&T**: 17.7(7.2–29.3) / 7.2 (5.4–12.7) **# of turn steps**** 2.5 (1.7–3.5) / 3.3 (2.8–3.9) **Max head–trunk rotation (°)*** 17.7 (7.2–29.3) / 7.2 (5.4–12.7) **Approach step length (%BH)** 38.8 (30.2–47.3) / 36.7 (27.2–41.1)	PwPD displays a significantly smaller peak cranio-thoracic separation amplitude and requires more steps while turning than HC. Results suggest that intersegmental rigidity is not a major contributor to turn performance differences

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
Bertoli et al., 2019[35]	Quantify and compare kinematic differences in freezers and non-freezers while performing 180° turns while walking	**PD+FoG (n=24)** (19M/5F) Age (years): 69.2 ± 7.1 Disease duration (years): 8.7 ± 6.2 MDS-UPDRSIII: 45.8 ± 12.1 0.56 PIGD sub score 7.6 ± 3.7 <0.01 MoCA: 24.9 ± 4.9 **PD-FoG(n=18)** (14M/4F) Age (years): 70.3 ± 6.8 Disease duration (years): 7.7 ± 4.3 MDS-UPDRSIII: 43.6 ± 11.3 PIGD subscore 3.8 ± 2.5 MoCA 26.2 ± 3.3	Participants perform a series of motor tasks OFF medication (≥ 12h) while wearing 3 IMUs located on the dorsal aspects of both feet and the fifth lumbar vertebra region. This review examined the third task, which required 180° turns while walking for 2 minutes along a 7 - meter pathway at a comfortable speed.	NA	Results are Mean (SD) and presented as -FoG/+FoG. **Duration (s)**:** 2.55(.58) / 3.2(.75) **# steps**:** 5.24 (1.18) / 6.41(1.31) **Peak velocity(°/s)**:** 143.87 (26.18)/106.77 (26.61) **ML jerk(m^2/s^5):** 3.43 ± 2.72 / 1 ± 3.74 **AP jerk (m^2/s^5):** 2.06 ± 1.80 / 1.71 ± 1.17	Participants with FoG displayed longer turn duration, took more steps, and performed turns with slower lumbar peak turn velocity, suggesting that turn performance worsens with motor symptom severity.
Stożek et al., 2016[41]	Assess the effects of rehabilitation on balance, gait, and trunk rotation in PwPD.	**Rehabilitation (n=30)** Age (years): 64.0 ± 9.9 13M/17F Disease duration (years): 4.6 ± 2.7 H&Y:2.3 ± 0.6 UPDRS III: 19.7 ± 7.8 **Control (n=31)** Age (years): 67.0 ± 11.3 16M/15 F Disease duration (years): 4.3 ± 2.6 H&Y: 2.3 ± 0.6 UPDRS III: 23.2 ± 10.5	RCT All participants were randomly allocated to (1) rehabilitation or (2) Control. Assessments were performed "ON" during Pre, Post, and 1-month follow-up assessments. Assessments included seated ROM testing of the lumbar and thoracolumbar spine using a tape measure.	**Rehabilitation** 28, 2-hour sessions in small groups (2-3 participants) Weeks1-2 2x/day, 6 days/week Weeks 3-4: 1x/day, 3 days/week The program included: relaxation, breathing, ROM, trunk rotation in various positions, postural reeducation, gait training, dance, weight shifting, and attentional strategy. The control group (CON)remained on	Presented as REHAB / CON Mean ± SD **# steps 360 turn:** Pre: 10.70 ± 5.80/ 10.60 ± 6.80 Post*: 6.90 ± 2.10 0 / 9.80 ± 4.10 Follow-up*: 6.70 ± 2.00 / 10.80 ± 6.90 **Thoracolumbar ROM L (cm):** Pre: 4.70 ± 1.98 / 4.76 ± 2.22 Post*: 7.63 ± 1.84 / 4.46 ± 2.10 Follow-up*: 7.31 ± 1.68 / 4.10 ± 1.98	REHAB group took fewer steps at follow-up, while the CON group remained unchanged, suggesting participants improved dynamic postural stability following rehabilitation. Seated thoracolumbar ROM improves in PwPD following 4 weeks of intervention

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
				prescribed medication and was offered rehabilitation after 4 weeks.		
Conradsson et al., 2015[86]	Investigate the short-term effects of a 10-week program with an emphasis on motor and cognitively challenging balance exercises in elderly individuals with PD	**Training (n=51)** Age (years) 72.9 (6.0) Gender: 28M(60) / 19F(40) Weight (kg): 75.8 (14.1) Height (cm): 171.8 (9.2) H&Y 2/3: 20 (43) / 27 (57) UPDRS III: 36 (10) Disease duration (years): 6.0 (5.1) Recurrent faller, yes/no 25(53) / 22 (47) **CON (n=49)** Age (years) 73.6 (5.3) Gender, male/female 23M (51) / 22 F (49) Weight (kg) 76.4 (13.9) Height (cm) 171.2 (9.0) H&Y, 2/3: 19 (43) / 25 (57) UPDRS III: 37 (11) Disease duration (years): 5.6 (5.0)	Double-blinded RCT Block randomization Pre- and post-assessments included gait and balance performance tests and self-report questionnaires	**Training** Group exercise (4-7 people) 60-minute session 3x/week for 10 weeks Emphasize sensory integration, anticipatory postural adjustments, motor agility, stability. **CON:** Usual exercise routine x 10 weeks	Results presented as Pre/Post/Difference **Mini Best**:** Training:19.2(0.5) / 22.2 (0.5) / 3 CON:18.4 (0.5) / 19.3 (0.5) /0.9 ES= 0.82 MFE time(s) NS Training: 25(13 / 24(13 / -3(6 CON: 27(16 / 26(9 / -2(5 ES= 0.00 MFE(steps) NS Training: 2(4 / 2(3 / -3(6 CON: 2(4 / 2(3 / -2(7 ES: 0.25	Participants significantly improved balance following training, evidenced by increased Mini BEST score and high effect size. Training did not significantly change MFE time but showed a small effect on the number of steps. The intervention can improve postural control during linear gait but does not affect rotational activities.
Tollár et al., 2019[56]	Compare the effects of agility exergaming (EXE) and stationary cycling (CYC) exercise training on mobility and clinical symptoms of people with PD.	**EXE (n=25):** Age(years): 70.0±4.69 Height(cm): 173.0±6.91 Mass (kg): 72.2±6.33 BMI: 24.2±3.13 Disease Duration (years): 7.5±1.76 7.5±2.16 7.3±2.21 0.644 Disease Duration (years): 7.5±1.76 H&Y: 2.3±0.48	RCT with waitlisted control group testing "ON" state (1-2h). Participants completed Measurements taken pre-and post-intervention; waitlisted control group offered enrollment into exercise program following study completion.	All interventions were performed over five weeks, 5x/week for 1 hour at 80% age-predicted HRmax. **EXE:** Exercise with virtual reality for postural control,	**Dynamic Gait Index change*:** EXE: 0.7±1.77 CYC: 0.3±0.98 CON: –0.5±1.31 **6MWT change*:** EXE: 129.6±68.90m CYC: 141.6±51.53 m CON: –16.3±81.61 m	Participants that train postural stability while standing make significantly greater improvements in gait adaptability, as evidenced by the DGI score increase.

Authors and Year	*Aim(s)*	*Participant Characteristics*	*Study Design and Protocol*	*Intervention*	*Results*	*Future Implications*
				gait mobility, gait stability, turning,		
		CYC (n=25): Age(years): 70.6±4.10 Height(cm): 173.8±6.11 Mass (kg): 75.1±6.91 BMI: 24.9±2.65 Disease Duration (years): 7.5±2.16 H&Y: 2.4±0.51		**CYC:** spin class @ 110-140 rpm without visual feedback.		
		CON (n=24): Age(years): 67.5±4.28 Height(cm): 174.7±7.48 Mass (kg): 73.6±8.65 BMI: 24.2±3.21 Disease Duration (years): 7.3±2.21 H&Y: 2.4±0.51		**CON:** continued regular activity, medication, and diet and offered enrollment at study completion		

ABBREVIATIONS: CYC, Cycling group; EXE, Exergaming group; CON, Control group; IQR, Inter-Quartile Range; HRmax, maximal heart rate; DS, Dynamic Stability; DT, Dual Task; ES, Effect Size; NA, Not Applicable; PwPD, People with Parkinson's disease; PWS, Preferred Walking Speed; FWS, Fast Walking Speed; SWS, Slow Walking Speed; STN-DBS, Sub-Thalamic Nucleus Deep Brain Stimulation; PTV, Peak Angular Turn Velocity; TUG, Timed Up and Go; "*" indicates $p < 0.05$; "**" indicates $p < 0.01$.'

APPENDIX C

POSSabilities Routine

Forwards / Backwards Warm-Up

Exercise: 20s on; 10s rest; (circuit x 2)
Marching in place with arm swings
Squats (depth as tolerated) (slow down – up safely)
Single leg swing (stand close to the wall. Goal is to minimize the use of hand on the wall for balance)
Back extensions (reach for ceiling)
Marching in place with snow angel arms
Exercise: 20s on; 10s rest; (circuit x 2)
Walking high knee marches

Walking backward with single arm rotation reach
Walking with straight leg forward kicks (forward Frankenstein's)
Walking with butt kicks
Walking split step with contralateral overhead reach
Exercise: 20s on; 10s rest (circuit x 2)
Calf stretch on wall
Lateral lunge adductor stretch

Lateral / Rotation Warm-Up

Exercise: 20s on; 10s rest; (circuit x 2)
Trunk Rotations
Manual resisted isometric trunk rotation (apply smooth force)
March circles - 90° turns – (emphasize hip rotation both legs)
Clock lunges (depth as tolerated)
Exercise: 20s on; 10s rest; (circuit x 2)
Walking march with 45° turns on every 3rd step – (emphasize hip rotation on open step)
Grapevines
Walking split step with trunk rotation – (rotate towards lead leg)
Lateral Frankenstein's - avoid trunk tilting – (1 leg down, other leg back)
Walking with rotational sword pull every 3rd step
Exercise: 20s on; 10s rest (circuit x 2)
Calf stretch on wall
Lateral lunge adductor stretch

Integration: 40 sec per drill (1,1,1) (2,2,2) (3,3,3) (4,4,4) (5,5,5) (6,6,6) (7,7,7)
1. Wall drill – hands on wall – push through floor – knees up
2. Staggered weight shift – 20 seconds each side (emphasize stacked finished position on front leg)
3. Forward walking (pause in middle of each step) (emphasize stacked position on balance leg)
4. Squat steps – non-alternating
5. Squat steps – alternating (switch sides every 3 repetitions)
6. Skater strides
7. Skater strides (3 normal – 3 short and quick – 3 normal – etc)
Rehearsal: 40 sec per drill (8,8,8) (9,9,9) (10,10,10)
8. Forward walking (4 big steps – full stop – 4 normal steps – full stop) - repeat
9. Forward walking
10. Forward walking – pre-planned starts and stops – (use cones)

GMU Rehabilitation Science POSSabilities - Phase 1 session 1 (forwards, gait initiation, power) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop ( ) ( )

Integration: 40 sec per drill (1,1,1) (2,2,2) (3,3,3) (4,4,4) (5,5,5) (6,6,6) (7,7,7)
1. Even – open step 45° - return to even
2. Staggered – forward step with open 45° – return to staggered
3. Forward walking with alternating open 45° stepping (every 3rd step)
4. Forward walking with alternating open 45° stepping (every 3rd step) (light band resistance)
5. Forward walk to cone – stop – 360° march circle (emphasize hip rotation both legs) – finish length (utilize turning in both directions)
6. Y-drill - forward progression throughout
7. Fast forward walk full length – stop – 180° march circle (emphasize hip rotation both legs) – (utilize turning in both directions)
Rehearsal: 40 sec per drill (8,8,8) (9,9,9) (10,10,10)
8. Figure 8 drill – forward walk whole time
9. Box drill (with cones) – forward walking – (emphasize open stepping around corners)
10. Continuous forward walking laps with pre-planned speed changes (use cones)

GMU Rehabilitation Science POSSabilities - Phase 1 session 2 (rotational, steady state, stepping) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

Integration: 40 sec per drill (1,1,1) (2,2,2) (3,3,3) (4,4,4) (5,5,5) (6,6,6) (7,7,7)
1. Even – backwards step with high knee pause – staggered – return to even (20 sec each side)
2. Staggered – backwards step with high knee pause – staggered – return to staggered (20 sec each side)
3. Backwards stepping to even stance (non-alternating)
4. Backwards stepping to even stance (alternating)
5. 3 steps forward – 3 steps backward (with pause on one leg in between)
6. 3 steps forwards – 3 steps backward (with high knee pause on one leg in between)
7. Big backwards steps (5 steps – rest - repeat) (full steps)
Rehearsal: 40 sec per drill (8,8,8) (9,9,9) (10,10,10)
8. backwards steps (full steps) (5 big, 5 normal – repeat) (no rest during step length transition)
9. Backwards walking – forwards walking (shuttle drill with 4 cones)
10. V-drill (forwards and backwards walking)

GMU Rehabilitation Science POSSabilities – Phase 1 session 3 (backwards, gait initiation, stability) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

Integration: 40 sec per drill (1,1,1) (2,2,2) (3,4,5) (3,4,5) (4,3,5) (6,7) (6,7) (6,7)
1. Side to side skaters (load and spring) (try for one leg on ground at a time)
2. Even – lateral step – return to even (push-off on return) (talk about force generation through posterior chain/leg and how forefoot is the final point of energy transfer)
3. Even – lateral step – return to even (push-off hard and high knee pause on return)
4. Side stepping with push off (emphasize proper stability with drive leg prior to power development through the floor) (use slight pause at beginning of each rep to coach loading)
5. Side stepping with push off (band resistance) (emphasize proper stability with drive leg prior to power development through the floor)
6. Fast side stepping (emphasize relaxed body, fast/dynamic steps)
7. 4 steps forward walk – 2 dynamic lateral steps (emphasize proper stability with drive leg prior to power development through the floor)
Rehearsal: 40 sec per drill (8,8,8) (9,9,9) (10,10,10)
8. Box drill (use cones) (face same direction throughout) (push off with drive leg)
9. 4 backwards steps – 2 side steps (repeat other direction) (continuous)
10. Forward walking with preplanned speed changes (use 2 cones) (very fast – very slow – very fast)

POSSabilities - Phase 1 session 4 (lateral, steady state, power)
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

Integration: 40 sec per drill (1) (2,3,4) (1) (2,3,4) (1) (2,3,4) (5,5,5) (6,6,6) (7,7,7)
1. Staggered – high knee/dorsiflexion – staggered – return to staggered (20 sec each side)
2. Ankling (1 set slow) (1 set fast) (1 set medium)
3. Calving (non-alternating) (1 set slow) (1 set fast) (1 set medium)
4. Calving (alternating) (1 set slow) (1 set fast) (1 set medium)
5. Calving with pre-planned speed changes (alternating)
6. 3 meters fast forward walk – 3 meters slow calving – 3 meters fast forward walk (use cones) (alternating)
7. Calving (as big as possible) (alternating) (1 set slow) (1 set fast) (1 set medium)
Rehearsal: 40 sec per drill (8,9,10) (8,9,10) (8,9,10)
8. Forward walking fly ins (long hallway) (coach them through tall posture and relaxed body)
9. Forward walking with sporadic band resistance (long hallway) (tall posture and relaxed body)
10. Forward walk with pre-planned speed changes (use cones) (medium, fast, slow, fast, medium) (long hallway) (tall posture and relaxed body)

GMU Rehabilitation Science POSSabilities – Phase 1 session 5 (forward, steady state, stepping) Date:

Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

Integration: 40 sec per drill (1,1) (2,2) (3,4) (4,3) (2,4,3) (5,5,5) (6,6,6) (7,7,7)
1. Even – lift foot – pause - open step 45° - finish tall and stacked – return to even
2. Even – high knee with pause – open step 90° – finish tall and paused - return to even
3. Even – right open big step 45 – even – left open big step 45 – even (forward progression) (dynamic stepping encouraged)
4. Even – right open big step 45 – even – left open big step 45 – even (forward progression) (heavy band resistance) (emphasize power through floor and balance throughout)
5. Even – high knee with pause – slow open step 45° – walk 5 meters (repeat other direction) (slow walk, medium walk, fast walk)
6. Even – high knee with pause – slow open step 90° – fast walk 5 meters (repeat other direction) (slow walk, medium walk, fast walk)
7. Forward walk full length – stop – 180° march circle (emphasize hip rotation both legs) – forward walk return (80% max pace)
Rehearsal (8) (9) (10)
8. Figure 8 drill (80 % max pace) (3 mins)
9. Zig-zag cone course (forward walking with 45° turns) (80% max pace) (3 mins)
10. Laps around training perimeter. (3 mins) (switch directions at 90 sec) (90% max pace)

GMU Rehabilitation Science POSSabilities – Phase1 session 6 (rotational, gait initiation, stability) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

Integration: 40 sec per drill (1,1) (2,2) (1,2) (3,4,3) (3,4,3) (5,4,5) (5,4,5) (6,4,6) (6,4,6)
1. ((Staggered – to even x2) (staggered – staggered x2)) (hand weights)
2. Backwards walking (one leg fast, one leg slow)
3. Backwards walking (medium pace)
4. Dynamic/powerful backwards steps (band resisted) (coach them to sit hips back and keep chest on top of feet)
5. 3 long backwards steps – 3 normal backwards steps – repeat (emphasize good posture and relaxed body)
6. 3 fast backwards steps – 3 slow backwards steps – repeat (emphasize good posture and relaxed body)
Rehearsal (1,2) (1,2) (3)
1. Forward walking with band resistance from behind (70% pace. Tell them to drive through resistance with each step) (90 sec)
2. V-drill (facing same direction throughout) (70% pace) (90 sec)
3. Forward walking (85% pace – 4 mins)

GMU RHBS POSS - Phase 1 session 7 (backwards, steady state, power) Date: Subject ID:

BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

Integration 123. 123. 456. 456. 78. 78. 1234. 56. 78. 9
1. Side to side skaters (load and spring) (try for one leg on ground at a time) (hold weights)
2. Side to side stepping (step right. Step left) (emphasize balanced weight acceptance on landing leg)
3. Side to side stepping (step right. Step left) (emphasize push off)
4. Side to side stepping (load majority of weight into drive leg and wait) (when trainer claps, push-off and take a dynamic step to the side) (reset, repeat other direction)
5. Lateral stepping triplets (3 dynamic steps left. 3 dynamic steps right) (push-off emphasis) (heavy band lateral walking GAIT INITIATION DRIVING)
6. Lateral stepping (lift feet up above ankle height) (light band resistance around waist) (choo-choo train)
7. Lateral stepping (high knee with lead leg)
8. Lateral stepping (high knee with trail leg)
Rehearsal (9,9) (10)
9. Tetris cone drill (high knees on lateral section) (complete as fast as possible) (80% max pace) 2 min
10. 4 mins continuous forward walking (85% max pace)

GMU Rehabilitation Science POSSabilities – Phase 1 session 8 (lateral, gait initiation, stepping) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

40 sec per drill (1,2,3,4) (1,2,3,4) (5,6,7) (5,6,7) (1,2,3,4) (5,6,7) (8,8,8) (9,9,9) (10)

1. Even – lift with pause – forward step – forward stack – return to even (slow, emphasize control)
2. Staggered weight shift (unplanned speed changes – trainer communicates)
3. Forward walking (1 foot very fast, 1 foot very slow) (switch sides every pass)
4. Forward walking (1 foot very fast, 1 foot very slow) (trainer randomly pushes side of hip and shoulder to supply perturbation) (switch sides every pass)
5. 5 forward steps – stop in stance – 5 forward steps - stop in stance – repeat (1 set slow – emphasize control) (1 set fast – emphasize speed) (1 set medium)
6. Fast forward walking – random change to fast forward ankling (trainer dictates change) (band resistance around waist)
7. Band resisted fast forward walking (emphasize powerful dynamic steps) (variable band resistance from trainer) (use hallway)
8. Forward walk full length with resistance on one side (1 set slow, 1 set faster, 1 set medium)
9. Forward walking trainer walks behind and applies random lateral perturbations to shoulders and hips (jostling) (1 set slow long steps, 1 set faster normal steps, 1 set)
10. Forward walking (4 mins)

GMU RHBS POSS - Phase 2 session 9 (forwards, gait initiation, stability) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

Integration: 40 sec each drill (1,2,3,4) (1,2,3,4) (5,6,5) (5,6,5) (7,6,7) (7,6,7) (8,9,8) (8,9,8)
1. 45 open stance weight shifts (stay tall, rotate hips, medium stance length) (hand weights)
2. 45 open stance weight shifts (load into back leg, push off and drive up tall to forward leg) (hand weights)
3. Even – forward open 45 step – return to even (hand weights)
4. Staggered – forward step with open 45° – return to staggered (hand weights)
5. Forward walking with open 45 turn (every 3rd step) (eccentric lunge on 3rd step) (hand weights)
6. Forward walking with open 45 turn (every 3rd step) (band resistance) (coach drive turn)
7. Forward walking with open 45° turn (every 3rd step) (fast pace and long/dynamic steps)
8. Figure 8 drill – forward walk whole time (band resistance from behind)
9. Fast walk to cone – stop – slow march circles – finish walk fast (85% max pace walk)
Rehearsal (1,2) (1,2)
1. Forward walking zig zag course (2 mins 80% max pace)
2. Forward walk around training perimeter 2 mins (85% max pace) (switch directions at 1 min)

GMU RHBS POSS - Phase 2 session 10 (rotational, steady state, power) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

40 sec per drill (1,2,3,4) (1,2,3,4) (5,6) (5,6) (7,8) (7,8) (1,2,3,4) (5,6,7,8) (9,10) (9,10)
1. Forward Staggered – high knee hold – forward staggered – (hand weights at side)
2. Forward Staggered – high knee – backwards step – backwards staggered - return to forward staggered (hand weights at side)
3. Backwards walking (high knee on one leg)
4. Backwards walking with high knee
5. Backwards walking with high knee (light band resistance)
6. Backwards walking with long steps (groups of 3) (trainer randomly dictates start of each group) (pause in stance position)
7. backwards walking medium pace – trainer randomly claps – 5 fast forwards steps (emphasize clean transition with definitive first step)
8. Fast backwards walk – stop – 10 high knees in place – fast backwards walk (divide room in half) (80% max pace)
9. V drill (forward and backwards walking) (stay on outside of cones) (80 % max pace) (2 mins continuous)
10. 2 mins continuous forward walking (80% max pace)

GMU Rehabilitation Science POSSabilities - Phase 2 session 11 (backwards, gait initiation, stepping) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

Integration 40 sec per drill 123. 123. 4567. 4567. 123. 4567. 888.
1. Lateral weight shift (feet slightly wider than hip width) (emphasize complete acceptance of weight on one leg with good posture)
2. Even – lateral step – return to even (push-off on return) (pause and hold with high knee on return)
3. Side to side skaters (load and spring) (try for one leg on ground at a time) (60 seconds)
4. Lateral ankling – (short and fast) – switch at cone – (long and slow)
5. Lateral ankling – (medium pace) – (light band resistance) – choo choo train
6. Lateral calving – trainer stands close behind and applies random lateral perturbations to hips
7. Lateral walking (very fast - very slow - very fast) – 2 cones to dictate speed change
8. Dynamic/fast lateral step x2 to forward walk 4 fast steps (facing one direction)
Rehearsal (9,9,9) (10,10,10) (11)
9. Tennis ball partner catch lateral shuffle (2 cones) (3 meters) (toss directly to them) 40 sec total
10. Box drill with small obstacle step over (use half of figure 8) (switch at 20 seconds to ensure equal work on both sides) (4 sec total)
11. Forward walking (90% speed 4 mins)

GMU RHBS POSS - Phase 2 Session 12 (lateral, steady state, stability) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

(1,1) (2,2) (3,3) (4,5,6) (4,5,6) (7,8,9) (7,8,9) (1,2,3) (4,5,6) (7,8,9) (10,11) (10,11) (10,11)

1. Staggered weight shift (tall posture, rock back and forth) (40 sec)
2. Staggered weight shift (tall posture, long stance, load into back leg and drive to stacked finished position) (40 sec)
3. Staggered – load into back leg and push off to high knee with pause – forward staggered stacked finish – return to staggered (40 sec)
4. Forward walking (1 leg high knee march – other leg normal) (band resistance from behind) (up tempo pace, drive through resistance) (40 sec)
5. Walking knee drive march (partner resisted) (drive into ground with each step) (40 sec)
6. Walking fly ins (40 sec)
7. Forward high knee march (alternating) (band resistance from behind) (40 sec)
8. Partner resisted forward walk (40 sec)
9. Walking (continuous – longest strides possible) (40 sec)
10. Band resisted forward walking (heavy) (40 sec)
11. Forward walking (80% pace) (90 sec)

GMU Rehabilitation Science POSSabilities - Phase 2 Session 13 (forward, steady state, power) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

Integration: 40 sec each drill (1,1) (2,2) (3,3) (4,4) (5,6) (5,6) (1,2,3,4,5,6) (7,9,8) (9,8) (9,8) (10)
1. Even – open step 45 – stack and finish tall – return to even
2. Even – open step 45 – stack and finish tall - return to even (resistance band around hips) (movement away from resistance)
3. Even – open step 45 – stack and finish tall - return to even (longer step) (load slightly into back leg and drive to forward tall finish position)
4. Even – quick high knee with pause – open step 45 – stack and finish tall – return to even
5. Even – right open step 45 – even – left open step 45 – even (resistance band around hips providing posterior resistance) (forward progression) (work on powerful dynamic steps)
6. Even – right open step 45 – even – left open step 45 – even (cue them to translate the power practiced in drill 5 into speed)
7. Zig zag obstacle course facilitating 45 degree turns (6 cones total) (coach powerful open step around turns) (use slight pause on drive leg to initially coach the movement) (allow them to flow through the drill after they acclimate to the turns)
8. Zig zag obstacle course facilitating 45 degree turns (6 cones total) (coach powerful open step around turns) (reinforce powerful open step turns from drill 6 – but place focus on posture, relaxation, and SPEED)
9. Zig zag obstacle course facilitating 45 degree turns (6 cones total) (band resistance from behind) (emphasize powerful dynamic steps)
10. X-drill - Fast forward walk to vertex – stop – mini high knee march in place – trainer points to either top cone – participant walks to that cone – repeat (3 mins)
Rehearsal (1)
1. Forward walk 4 mins (90% max pace) (use training space perimeter marked with 4 cones) (switch directions after 2 mins) (emphasize crisp turns around corners) (motivate them to maintain 90% max pace)

GMU Rehabilitation Science POSSabilities - Phase 2 session 14 (rotational, gait initiation, stepping) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

40 sec per drill: (1,1) (2,2) (3,3) (4,5) (4,5) (6,7,8) (6,7,8) (1,2,3,4) (5,6,7,8)

1. Forward Staggered – high knee hold – forward staggered (hand weights at side)
2. Forward Staggered – high knee – backwards step – backwards staggered - return to forward staggered (hand weights at side)
3. Fwd/bkwd rocker drill w/ push off (gradually longer/ more push off)
4. Backwards walking (1 leg fast) (1 leg slow)
5. Bkwd walking (1 leg high knee) (1 leg reg step)
6. Bkwd walking w/ band resistance (long strides)
7. Bkwd walking (longest strides possible)
8. Fwd walking figure 8 (as fast as possible)
Rehearsal (123) (123) (123)
1. Continuous forwards walking (band resistance) (trainer randomly varies the resistance) (90 sec)
2. Continuous backwards walking (band resistance) (trainer randomly varies the resistance) (90 sec)
3. Forward walking (90 sec) (90% max pace)

GMU RHBS POSS – Phase 2 session 15 (backwards, steady state, stability) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

Integration: 40 sec per drill 123. 123. 456. 456. 7. 67. 123. 456. 7.
1. Side to side rocking (load and spring) (try for one leg on ground at a time)
2. Side lunge right – push off towards even – side lunge left – push off towards even (use med ball or hand weight) (slow eccentric phase)
3. Side to side stepping (step right. Step left) (emphasize push-off)
4. Side to side stepping (load majority of weight into leg and wait) (when trainer claps, push-off and take a dynamic step to the side) (reset, repeat other direction)
5. Heavy band resisted lateral walking (emphasize push off)
6. Lateral stepping triplets (3 dynamic steps left. 3 dynamic steps right) (push-off emphasis)
7. Lateral stepping (lift feet up above ankle height) (light band resistance around waist) (choo-choo train)
8. Forward walk with 2 random dynamic lateral steps (emphasize push off) (trainer randomly dictates direction and timing of lateral steps (1 min continuous) (85% max pace)
Rehearsal. 12. 12. 12.
1. Tennis ball partner catch lateral shuffle (use 2 cones to set boundaries) (3 meters) (throw directly to them) (90 sec)
2. Forward walking (90% max pace) (2 min)

GMU Rehabilitation Science POSSabilities – Phase 2 Session 16 (lateral, gait initiation, power) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

Order: (1,2) (1,2,3) (2,3) (5,4a) (5,4b) (5,4c) (1,2,3) (6,7a) (6,7b) (6,7c) (8,9,10) (8,9,10) (8,9,10)

1	Forward staggered weight shift – regular stance (hand weights held at sides)	-Forward stack finish
2	Forward staggered weight shift – long stance (hand weights held at sides)	-Load into back leg -Push-off to forward stack finish
3	Even stance – high knee – forward step – return to even (hand weights held at side)	-Land softly and smoothly on forward stepping foot -Forward stack finish
4	Forward walking - non-alternating calving	-4a) slow speed -4b) fast speed -4c) medium speed
5	Forward walking – non-alternating calving (70 % max speed)	-Band resistance from behind -Emphasize driving through resistance with control
6	Forward walking (85% max speed)	-Band resistance from behind -Random variations in the magnitude of resistance -Participant must react to varying resistance and adjust gait to maintain 85% speed
7	5 forward steps – stop in staggered stance – 5 forward steps - stop in staggered stance – repeat	-7a) slow speed – emphasize control -7b) fast speed – emphasize dynamic steps -7c) medium speed – emphasize confidence
8	Forward high knee march (70 % max pace) (30 sec)	-Give motivation to drive knees high
9	Forward walking (70% max pace) (40 sec)	-Longest possible strides -Emphasize push off
10	Forward walking (90 % max pace) (90 sec)	-Give motivation to maintain speed

GMU RHBS POSS - Phase 3 Session 17 (forward, gait initiation, stepping) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

40 sec each drill: (1,2) (1,2) (3,4) (3,4) (5,6) (5,6) (1,2,3,4,5,6) (7,8,9) (7,8,9) (7,8,9)

1. Even – high knee with pause - open step 45 – stack and finish tall - return to even (hand weights)
2. Staggered – forward high knee with pause - open step 45 – stack and finish tall – return to staggered (hand weights)
3. Forward walk with open step every 3rd step (pause and hold on every 2nd step)
4. Forward walk with open step every 3rd step (mini eccentric lunge on every 2nd step) (hand weights)
5. Zig zag obstacle course facilitating 45 degree turns (variable band resistance) (6 cones total)
6. Zig zag obstacle course facilitating 45 degree turns (fast speed) (6 cones total)
7. Figure 8 drill – up tempo speed trainer applies random perturbations to shoulder and hip
8. Figure 8 drill – fast speed – variable band resistance from behind
9. Continuous laps around training perimeter. 2 mins (change direction after 1 min) (fast)

GMU Rehabilitation Science POSSabilities - Phase 3 Session 18 (rotational, steady state, stability) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

(1,2,3) (1,2,3) (4,5,6,7) (4,5,6,7) (1,2,3) (4,5,6,7) (8,9,10) (8,9,10) (8,9,10)

1. staggered weight shift (band resistance from in front) (40 sec)
2. forward stack – high knee – forward stack (40 sec)
3. Fwd / bkwd rocker drill (gradually longer) (40 sec)
4. Backwards walking (non-alternating) (normal step – big step) (band resistance) (40 sec)
5. Backwards walking (non-alternating) (normal step – big step) (40sec)
6. Backwards walking with heavy band resistance (emphasize powerful steps) (40 sec)
7. Backwards walking (40 sec)
8. Forward walk – stop – 5 backwards steps (emphasize clean transition) (trainer dictated transition) – 90% max pace – 1 min
9. forward backward drill – 1 min (max pace)
10. Forward walking - 90% max pace – 90 sec

GMU RHBS POSS - Phase 3 Session 19 (backwards, gait initiation, power) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

(1,2,3,4) (1,2,3,4) (1,2,3,4) (5,6) (5,6) (5,6) (7,8) (7,8) (7,8)

1. Wide stance – push off – high knee – return to wide stance (40 sec)
2. Side to side skaters with high knee (40 sec)
3. Lateral stepping (high knee with trail leg) (one set slow) (one set fast) (one set medium) (40 sec)
4. Lateral stepping (high knee with lead leg) (one set slow) (one set fast) (one set medium) (40 sec)
5. Lateral stepping (trainer randomly dictates step height) (light band resistance around waist) (choo-choo train) (40 sec)
6. 4 steps forward – 3 high knee lateral steps (right) – 4 steps forward – 3 high knee lateral steps (left) – repeat (40 sec)
7. Tennis ball partner catch lateral shuffle (2 cones) (6 meters) (toss directly to them) (1 min)
8. Forward walking (90 seconds) (as fast as safely can)

GMU Rehabilitation Science POSSabilities - Phase 3 Session 20 (lateral, steady state, stepping) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

(1,1) (2,2) (3,4) (3,4) (5,6,7) (5,6,7) (1,2,3,4,5,6,7) (8,9) (8,9) (8,9)

1. Even – forward step – stack tall – return to even (hand weights) (40 sec)
2. Staggered – forward step through to staggered – pause in mid-swing – stack a finish tall – return to staggered (hand weights) (40 sec)
3. Forward walking – alternating pause at midstance (40 sec)
4. Forward walking (1 leg fast – 1 leg slow) (40 sec)
5. Forward walking – alternating pause (trainer applies random lateral perturbations to hips and shoulders) (40 sec)
6. Forward walking (trainer randomly dictates speed changes – very fast or very slow) (40 sec)
7. Band resisted forward walking (variable band resistance) (40 sec)
8. Figure 8 drill (90 sec) (70% max pace)
9. Forward walking (90 sec) (80% max pace)

GMU Rehabilitation Science POSSabilities - Phase 3 Session 21 (forward, steady state, stability) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

(1,1) (2,2) (3,3) (1,2,3) (4,5,6) (5,6) (5,6) (7,8,9) (7,8,9) (7,8,9) (10)

1. Open 45 weight shift (rock back and forth) (hand weights) (40 sec)
2. Open 45 weight shift (band resistance from behind only on forward portion of movement) (40 sec)
3. Even – open 45 step - return to even (hand weights) (long step w/ push off) (40 sec)
4. Zig zag obstacle course (encourage proper open step turn with good push off) (40 sec)
5. Zig zag obstacle course (band resistance) (drive through resistance) (40 sec)
6. Zig zag obstacle course (fast speed) (40 sec)
7. Figure 8 (band resistance) (emphasize powerful open step at corners) (40 sec)
8. Figure 8 (band resistance) (drive through resistance) (40 sec)
9. Figure 8 (fast speed) (40 sec)
10. Perimeter walk (fast pace) (4 mins) (switch directions every minute)

GMU Rehabilitation Science POSSabilities - Phase 3 Session 22 (rotational, gait initiation, power) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

(1,1) (2,2) (3,3) (1,2,3) (4,5,6) (4,5,6) (4,5,6) (7,8) (7,8) (7,8) (9,10) (9,10) (9,10)

1. Forward stacked – high knee hold – forward stacked (hand weights at side) (40 sec)
2. Forward stacked – high knee – backwards step – backwards staggered – return to forward stack (hand weights at side) (40 sec)
3. Backwards ankling (band resistance from in front) (unplanned speed change) (first set without the band to acclimate) (40 sec)
4. Backwards ankling / calving / marching (unplanned transition in step height) (1 set slow pace) (1 set fast pace) (1 set medium pace) (minimum 3 – 4 steps in pattern before change) (40 sec)
5. Backwards long steps / normal steps (unplanned transition – trainer dictates) (40 sec)
6. Backwards long steps (band resistance) (emphasize push off) (40 sec)
7. 5 big backwards steps – stop – 5 fast high knees in place – repeat (40 sec)
8. Backwards fly in (do NOT use hallway) (40 sec)
9. Backwards V drill facing same direction throughout (fast speed) (time competition)
10. Forward walk (90 sec 80% max pace)

GMU RHBS POSS Phase 3 Session 23 (backwards, steady state, stepping) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

(1,2,3) (1,2,3) (1,2,3) (4,5) (4,5) (4,5) (6,6,6) (7,7,7) (8,8,8) (9)

1. Side to side skaters (load and spring) (try for one leg on ground at a time) (40 sec)
2. Even – lateral step – return to even (high knee with pause on return) (40 sec)
3. Even – lateral lunge weight shift – return to even with high knee pause – 5 steps forward (initiate forward walk from single leg balance) (40 sec)
4. Diagonal skater steps (long steps) (pause on each leg) (40 sec)
5. Diagonal skater steps (medium steps) (no pause) (40 sec)
6. Band resisted lateral stepping (groups of 3) (randomly different magnitude of resistance for each group) (40 sec)
7. Tennis ball partner catch lateral shuffle (emphasize speed) (2 cones) (6 meters) (toss directly to them) (40 sec)
8. Fast forward walk with unplanned 3 quick lateral steps (trainer dictates direction and timing of steps) (aim for 2 sets per pass) (40 sec)
9. Forward walking (80% max speed 4 mins)

GMU RHBS POSS - Phase 3 Session 24 (lateral, gait initiation, stability) Date:
Subject ID: Total time: BP pre/post: ( ) ( ) HR pre/post: ( ) ( ) HR monitor start/stop: ( ) ( )

APPENDIX D

Study Documents

Link to ClinicalTrials.gov

To view the study registration on ClinicalTrials.gov, please see the link below:

https://clinicaltrials.gov/ct2/show/NCT03864393

Medical History Form

George Mason University
Department of Rehabilitation Science
Evaluation of a Power, Agility, and Coordination Program for Individuals with Parkinson's Disease
HEALTH HISTORY FORM

Participant Name:_____ ID #:_____

Date of Birth:_____ *PD Only*: Diagnosis Date:_____

Emergency Contact:_____Relationship:_____Phone #:_____

What is your dominant: *a) Arm*: ☐Right ☐Left *b) Leg*: ☐Right ☐Left

For PD Only: Which limb is more affected by the disease? ☐Right ☐Left Other:_____

SOCIAL/CULTURAL

Race (Please check all that apply)

- ☐American Indian or Alaska Native
- ☐Asian
- ☐Black or African American
- ☐Hispanic or Latino
- ☐Native Hawaiian or Other Pacific Islander
- ☐White

Language (Please check all that apply)

- ☐English understood
- ☐Interpreter needed
- ☐Language you speed most often:_____

Education *(Circle highest grade level completed)*

Grades: 1 2 3 4 5 6 7 8 9 10 11 12

Some College / Technical School

College Graduate

Graduate School

Cultural/Religious: Any customs or religious beliefs or wishes that might affect participation? _____

_____

_____

Living Environment

With whom do you live: _____

Does your home have: *(Circle all that apply)*

Stairs, no railing Elevator

Stairs, railing Uneven terrain

Ramps Assistive devices in bathroom,atc

Do you use: *(Circle all that apply)*

Cane Hearing aids

Walker or rollator Glasses

Other:_____

George Mason University
Department of Rehabilitation Science
Evaluation of a Power, Agility, and Coordination Program for Individuals with Parkinson's Disease
HEALTH HISTORY FORM

Participant Name:_____ ID #:_____

Date of Birth:_____ *PD Only*: Diagnosis Date:_____

Emergency Contact:_____Relationship:_____Phone #:_____

What is your dominant: *a) Arm*: ☐ Right ☐ Left *b) Leg*: ☐ Right ☐ Left

For PD Only: Which limb is more affected by the disease? ☐ Right ☐ Left Other:_____

SOCIAL/CULTURAL

Race (Please check all that apply)

- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Hispanic or Latino
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White

Language (Please check all that apply)

- ☐ English understood
- ☐ Interpreter needed
- ☐ Language you speed most often:_____

Education *(Circle highest grade level completed)*

Grades: 1 2 3 4 5 6 7 8 9 10 11 12

Some College / Technical School

College Graduate

Graduate School

Cultural/Religious: Any customs or religious beliefs or wishes that might affect participation? _____

_____

_____

Living Environment

With whom do you live: _____

Does your home have: *(Circle all that apply)*

Stairs, no railing Elevator

Stairs, railing Uneven terrain

Ramps Assistive devices in bathroom,etc

Do you use: *(Circle all that apply)*

Cane Hearing aids

Walker or rollator Glasses

Other:_____

George Mason University
Department of Rehabilitation Science
Evaluation of a Power, Agility, and Coordination Program for Individuals with Parkinson's Disease
HEALTH HISTORY FORM

GENERAL HEALTH / HEALTH HABITS

Health Rating Please rate your health: Excellent Good Fair Poor

Tobacco use

☐ No

☐ Yes: Cigarettes: # or packs/day_____

Cigars/Pipes: # per day_____

☐ Past Year quit:_____

Alcohol use

How many days per week?_____

How many drinks on an average?_____

Exercise

Do you exercise beyond normal daily activities and chores?

☐ Yes Describe the exercise: _____

How many days/week: _____ How many minutes:_____

☐ No

MEDICAL HISTORY (Please check all medical diagnoses and conditions that apply)

☐ Anemia
☐ Arthritis
☐ Bleeding Disorders
☐ Cancer: _____
☐ Chemical Dependency
☐ Communicable Disease
☐ HIV+ ☐ VRE ☐ MRSA
☐ E Coli ☐ Scabies
☐ Depression
☐ Diabetes
☐ Dizziness
☐ Emphysema
☐ Gout
☐ Heart Disease
☐ High Blood Pressure
☐ Irregular or Rapid Heart Beat
☐ Joint Replacement
☐ Kidney Problems
☐ Osteoporosis
☐ Pacemaker
☐ Parkinson's Disease
☐ Current Pregnancy
☐ Stroke
☐ Thyroid Problem

☐ *Other medical condition not listed above:*_____

CURRENT SYMPTOMS (Please check all symptoms you currently have)

☐ Productive cough
☐ Fever/Chill
☐ Coughing up blood
☐ Night sweats
☐ Nausea/Vomiting
☐ Chest pain
☐ Trouble breathing
☐ Joint pain
☐ Joint stiffness
☐ Rashes or skin changes
☐ Visual changes
☐ Hearing changes
☐ Constipation
☐ Bloody Stools
☐ Pain with urination
☐ Incontinent bladder
☐ Incontinent bowel
☐ Other:_____

George Mason University
Department of Rehabilitation Science
Evaluation of a Power, Agility, and Coordination Program for Individuals with Parkinson's Disease
HEALTH HISTORY FORM

FALLS (Please check)

Are you concerned about falling? ☐ Yes ☐ No Have you fallen in the last year? ☐ Yes ☐ No If yes, Date:

Have you fallen more than 2 times? ☐ Yes ☐ No Has any resulted in injury? ☐ Yes ☐ No

---

SURGERIES/HOSPITAL PROCEDURES (Please list the procedure and date)

_____
_____
_____
_____

ALLERGIES / DRUG INTERACTIONS

_____
_____

CURRENT MEDICATIONS

Medication Name	Dose	Frequency	Reason	Time Since Start

Data Collection Sheet

Date:_____ Time of Day: _____ Time of medication:_____ POSS_____ 1

POSSabilities Assessment Pre/Post

COSMED turbine:

Assessment Team

BP	HR	Height(in)	Weight(lbs)

Mini-mental Exam	
Hoehn & Yahr Scale	
HHQ	

10 Minute Walk

(COSMed, APDM):

POSS###_Pre/Post_10min

sit: 3 min. stand 4 min. walk 10 min. stand recovery 10 min.

PFS	
Before	After

BP (sit) – 1:00	BP stand – 3:30	BP stand – 5:30		
BP stand – 7:30	BP stand – 9:30	BP at 1:00 recovery	BP at 4:00 recovery	BP at 9:00 recovery

Breaks Taken:

Total distance:

Time delay:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50

"check mark" in box = lap completed... T1, T2, T2.5, T3, T4, T5, T6, T7, T7.5, T8, T9, T10 in box = tape measurement during lap

Informed Consent

Department of Rehabilitation Science

4400 University Drive, MS 2G7, Fairfax, Virginia 22030
Phone: 703-993--1950; Fax: 703-993-6073

INFORMED CONSENT

Effect of Multimodal Exercise Training on Walking Economy in Individuals with Parkinson's Disease

RESEARCH PROCEDURES

This research study is being conducted to understand the influence of a multimodal overground locomotor training program (OLT) on walking economy and secondary effects with regard to performance fatigability and propulsion during ambulation in individuals with Parkinson's Disease (PD). If you agree to participate, you will be asked to participate in 24 training sessions following an initial evaluation of your health history and functional abilities, including your cardiorespiratory fitness, and motor function including gait. Training sessions will occur twice per week for 12 weeks. Each session will last approximately one hour. You will also be asked to repeat your initial assessment as a final evaluation following the completion of the training sessions.

Examination Procedures

You may be asked to complete the following as part of the pre and post training evaluations:

- Health history questionnaire
- Psychological assessments: used to obtain measurements such as your intellectual function, cognition, memory, judgement, and mood
- Parkinson's disease scales: standardized measures of the course, progression, and severity of PD
- Body composition assessments: measures such as your height and weight
- Fitness assessments: tests and measures of your body's response to physical activity while walking overground, on a treadmill, or cycling on a bike; this often requires wearing a facemask that will collect the air you breathe in and out
- Muscle strength tests: measures of your muscle strength and power which include asking you to push against various types of resistance while wearing sensors over the muscles being used
- Gait and Balance assessments: tests and measures of your walking characteristics and abilities and of your ability to balance during static and dynamic activities; this may include wearing sensors when walking on a platform or treadmill
- Agility, Coordination, and Motor Control Assessments: tests and measures of your ability to plan and execute coordinated movements

The evaluation and assessment will last approximately 90 minutes, one session prior to training and one after training (3 hours of testing total). The testing session will begin with a Health History Questionnaire, Parkinson's Disease scales, psychological state assessment, and assessment of body composition. The order of the remaining assessments will be determined by every other participant drawing a slip of paper with either a 1 or 2 written upon it. When drawing a number from the envelope the chance of drawing either number is 50%.

Training Procedures

The training will involve various forms of exercise designed to address your cardiorespiratory fitness, muscle strength and power, and motor function (including balance and gait). Each training session will last approximately 60 minutes, twice a week for 12 weeks. A heart rate monitor and step watch will be used to monitor intensity and volume during each training session. The heart rate monitor consists of a strap around your chest and wrist watch and the step watch is worn around the ankle.

Videography and photography

Testing and training sessions may be videotaped. During testing, the motion capture system used to analyze gait includes a video component. Video and photographs may be included in the dissemination of results such as research presentations at conferences and in teaching presentations. You have the right to decline videotaping at any session or at any given point while videotaping. Videos will be used for training and teaching purposes. To the extent possible, you will be videotaped in ways that will diminish facial recognition. Video material (photos and videos) will remain on a secure computer and will be deleted after 5 years after the study is completed. You also may request at any time that your videotapes be completely erased immediately either while participating in the study or after your participation has ended.

Re-testing Procedures

At the conclusion of 24 sessions or 12 weeks, you will be retested in the same ways you were tested at the start of the program.

Time Commitments

Participants will need to be available for approximately 1.5 hours of testing prior to and following training for approximately 3 total hours of testing and a total of 24 training sessions (two 60-minute sessions per week for 12 weeks). The total time commitment will be approximately 27 hours.

RISKS

The foreseeable risks or discomforts are similar to the risks that you take when exercising or engaging in moderate physical activity on your own, with or without supervision, at home or in a gym or other facility. The level of exercise or physical activity is in your control, and you will not be asked to engage in any activity that you believe is beyond your ability or tolerance.

You may have some minor discomfort during testing procedures that are similar to any temporary discomfort that you may experience in a routine medical examination or annual physical examination.

You may experience some discomfort from any of the testing or training including muscle fatigue, muscle or joint soreness, and lightheadedness during or in the hours following testing or training. Straining a muscle or spraining a ligament is a very small possibility during testing or training.

You may experience a fall, slip, or trip during testing or training. Every effort will be made to minimize these risks. You will have a research assistant nearby at all times to avoid a fall, slip, or trip.

The risks of exercise testing and supervised training are generally low, although sometimes medical complications do occur. During exercise and moderate physical activity, certain changes in heart rate and rhythm, blood pressure, and respiratory rate are expected, but abnormal or unanticipated changes are small possibilities. Every effort will be made to minimize these risks.

Although rare in occurrence the most serious risks of exercise testing and training include sudden death, heart attack, dizziness, chest pain or tingling in the arm, jaw, or back, shortness of breath, and/or extreme fatigue. Please let the researcher know if you experience any of these symptoms during testing or training activities.

In case of injury during testing or training procedures, the George Mason University research team may provide basic first aid. If appropriate, the staff will call the emergency response team at 911. Neither George Mason University nor the investigators have funds available for payment of medical treatment for injuries that you may sustain while participating in this research. Should you need medical care, you or your insurance carrier will be responsible for payment of the expenses required for medical treatment.

BENEFITS

There are no direct benefits to you as a participant other than to further the research of interventions designed for people with PD.

CONFIDENTIALITY

The data in this study will be confidential, including in publications and reports resulting from the research. All participants will be assigned an identification number after agreeing to participate, and all de-identified data will be stored using this identification number. The signed informed consent and the identification number linking data to individuals will be stored by the lead researcher in a locked cabinet in a locked office along with any other forms or papers that have protected personal or health information. Only members of the research team will have access to this information. The de-identified data could be used for future research without additional consent from participants. Monitors, auditors, the Institutional Review Board, and regulatory authorities may have access to the data for verification of clinical trial procedures without violating the confidentiality of the participants to the extent permitted by law.

PARTICIPATION

Your participation is voluntary, and you may withdraw from the study at any time and for any reason. If you decide not to participate or if you withdraw from the study, there is no penalty or loss of benefits to which you are otherwise entitled. There are no costs to you or any other party except transportation to and from testing or training sessions and parking in compliance with University regulations. You will receive information on how PD has affected your abilities from the testing we will do, and you may or may not improve in these abilities after training.

Your participation in testing or training may be stopped at any time by a member of the research team without your consent for reasons that include a belief by the research team that continued testing or training may affect your health or safety; you are unable to follow or adhere to testing or training instructions; or other administrative reasons that require your withdrawal.

CONTACT

This research being conducted is led by Dr. Andrew Guccione, Department of Rehabilitation Science, at George Mason University. He may be reached at 703-993-4650 for questions or to report a research-related problem. You may contact the George Mason University Institutional Review Board Office at 703-993-4121 if you have questions or comments regarding your rights as a participant in the research.

This research has been reviewed according to George Mason University procedures governing your participation in this research, IRBnet #: **1374615-1**.

CONSENT

I have read this form, all my questions have been answered by the research staff, and I agree to participate in this study.
Please indicate below your preference for videography/photography. This will not affect your participation in the study.

☐ I grant permission to videotape my image and likeness as part of this research study.

☐ I DO NOT grant permission to videotape my image and likeness as part of this research study.

_____ _____

Name **Date of Signature**

_____

Signature

Standardized Mini-Mental State Examination

Name of patient:		DOB:	/ /	Name of examiner:		Date of test:	/ /

Standardised Mini-Mental State Examination (SMMSE)

Please see accompanying guidelines for administration and scoring instructions

Say: *I am going to ask you some questions and give you some problems to solve. Please try to answer as best you can.*

1. Allow ten seconds for each reply. **Say:**

   a) *What year is this?* (accept exact answer only) /1
   b) *What season is this?* (during the last week of the old season or first week of a new season, accept either) /1
   c) *What month is this?* (on the first day of a new month or the last day of the previous month, accept either) /1
   d) *What is today's date?* (accept previous or next date) /1
   e) *What day of the week is this?* (accept exact answer only) /1

2. Allow ten seconds for each reply. **Say:**

   a) *What country are we in?* (accept exact answer only) /1
   b) *What state are we in?* (accept exact answer only) /1
   c) *What city/town are we in?* (accept exact answer only) /1
   d) <At home> *What is the street address of this house?* (accept street name and house number or equivalent in rural areas) /1
      <In facility> *What is the name of this building?* (accept exact name of institution only) /1
   e) <At home> *What room are we in?* (accept exact answer only) /1
      <In facility> *What floor of the building are we on?* (accept exact answer only) /1

3. **Say:** *I am going to name three objects. When I am finished, I want you to repeat them. Remember what they are because I am going to ask you to name them again in a few minutes* (say slowly at approximately one-second intervals).

   Ball Car Man

   For repeated use: Bell, jar, fan; bill, tar, can; bull, bar, pan

   Say: *Please repeat the three items for me* (score one point for each correct reply on the first attempt) /3

   Allow 20 seconds for reply; if the person did not repeat all three, repeat until they are learned or up to a maximum of five times (but only score first attempt)

4. **Say:** *Spell the word WORLD* (you may help the person to spell the word correctly). **Say:** *Now spell it backwards please* (allow 30 seconds; if the person cannot spell world even with assistance, score zero). Refer to accompanying guide for scoring instructions (score on reverse of this sheet) /5

5. **Say:** *Now what were the three objects I asked you to remember?* /3

   (score one point for each correct answer regardless of order; allow ten seconds)

6. Show wristwatch. **Ask:** *What is this called?* /1

   (score one point for correct response; accept 'wristwatch' or 'watch'; do not accept 'clock' or 'time', etc.; allow ten seconds)

1

7. **Show pencil. Ask:** *What is this called?* /1

   (score one point for correct response; accept 'pencil' only; score zero for pen; allow ten seconds for reply)

8. **Say:** *I would like you to repeat a phrase after me: No ifs, ands, or buts* /1

   (allow ten seconds for response. Score one point for a correct repetition. Must be exact, e.g. no ifs or buts, score zero)

9. **Say:** *Read the words on this page and then do what it says* /1

   Then, **hand** the person the sheet with CLOSE YOUR EYES (score on reverse of this sheet) on it. If the subject just reads and does not close eyes, you may repeat: *Read the words on this page and then do what it says*, a maximum of three times. See point number three in Directions for Administration section of accompanying guidelines. Allow ten seconds; score one point only if the person closes their eyes. The person does not have to read aloud.

10. **Hand** the person a pencil and paper. **Say:** *Write any complete sentence on that piece of paper* (allow 30 seconds. Score one point. The sentence must make sense. Ignore spelling errors). /1

11. **Place** design (see page 3), pencil, eraser and paper in front of the person. **Say:** *Copy this design please.* Allow multiple tries. /1

    Wait until the person is finished and hands it back. Score one point for a correctly copied diagram. The person must have drawn a four-sided figure between two five-sided figures. Maximum time: one minute.

12. **Ask** the person if he is right or left handed. **Take** a piece of paper, hold it up in front of the person and **say** the following: *Take this paper in your right/left hand* (whichever is non-dominant), *fold the paper in half once with both hands and put the paper down on the floor.*

Takes paper in correct hand_____ /1

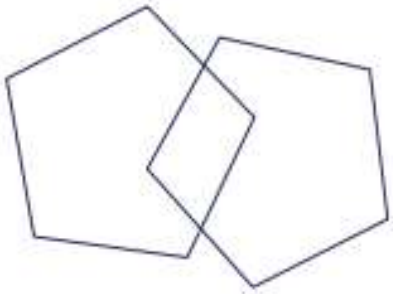
Folds it in half_____ /1

Puts it on the floor_____ /1

TOTAL TEST SCORE: /30

ADJUSTED SCORE: /

Molloy DW, Alemayehu E, Roberts R. Reliability of a standardized Mini-Mental State Examination compared with the traditional Mini-Mental state Examination. *American Journal of Psychiatry*. Vol. 14, 1991a, pp.102-105.



Time:

D	L	R	O	W

=

CLOSE YOUR EYES

Approved IRB Application for Parent Study

GEORGE MASON UNIVERSITY

Institutional Review Board

Application Form

Instructions:

1. CITI certification (www.citiprogram.org) must be completed for all team members at the time of application submission.
2. Complete all sections and required addenda. Submit one complete package via IRBNet.
3. Projects with funding/proposed funding must include a copy of the grant application or proposal.
4. Research may not begin until you have received notification of IRB approval.
5. Handwritten and incomplete forms cannot be accepted.

1. Study Title: **Effect of Multimodal Exercise Training on Walking Economy in Individuals With Parkinson's Disease**

2. Study Investigators

A. Principal Investigator (*must be faculty/staff and meet PI Eligibility, University Policy 4012*)

Name: **Andrew Guccione** Department: **Rehabilitation Science**

Phone: **703-993-4650** E-mail: **aguccion@gmu.edu**

B. Co-Investigator/Student Researcher

Name: **Clint Wutzke** Department: **Rehabilitation Science**

Phone: **703-993-1903** E-mail: **cwutzke@gmu.edu**

C. Are there additional team members? No ☐ Yes ☒ *If yes, complete Addendum J to list additional team members*

D. Do any investigators or team members have *conflicts of interest* related to the research?

No ☒ Yes ☐ If yes, explain

3. Study Type: ☒ Faculty/Staff Research ☒ Doctoral Dissertation ☐ Masters Thesis ☐ Student Project (**Specify** ☐ Grad or ☐ Undergrad) ☐ Other (Specify)

4. Complete Description of the Study Procedures

A. Describe the aims and specific purpose of the study:

Sustained ambulation is a challenge for individuals with Parkinson's disease (PD) as walking economy is frequently compromised. There are also various disease-related skeletal muscle alterations that may contribute to performance fatigability during ambulation. Concomitantly, individuals with PD experience substantial difficulty maintaining sustained forward progression at push-off during the gait cycle due to diminished force production. Exercise is commonly prescribed for these individuals, though traditional exercise approaches to PD have often applied a "one impairment-one modality" paradigm that addresses each impairment seperatly. Interventions to optimize movement should facilitate an individual's response to the challenge of responding to a complex interplay of constraints that are also specific to a task and its environmental context. Thus, there are multiple concurrent targets for exercise interventions that may not fit easily within a "one impairement-one modality" model. A multimodal intervention is designed to address an array of constraining impairments concurrently. However, the evidence-base for multimodal exercise approaches is still developing and far from conclusive. The purpose of this study is to demonstrate that multimodal overground locomotion training (OLT) can promote walking economy during sustained overground ambulation in individuals with PD, and produce concurrent secondary effects that decrease preformance fatigability and increase propulsion. The aims of this study are to 1)

1

Evaluate walking economy during sustained overground walking after 12 weeks of multimodal OLT, 2) Evaluate secondary effects of OLT.

B. Provide a COMPLETE description of the study procedures in the sequence they will occur including the amount of time each procedure will *take (attach all surveys, questionnaires, standardized assessment tools, interview questions, focus group questions/prompts or other instruments of data collection)*:

Protocol Overview: Subjects will be recruited from the greater Washington D.C. metro area and Northern Virginia areas by word of mouth, healthcare provider referral, support groups, social media posting, and by posted fliers. The study design and participation will be explained to those who are potentially interested in participating in the study. Individuals interested in participating as subjects will complete initial verbal screening to determine eligbility for inclusion. Those subjects who volunteer to participate will then be consented and enrolled for participation if exclusion and inclusion criteria are met.

Visit 1: (~ 90 minutes) Subjects meeting inclusion and exclusion criteria will be consented and enrolled in the study. They will then be asked to fill out a medical history form. Height and weight measurements will then be taken. The Hoehn and Yahr and Mini-metnal State Exams (described below) will then be administered by an investigator. Subjects will then be randomized as to the order of testing procedure. Randomization will be performed using blocks of two, whereby the first subjects will draw a number (1 or 2) out of an envelope with 1 indicating the 10-minute walk will be performed first and 2 indicating gait lab propulsion testing will be performed first. The next subject enrolled in the study will do the opposite. This testing pattern will continue with the third subject drawing randomly and the fourth subject doing the opposite and so on. These tests will be separated by a sufficient rest period or as long as it takes to set up for the next testing procedure, with a minimum rest period of 10 minutes but less than 20 minutes for consistency between subjects. Those subjects performing the the 10-minute walk test first will be fitted with a portable metabolic unit consisting of a face mask and torso apparatus similar to a backpack. Wearable sensors will be secured with velcro to both arms, trunk, and legs. The walk will take place in a long corridor within the Peterson Health Sciences Building. Prior to starting the test, subjects will stand in a resting position for at least 3 minutes to gain resting metabolic data. They will then be asked to walk as far as they can in 10 minutes. Following the 10-minute walking period, subjects will again stand in a resting position to obtain recovery data. Subjects will then be provided a 10-20 minute resting period during the transition to the second test. For the second test, subjects will be fitted with reflective markers at pre-specified anatomical landmarks used in a standardized gait marker set, for example medial and lateral knee and ankle joints. Electromyography (EMG) sensors will be placed on lower limb muscles. Subjects will then be asked to walk at both their preferred and fast walking speed over a 6 meter platform with embedded force plates. Subjects will be asked to perform as many trials as necessary to collect sufficient force plate data which is anticipated to be between 20-30 passes. Following this test, subjects will be given the opportunity for a rest period if required before ending the testing day. For those subjects who start with the gait propulsion test, the testing order will include the same procedures yet in the reversed order.

Visits 2-25: (~1 hour each) For these visits, subjects will perform an overground multimodal locomotor training protocol. Subjects will train individually with 1-2 trained instructors. Each training session will consist of an initial warm-up period, the main training intervention, and a cool-down period. Subjects will wear a Polar chest strap and a StepWatch (research grade pedometer) during each session to enable instructors to modify training within the session to maintain a target intensity zone. The training protocol covers 12 weeks with two sessions per week for a total of 24 sessions.

Visit 26: (~90 minutes): Subjects will repeat the same testing procedures as they did in visit 1 in the same order as they did, determined by the initial randomization process.

Study Procedures:

10-Minute Walk Test: The purpose of this test is to provide a method of perturbation for measuring both performance and perceived fatigability. Subjects will wear a fitted face mask and a torso unit as part of a portable metabolic unit. Wearable sensors will be secured on the torso, upper and lower limbs to measure gait characteristics. Subjects will rest in a standing position for at least 3 minutes prior to beginning this test to collect baseline data. Subjects will then walk over a level corridor as far as they can over a 10-minute interval or until they have to stop walking. Distance covered will be recorded at at 2.5-minute intervals throughout the test and at the end of the time walked if not the full 10 minutes. Velocity will be computed from the distances covered at the time intervals (meters/sec). The 10-minute walk test will be performed during the pre-intervention testing visit and post-intervention testing visit. At least one member of the research team will conduct the test and give limited cueing throughout the test to ensure proper testing procedure but not excessive motivational encouragement. Following the 10-minute walk period (or total time if ended early) subjects will rest in the standing position to obtain recovery data for at least 6 minutes.

Gait Propulsion Testing: Subjects will be outfitted with reflective markers comprised of a standardized full-body marker set for motion capture analysis. EMG sensors will be placed on muscle bellies of lower limb muscles. To establish the maximum voluntary contraction, subjects will be asked to contract muscles against resistance. Subjects will be asked to stand for system calibration for less than one minute and may be asked to move various limbs through a range of motion to ensure accuracy of the system prior to starting the test. Subjects will then be asked to walk across a 6-meter platform with embedded force plates enclosed by safety rails at their preferred and fast walking speed. Subjects will perform approximately 20-30 passes to ensure sufficient data collection by the force plates as appropriate contact with the force plate must be made for valid measurement. Once sufficient data has been collected, markers and sensors will be removed and the subject will be offered a seated rest period if needed.

Multimodal Exercise Intervention: The intent of the multimodal training intervention is to encompass cardiovascular adaptations and locomotor improvements. Cardiovascular adaptations, as evidenced by improved in AT-VO2, have been demonstrated to improve performance fatigability in other clinical populations. To promote cardiovascular adaptation, training sessions will be adjusted in real-time to achieve a pre-determined target HR zone for each subject. HR will be monitored coninuously during each training session. The target HR

intensity during training sessions will be 60% of the subjects predicted maximal HR. The target HR zone will be 60% of predicated maximal HR +/- 5%. The subjects predicted maximal HR will be calculated using the formula: 220-age. To promote locomotor improvements, training procedures will include drills based on gait initiation and termination, agility, muscular power, and steady state actions. Drills will be conducted with an emphasis on direction change beyond usual forward progression. As subjects become familiar with the various drills, instructors will gradually increase the complexity, speed, and volume.

Propulsion Measures: For this study, propulsion will be defined by anterior peak positive ground reaction force (GRF) during overground walking. The force plates measure the GRF in response to the force placed upon it by the subject. In conjuction with motion capture analysis, the propulsive phase of gait can be determined and within that phase the anterior peak vector will be calculated. Peak propulsive force will be determined as the maxima (one point) of the anterior GRF.

Performance Fatigability Test Scoring: Performance fatigability is the rate or extent to which tissue, organ, system or total body function (fatigue) declines in response to a given task. After a 10-minute period of quiet rest in the sitting position, subjects will complete the 10-minute walk test. Distance covered will be recorded at the 2.5-minute interval of the test and for the total test. Velocities for the entire test (total distance walked / total minutes of test) and the first 2.5 minutes of the test (distance covered in the first 2.5 minutes / 2.5 minutes) will be calculated. The fractional change in velocity will then be computed as the quotient of total test velocity / 2.5 minute velocity. For example if the total test velocity and the 2.5-minute velocity were both 82 meters/minute, the total test velocity would be 100% of the velocity at 2.5 minutes. However, if the total test velocity were 80 meters/min and the velocity at 2.5 minutes were 82 meters/minute, then the total test velocity would be only .98 of the 2.5-minute velocity. To calculate the performance fatigability score, the fractional change in velocity will be divided by the distance covered. Thus any 2 subjects could have similar change in velocity scores (for example 0.5) but different total distances (100 versus 200 meters). In this case the performance fatigability score for the first subject would be 0.5/100 = 0.005 versus .5/200 = 0.0025. Scores are multiplied by 1000 to facilitate reporting. A small score indicates lower fatigability. Thus, even though the fractional change in velocity was similar for the 2 hypothetical subjects above, fatigability was less in the second subject as demonstrated by a lower performance fatigability score.

Perceived Fatigability Test Scoring: Perceived fatigability is the rate or magnitude of change in feelings of tiredness or weariness (symptoms of fatigue or perceived fatigue) in response to a given task. After the initial 10-minute sitting rest period, subjects will rate their perception of fatigue or vigor using the left side of the Fatigue and Fatigability Scale. Following the 10-minute walk test, subjects will be asked "compared to when you started, how would you rate your level of tiredness now" using the right side of the scale. The left side is considered a measure of fatigue because a change in fatigue was not assessed. The right side is considered to be a rating of fatigability because it assesses the change in tiredness. The score for the change in tiredness is then normalized to the total distance covered to calculate the perceived fatigability score: perceived fatigability = (change in tiredness / total distance walked) x 100 (multiplied by 100 to facilitate reporting and comparison).

4

Cardiopulmonary Gas Exchange Analyes: All gas exchange will be collected using a wearable metabolic unit, the COSMED K5© portable cardiorespiratory testing system. The K5 system uses a galvanic fuel cell and non-dispersive infrared sensor for the analysis of oxygen consumption (VO2) and carbon dioxide expiration (VCO2) in the inhaled and exhaled air and an optoelectronic reader with a high performance turbine flowmeter to measure flow rate. After the unit warms up for approximately 20-30 minutes, flowmeter, gas, scrubber, and delay time calibrations are performed following manufacturer's recommendations. The two-point gas calibration is completed sampling the ambient air and the gas from a certified tank containing 16% O2, 5% CO2, and standard atmospheric Nitrogen. Flowmeter calibration was performed connecting the turbine to a calibrated Hans Rudolph 3-liter syringe and completing six full strokes at a respiratory frequency of 20-25 breaths/min. Delay time calibration was performed with the flowmeter and the sampling line connected to the face mask and by executing six breaths at a given rhythym while breathing in the facemask. The unit uses OMNIA software and has both wireless and bluetooth capabilities. Subjects interface the system by wearing a form-fitting facemask and chest unit. The unit is calibrated prior to each test.

Motion capture system: Our dedicated gait lab includes infrared cameras that capture movements of reflective markers worn by subjects within the volume. Reflective markers will be placed about the subject according to a predetermined full body gait marker model. VICON Nexus software, installed on a PC, is used to collect, identify, and reconstruct the movement data.

EMG sensors for measurement of muscle activity: Noraxon EMG Wireless TeleMyo allows the wireless collection of up to 16 channels of EMG, as well as other analog signals, in real time for up to 300 feet away. The 16 channel DDTS is equipped with EMG preamplifiers, operating in the standalone analog out mode to synchronize with the VICON Nexus software. EMG sensors, DTS EMG probe with EMG lead are attached to Noraxon Dual EMG Electrodes that are secured to the subject's skin over the muscle belly of interest. The sensor and electrode are covered with tape to minimize movement artifacts.

Force plates for GRF measurement: 4 Bertc forceplates are embedded in the center of the 6 meter walkway. The forceplates measure x, y and z axes of the force and moment components, with the output signal fed into an amplifier. This signal output is displayed and recorded into the VICON Nexus software suite.

Wearable sensors for measurement of gait characteristics: APDM wearable sensors contain accelerometers, gyroscopes, and magnetometers. Measurements are collected on the x, y, and z axes at a sample rate of 128 Hz. These sensors are attached to the preselected locations on the subject's body. This data is either wirelessly streamed via an access point and/or logged and stored in the sensor. Participants will also wear a step counter during each training sessions to record the total number of steps taken

Questionnaire:

Medical History Form: Subjects will fill out the medical history form on visit 1.

5

Testing/Forms:

Hoehn and Yahr: The Hoehn and Yahr scale (HY) is a widely used clinical rating scale, which defines broad categories of motor function in Parkinson's disease. This test will be adminstered by the researchers on visit 1.

Standardised Mini-mental State Exam: This test will be administered by researchers on visit 1 and is a 12-point questionnaire that addresses cognitive function.

C. Describe the target population (age, sex, ethnic background, health status, etc.): **The target population includes men and women over the .age of 18 diagnosed with mild to moderate, Hoehn & Yahr (H&Y) stage 1-3, Parkinson's Disease.**

1. Summarize the inclusion/exclusion criteria for participation in the study:
- Inclusion Criteria: age > 18; diagnosis of mild to moderate Idiopathic Parkinson's Disease (H&Y 1-3); able to speak English; able to ambulate with no assistive device
- Exclusion: neurological disease diagnosis other than PD; uncontrolled cardiovascular, pulmonary, neurological, or metabolic disease which may impact the ability to exercise or in which exercise is contraindicated; any medications, such as beta-blockers, that may alter HR or metabolic data; cognitive or psychiatric impairment precluding informed consent or ability to following unstructions; mini-Mental State Examination score <24; pregnancy; inability to ambulate without assistive device

2. Are there any enrollment restrictions based on gender, pregnancy, race or ethnic origins? ☒Yes ☐No If yes, please describe the process and reasons for restriction(s): **Those who are pregnant will be excluded from participation in the study as pregnancy may alter the exercise response and adaption and is possibly unsafe to pregnant females.**

3. Do any researchers listed on the application have a relationship to any of the participants that could unduly influence them to participate (including a teacher/student relationship)? ☐Yes ☒No If yes, please describe the relationship and how any possibility of undue influence will be managed:

4. Estimated number of subjects (may use a range): **20-30 individuals with mild to moderate PD**

5. Estimated amount of total participation time per subject: **Total hours = 27. Approximately 3 hours total for testing (pre and post intervention). Approximately 24 hours for training intervention (2x week/12 weeks)**

D. Where will the study occur (*list all study sites and collaborators*)? **RHBS Functional Performance Laboratory; Peterson Hall. George Mason University Fairfax Campus**

E. Describe other approvals that have been/will be sought prior to study initiation (facility authorizations, biosafety review, IRB approval from collaborating institutions, approval from public school system IRBs, etc.): **This study will be registered and approved on Clinicaltrials.gov**

F. Is this study a clinical trial that requires registration on ClinicalTrials.gov? ☒Yes ☐No If yes, please provide the NCT number assigned to the study: to be forwarded when approved

5. Recruitment and Consent

A. Describe the processes used for selecting subjects and the methods of recruitment including when, how, and by whom the subjects will be recruited (***attach all recruitment materials including flyers, emails, SONA posting, scripts, etc. and please include the IRBNet number of***

the project and the PI's name on all recruitment documents)? **Patients will be recruited using fliers, word of mouth, support groups, social media, physicians and physical therapist referral. Approval will be sought from social media administrators, support groups, physician and physical therapist offices, and other advertising locations prior to advertising.**

B. Describe the consent process including how and where the consent will take place, who will conduct the consent process, information that will be discussed with and distributed to subjects, and how participants will indicate consent even if a waiver of signature is being requested below (*attach all consent documents*): **Potential subjects will have the rationale for the study, study procedures, rights as a human subject, and their ability to terminate participation in the study explained to them. Subjects will have the opportunity to read over the consent form and ask any questions prior to signing. The consent process will take place in a private room in the Functional Performance Laboratory by one of the investigators on the study.**

C. Is a waiver of signature on the Informed Consent being requested? ☐ Yes ☒ No

If yes, complete the following:

1. This waiver is being sought because (*check one*):
   - ☐ The only record linking the subject and the research would be the consent document AND the principal risk would be potential harm resulting from a breach of confidentiality.
   - ☐ The research presents no more than minimal risk of harm to subjects AND involves no procedure for which written consent is normally required outside of the research context.
2. Explain why the waiver of signature is being requested:

6. Privacy & Confidentiality

A. How will the researchers protect the *privacy* of the participants and the *confidentiality* of the data obtained? **Information contained in the database spreadsheet will be identifiable only by a unique identification code. The identification key and data will be accessible only by the Principal and Co-Investigators.**

B. What individually identifiable information will be collected as part of the study data and who will have access to that information? **Identifiable data will include the subject's name, signature, birthday, and medical history. This data willl be listed with the subject's unique identification number on the identification key. This information will be kept in a locked cabinet accessible only to the PI and Co-I, and student investigators.**

C. When will identifiable information/the identification key be destroyed (if applicable)? *Please note that when feasible, the IRB recommends that personal identifiers be destroyed as soon as possible, though research data must be stored for 5 years.* **Signed consent forms and data will be destroyed 5 years after the end of the study. The identification key will be also be destroyed 5 years after the end of the study, though may be destroyed earlier if data collection and analysis are completed sooner.**

D. Where will the data be stored (*Copies of records must be stored on Mason property—for example, in the PI's office*)? **The signed consent form and identification key will be stored in a locked file in the PI's office. Deidentified and non-identifiable data will be kept in a file on a password-protected computer in the Functional Performance Laboratory. Copies of deidentified and non-identifiable data may also be stored on investigators' (PI and Co-Investigators) personal password-protected computers for analysis.**

E. How long will the data be stored (*data must be retained for at least 5 years after the study ends*)? **Deidentified will be stored indefinitely, but for at least 5 years, after the end of the study.**

F. What, if any, are the final plans for disposition/destruction of the data? **The identification key, signed consent forms, or any other identifiable data will be shredded or deleted five years after completion of the study.**

G. Will results of the research be shared with the participants? ☒ Yes ☐ No If yes, describe how this will be accomplished: **Individual results overall will be shared with participants upon request of the participant following completion of data collection and analysis.**

H. Will individually identifiable information be shared with anyone outside of the research team (*If yes, please explain and be sure to include this information in the consent form*)?
☐ Yes ☒ No If yes, please explain:

I. Does the research involve possible disclosure by participants of intent to harm themselves or others or possible disclosure of child abuse or neglect? (*If yes, please explain and be sure to include this information in the consent form*)?
☐ Yes ☒ No If yes, please explain:

7. Risks

A. Summarize the nature & amount of risk if any (*include side effects, stress, discomfort, physical risks, psychological and social risks*): **Risks to the participants in this study are minimal.**
-The participant may experience some discomfort from any of the testing or training including muscle fatigue and/or muscle or joint soreness following testing or training. Straining a muscle or spraining a ligament is a very small possibility during testing or training.
-The risks of the protocol exercise testing and supervised training are low as the testing and training intensity are designed and anticipated to be of moderate intensity or below. As with all exercise intervention, there is minimal risk including risk of falling, dizziness, sudden death, heart attack, chest pain or tingling in the arm, jaw, or back, shortness of breath, and/or extreme fatigue. In case of injury during testing or training procedures, the George Mason University research team may provide basic first aid. If appropriate, the team will call the emergency response team at 911. All of the research team have been trained and certified in CPR/AED administration.

B. Estimate the probability if any (e.g. not likely, likely, etc.) that a given harm may/will occur and its severity: **It is unlikely that a given harm may occur. The testingand training risks are relatively low and all testing is supervised and monitored directly.**

C. What procedure(s) will be utilized to prevent/minimize any potential risks? **Personnel trained in CPR and AED will be present at each testing and exercise testing. Subjects will be monitored at all times during testing and training visually and using heart rate monitors to ensure compliance with target intensity zones. Furthermore, personnel will alter to the balance deficiencies of this population and attendant at all times to the subject to prevent falls if a loss of balance occurs.**

8. Benefits

A. Describe any probable benefits (if any) of the research for the subject(s) (*Do not address compensation in this section*): **There are no known direct benefits of this research.**

B. Describe the benefits to society and general knowledge the study is likely to yield: **The health and social costs of living with chronic illness such as PD to society is quite large, particularly with respect to the myriad secondary conditions that may ensue as a result of chronic decreased mobility. This intervention, if effective, may offer an affordable way for individuals with PD to maintain their health and fitness and accrue the same health-related benefits of physical activity as others.**

9. Financial Information

A. Is there any internal or external funding or proposed funding for this project? ☐ Yes ☒ No
If yes, funding agency and OSP # (if external funding) *(attach grant application)*
B. Are there financial costs to the subjects? ☐ Yes ☒ No If yes, please explain:
C. Will subjects be paid or otherwise compensated for research participation? ☐ Yes ☒ No
If yes, please respond to the following questions:
1. Describe the nature of any compensation to subjects (cash, gifts, research credits, etc.):
2. Provide a dollar amount/research credit amount, if applicable:
3. When and how is the compensation provided to the subject?
4. Describe partial compensation if the subject does not complete the study:
5. If research credit, what is the non-research alternative to research participation?

10. Special Topics

A. Will the study involve minors? ☐ Yes ☒ No
If yes, complete addendum A

B. Will the study involve prisoners? ☐ Yes ☒ No
If yes, complete addendum B

C. Will the study specifically target pregnant women, fetuses, or neonates? ☐ Yes ☒ No
If yes, complete addendum C

D. Will the study involve FDA regulated drugs (other than the use of approved drugs in the course of medical practice)? ☐ Yes ☒ No
If yes, complete addendum D

E. Will the study involve evaluation of the safety or effectiveness of FDA regulated devices? ☐ Yes ☒ No
If yes, complete addendum E

F. Will false or misleading information be presented to subjects (deception)? ☐ Yes ☒ No
If yes, complete addendum F

G. Will participants be audio or videotaped? ☒ Yes ☐ No
If yes, complete addendum G

H. Will the research involve other potentially vulnerable participants (e.g. disabled or addicted individuals, populations engaging in illegal behavior)? ☐ Yes ☒ No
If yes, complete addendum H

I. Will the research be conducted outside of the United States? ☐ Yes ☒ No
If yes, complete addendum I

11. Investigator Certification

I certify that the information provided in this project is correct and that no other procedures will be used in this protocol. I agree to conduct this research as described in the attached supporting documents. I will request and receive approval from the IRB for changes prior to implementing these changes. I will comply with all IRB policies and procedures in the conduct of this research. I will be responsible for ensuring that the work of my co-investigator(s)/student researcher(s) complies with this protocol. I understand that I am ultimately responsible for the entire conduct of this research.

REFERENCES

1. Dorsey ER, Elbaz A, Nichols E, et al. Global, regional, and national burden of Parkinson's disease, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *The Lancet Neurology*. 2018;17(11):939-953. doi:10.1016/S1474-4422(18)30295-3

2. Shulman LM, Gruber-Baldini AL, Anderson KE, et al. The evolution of disability in Parkinson disease: Evolution of Disability in PD. *Mov Disord*. 2008;23(6):790-796. doi:10.1002/mds.21879

3. Carpinella I, Crenna P, Calabrese E, et al. Locomotor Function in the Early Stage of Parkinson's Disease. *IEEE Trans Neural Syst Rehabil Eng*. 2007;15(4):543-551. doi:10.1109/TNSRE.2007.908933

4. Mille ML, Creath RA, Prettyman MG, et al. Posture and Locomotion Coupling: A Target for Rehabilitation Interventions in Persons with Parkinson's Disease. *Parkinson's Disease*. 2012;2012:1-10. doi:10.1155/2012/754186

5. Kang GA, Bronstein JM, Masterman DL, Redelings M, Crum JA, Ritz B. Clinical characteristics in early Parkinson's disease in a central California population-based study. *Mov Disord*. 2005;20(9):1133-1142. doi:10.1002/mds.20513

6. Morris ME. Movement Disorders in People With Parkinson Disease: A Model for Physical Therapy. *Physical Therapy*. 2000;80(6):578-597. doi:10.1093/ptj/80.6.578

7. Hedman LD, Morris DM, Graham CL, et al. Locomotor Requirements for Bipedal Locomotion: A Delphi Survey. *Physical Therapy*. 2014;94(1):52-67. doi:10.2522/ptj.20120514

8. Winter D. Human balance and posture control during standing and walking. *Gait & Posture*. 1995;3(4):193-214. doi:10.1016/0966-6362(96)82849-9

9. Mazzoni P, Shabbott B, Cortes JC. Motor Control Abnormalities in Parkinson's Disease. *Cold Spring Harbor Perspectives in Medicine*. 2012;2(6):a009282-a009282. doi:10.1101/cshperspect.a009282

10. Magrinelli F, Picelli A, Tocco P, et al. Pathophysiology of Motor Dysfunction in Parkinson's Disease as the Rationale for Drug Treatment and Rehabilitation. *Parkinson's Disease*. 2016;2016:1-18. doi:10.1155/2016/9832839

11. Galvan A, Wichmann T. Pathophysiology of Parkinsonism. *Clinical Neurophysiology*. 2008;119(7):1459-1474. doi:10.1016/j.clinph.2008.03.017

12. Muniz AMS, Nadal J, Lyons KE, Pahwa R, Liu W. Long-term evaluation of gait initiation in six Parkinson's disease patients with bilateral subthalamic stimulation. *Gait & Posture*. 2012;35(3):452-457. doi:10.1016/j.gaitpost.2011.11.006

13. Oates AR, Van Ooteghem K, Frank JS, Patla AE, Horak FB. Adaptation of gait termination on a slippery surface in Parkinson's disease. *Gait & Posture*. 2013;37(4):516-520. doi:10.1016/j.gaitpost.2012.09.002

14. Canning CG, Ada L, Johnson JJ, McWhirter S. Walking Capacity in Mild to Moderate Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation*. 2006;87(3):371-375. doi:10.1016/j.apmr.2005.11.021

15. Glaister BC, Bernatz GC, Klute GK, Orendurff MS. Video task analysis of turning during activities of daily living. *Gait & Posture*. 2007;25(2):289-294. doi:10.1016/j.gaitpost.2006.04.003

16. Crenna P, Carpinella I, Rabuffetti M, et al. The association between impaired turning and normal straight walking in Parkinson's disease. Published online 2007:7.

17. Tan D, Danoudis M, McGinley J, Morris ME. Relationships between motor aspects of gait impairments and activity limitations in people with Parkinson's disease: A systematic review. *Parkinsonism & Related Disorders*. 2012;18(2):117-124. doi:10.1016/j.parkreldis.2011.07.014

18. Boonstra TA, Bloem BR. Gait disorders and balance disturbances in Parkinson's disease: clinical update and pathophysiology. :11.

19. Lamont RM, Morris ME, Woollacott MH, Brauer SG. Community Walking in People with Parkinson's Disease. *Parkinson's Disease*. 2012;2012:1-8. doi:10.1155/2012/856237

20. Hof AL, Gazendam MGJ, Sinke WE. The condition for dynamic stability. *Journal of Biomechanics*. 2005;38(1):1-8. doi:10.1016/j.jbiomech.2004.03.025

21. Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? *Age and Ageing*. 2006;35(suppl_2):ii7-ii11. doi:10.1093/ageing/afl077

22. Song J, Paul SS, Caetano MJD, et al. Home-based step training using videogame technology in people with Parkinson's disease: a single-blinded randomised controlled trial. *Clin Rehabil*. 2018;32(3):299-311. doi:10.1177/0269215517721593

23. Van Emmerik REA, Hamill J, McDermott WJ. Variability and Coordinative Function in Human Gait. *Quest*. 2005;57(1):102-123. doi:10.1080/00336297.2005.10491845

24. Huxham F, Baker R, Morris ME, Iansek R. Footstep adjustments used to turn during walking in Parkinson's disease: Online Turning in Parkinson's Disease. *Mov Disord*. 2008;23(6):817-823. doi:10.1002/mds.21932

25. Huxham F, Baker R, Morris ME, Iansek R. Head and trunk rotation during walking turns in Parkinson's disease: Rotation During Turning in Parkinson's Disease. *Mov Disord*. 2008;23(10):1391-1397. doi:10.1002/mds.21943

26. Orendurff MS, Segal AD, Berge JS, Flick KC, Spanier D, Klute GK. The kinematics and kinetics of turning: limb asymmetries associated with walking a circular path. *Gait & Posture*. 2006;23(1):106-111. doi:10.1016/j.gaitpost.2004.12.008

27. Peterson DS, Horak FB. Neural Control of Walking in People with Parkinsonism. *Physiology*. 2016;31(2):95-107. doi:10.1152/physiol.00034.2015

28. Horak FB, Dimitrova D, Nutt JG. Direction-specific postural instability in subjects with Parkinson's disease. *Experimental Neurology*. 2005;193(2):504-521. doi:10.1016/j.expneurol.2004.12.008

29. Cole MH, Naughton GA, Silburn PA. Neuromuscular Impairments Are Associated With Impaired Head and Trunk Stability During Gait in Parkinson Fallers. *Neurorehabil Neural Repair*. 2017;31(1):34-47. doi:10.1177/1545968316656057

30. Deshpande N, Metter EJ, Ferrucci L. Sensorimotor and Psychosocial Correlates of Adaptive Locomotor Performance in Older Adults. *Archives of Physical Medicine and Rehabilitation*. 2011;92(7):1074-1079. doi:10.1016/j.apmr.2011.02.006

31. Visser JE, Voermans NC, Nijhuis LBO, et al. Quantification of trunk rotations during turning and walking in Parkinson's disease. *Clinical Neurophysiology*. 2007;118(7):1602-1606. doi:10.1016/j.clinph.2007.03.010

32. Mellone S, Mancini M, King LA, Horak FB, Chiari L. The quality of turning in Parkinson's disease: a compensatory strategy to prevent postural instability? *J NeuroEngineering Rehabil*. 2016;13(1):39. doi:10.1186/s12984-016-0147-4

33. Stack E, Agarwal V, King R, et al. Identifying balance impairments in people with Parkinson's disease using video and wearable sensors. *Gait & Posture*. 2018;62:321-326. doi:10.1016/j.gaitpost.2018.03.047

34. Simieli L, Gobbi LTB, Orcioli-Silva D, et al. The variability of the steps preceding obstacle avoidance (approach phase) is dependent on the height of the obstacle in people with Parkinson's disease. Grahn JA, ed. *PLoS ONE*. 2017;12(9):e0184134. doi:10.1371/journal.pone.0184134

35. Bertoli M, Croce UD, Cereatti A, Mancini M. Objective measures to investigate turning impairments and freezing of gait in people with Parkinson's disease. *Gait & Posture*. 2019;74:187-193. doi:10.1016/j.gaitpost.2019.09.001

36. Forsell C, Conradsson D, Paquette C, Franzén E. Reducing gait speed affects axial coordination of walking turns. *Gait & Posture*. 2017;54:71-75. doi:10.1016/j.gaitpost.2017.02.020

37. Franzén E, Paquette C, Gurfinkel VS, Cordo PJ, Nutt JG, Horak FB. Reduced performance in balance, walking and turning tasks is associated with increased neck tone in Parkinson's disease. *Experimental Neurology*. 2009;219(2):430-438. doi:10.1016/j.expneurol.2009.06.013

38. Bertoli M, Cereatti A, Della Croce U, Mancini M. An objective assessment to investigate the impact of turning angle on freezing of gait in Parkinson's disease. In: *2017 IEEE Biomedical Circuits and Systems Conference (BioCAS)*. IEEE; 2017:1-4. doi:10.1109/BIOCAS.2017.8325122

39. Song J, Sigward S, Fisher B, Salem GJ. Altered Dynamic Postural Control during Step Turning in Persons with Early-Stage Parkinson's Disease. *Parkinson's Disease*. 2012;2012:1-8. doi:10.1155/2012/386962

40. Conradsson D, Paquette C, Franzén E. Medio-lateral stability during walking turns in older adults. Jan YK, ed. *PLoS ONE*. 2018;13(6):e0198455. doi:10.1371/journal.pone.0198455

41. Stożek J, Rudzińska M, Pustułka-Piwnik U, Szczudlik A. The effect of the rehabilitation program on balance, gait, physical performance and trunk rotation in Parkinson's disease. *Aging Clin Exp Res*. 2016;28(6):1169-1177. doi:10.1007/s40520-015-0506-1

42. Earhart GM. Dynamic control of posture across locomotor tasks: Posture Control Across Locomotor Tasks. *Mov Disord*. 2013;28(11):1501-1508. doi:10.1002/mds.25592

43. Hulbert S, Ashburn A, Roberts L, Verheyden G. Dance for Parkinson's—The effects on whole body co-ordination during turning around. *Complementary Therapies in Medicine*. 2017;32:91-97. doi:10.1016/j.ctim.2017.03.012

44. Tollár J, Nagy F, Kovács N, Hortobágyi T. A High-Intensity Multicomponent Agility Intervention Improves Parkinson Patients' Clinical and Motor Symptoms. *Archives of Physical Medicine and Rehabilitation*. 2018;99(12):2478-2484.e1. doi:10.1016/j.apmr.2018.05.007

45. Rose MH, Løkkegaard A, Sonne-Holm S, Jensen BR. Improved Clinical Status, Quality of Life, and Walking Capacity in Parkinson's Disease After Body Weight-Supported High-Intensity Locomotor Training. *Archives of Physical Medicine and Rehabilitation*. 2013;94(4):687-692. doi:10.1016/j.apmr.2012.11.025

46. Schenkman M, Moore CG, Kohrt WM, et al. Effect of High-Intensity Treadmill Exercise on Motor Symptoms in Patients With De Novo Parkinson Disease: A Phase 2 Randomized Clinical Trial. *JAMA Neurol*. 2018;75(2):219. doi:10.1001/jamaneurol.2017.3517

47. Bello O, Sanchez JA, Lopez-Alonso V, et al. The effects of treadmill or overground walking training program on gait in Parkinson's disease. *Gait & Posture*. 2013;38(4):590-595. doi:10.1016/j.gaitpost.2013.02.005

48. Newell A, Rosenbloom PS. MECHANISMS OF SKILL ACQUISITION AND THE LAW OF PRACTICE. :59.

49. Ranganathan R, Newell KM. Changing Up the Routine: Intervention-Induced Variability in Motor Learning. *Exercise and Sport Sciences Reviews*. 2013;41(1):64-70. doi:10.1097/JES.0b013e318259beb5

50. Gollie JM, Guccione AA. Overground Locomotor Training in Spinal Cord Injury: A Performance-Based Framework. *Topics in Spinal Cord Injury Rehabilitation*. 2017;23(3):226-233. doi:10.1310/sci2303-226

51. King LA, Horak FB. Delaying Mobility Disability in People With Parkinson Disease Using a Sensorimotor Agility Exercise Program. *Physical Therapy*. 2009;89(4):384-393. doi:10.2522/ptj.20080214

52. Justine M, Manaf H, Sulaiman A, Razi S, Alias HA. Sharp Turning and Corner Turning: Comparison of Energy Expenditure, Gait Parameters, and Level of Fatigue among Community-Dwelling Elderly. *BioMed Research International*. 2014;2014:1-6. doi:10.1155/2014/640321

53. Miller Koop M, Ozinga SJ, Rosenfeldt AB, Alberts JL. Quantifying turning behavior and gait in Parkinson's disease using mobile technology. *IBRO Reports*. 2018;5:10-16. doi:10.1016/j.ibror.2018.06.002

54. Stack E, Ashburn A. Early development of the Standing-start 180° Turn Test. *Physiotherapy*. 2005;91(1):6-13. doi:10.1016/j.physio.2004.07.003

55. Falvo MJ, Earhart GM. Six-Minute Walk Distance in Persons With Parkinson Disease: A Hierarchical Regression Model. *Archives of Physical Medicine and Rehabilitation*. 2009;90(6):1004-1008. doi:10.1016/j.apmr.2008.12.018

56. Tollár J, Nagy F, Hortobágyi T. Vastly Different Exercise Programs Similarly Improve Parkinsonian Symptoms: A Randomized Clinical Trial. *Gerontology*. 2019;65(2):120-127. doi:10.1159/000493127

57. Ellis T, Cavanaugh JT, Earhart GM, Ford MP, Foreman KB, Dibble LE. Which measures of physical function and motor impairment best predict quality of life in Parkinson's disease? *Parkinsonism & Related Disorders*. 2011;17(9):693-697. doi:10.1016/j.parkreldis.2011.07.004

58. Cole MH, Sweeney M, Conway ZJ, Blackmore T, Silburn PA. Imposed Faster and Slower Walking Speeds Influence Gait Stability Differently in Parkinson Fallers. *Archives of Physical Medicine and Rehabilitation*. 2017;98(4):639-648. doi:10.1016/j.apmr.2016.11.008

59. Senden R, Savelberg HHCM, Grimm B, Heyligers IC, Meijer K. Accelerometry-based gait analysis, an additional objective approach to screen subjects at risk for falling. *Gait & Posture*. 2012;36(2):296-300. doi:10.1016/j.gaitpost.2012.03.015

60. Kubo M, Holt KG, Saltzman E, Wagenaar RC. Changes in axial stiffness of the trunk as a function of walking speed. *Journal of Biomechanics*. 2006;39(4):750-757. doi:10.1016/j.jbiomech.2004.12.024

61. Spildooren J, Vercruysse S, Heremans E, et al. Head-pelvis coupling is increased during turning in patients with Parkinson's disease and freezing of gait: Head-Pelvis Dissociation When Turning in Freezers. *Mov Disord*. 2013;28(5):619-625. doi:10.1002/mds.25285

62. Retory Y, David P, Niedzialkowski P, de Picciotto C, Bonay M, Petitjean M. Gait Monitoring and Walk Distance Estimation With an Accelerometer During 6-Minute Walk Test. *Respir Care*. 2019;64(8):923-930. doi:10.4187/respcare.06144

63. Rampp A, Barth J, Schuelein S, Gassmann KG, Klucken J, Eskofier BM. Inertial Sensor-Based Stride Parameter Calculation From Gait Sequences in Geriatric

Patients. *IEEE Trans Biomed Eng*. 2015;62(4):1089-1097. doi:10.1109/TBME.2014.2368211

64. Sabatini A, Mannini A. Ambulatory Assessment of Instantaneous Velocity during Walking Using Inertial Sensor Measurements. *Sensors*. 2016;16(12):2206. doi:10.3390/s16122206

65. Salarian A, Zampieri C, Horak FB, Carlson-Kuhta P, Nutt JG, Aminian K. Analyzing 180° turns using an inertial system reveals early signs of progression of parkinson's disease. In: *2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. IEEE; 2009:224-227. doi:10.1109/IEMBS.2009.5333970

66. Swanson CW, Fling BW. Associations between Turning Characteristics and Corticospinal Inhibition in Young and Older Adults. *Neuroscience*. 2020;425:59-67. doi:10.1016/j.neuroscience.2019.10.051

67. Park H, Youm C, Lee M, Noh B, Cheon SM. Turning Characteristics of the More-Affected Side in Parkinson's Disease Patients with Freezing of Gait. *Sensors*. 2020;20(11):3098. doi:10.3390/s20113098

68. Conradsson D, Paquette C, Lökk J, Franzén E. Pre- and unplanned walking turns in Parkinson's disease – Effects of dopaminergic medication. *Neuroscience*. 2017;341:18-26. doi:10.1016/j.neuroscience.2016.11.016

69. Chou PY, Lee SC. Turning deficits in people with Parkinson's disease. *Tzu Chi Medical Journal*. 2013;25(4):200-202. doi:10.1016/j.tcmj.2013.06.003

70. Adusumilli G, Lancia S, Levasseur VA, et al. Turning is an important marker of balance confidence and walking limitation in persons with multiple sclerosis. Bayer A, ed. *PLoS ONE*. 2018;13(6):e0198178. doi:10.1371/journal.pone.0198178

71. Patla AE, Adkin A, Ballard T. Online steering: coordination and control of body center of mass, head and body reorientation. *Experimental Brain Research*. 1999;129(4):0629-0634. doi:10.1007/s002210050932

72. Simonsen EB. Contributions to the understanding of gait control. :23.

73. Huxham F, Gong J, Baker R, Morris M, Iansek R. Defining spatial parameters for non-linear walking. *Gait & Posture*. 2006;23(2):159-163. doi:10.1016/j.gaitpost.2005.01.001

74. Gavriliuc O, Paschen S, Andrusca A, Berg D, Schlenstedt C, Deuschl G. Spin turns in advanced Parkinson's disease: A new clinical gait sign? *Parkinsonism & Related Disorders*. 2019;69:19-22. doi:10.1016/j.parkreldis.2019.10.011

75. Yang WC, Hsu WL, Wu RM, Lin KH. Immediate Effects of Clock-Turn Strategy on the Pattern and Performance of Narrow Turning in Persons With Parkinson Disease: *Journal of Neurologic Physical Therapy*. 2016;40(4):249-256. doi:10.1097/NPT.0000000000000148

76. Yang W, Hamilton JL, Kopil C, et al. Current and projected future economic burden of Parkinson's disease in the U.S. *npj Parkinsons Dis*. 2020;6(1):15. doi:10.1038/s41531-020-0117-1

77. Shulman LM, Gruber-Baldini AL, Anderson KE, et al. The evolution of disability in Parkinson disease. *Movement Disorders*. 2008;23(6):7.

78. Bengevoord A, Vervoort G, Spildooren J, et al. Center of mass trajectories during turning in patients with Parkinson's disease with and without freezing of gait. *Gait & Posture*. 2016;43:54-59. doi:10.1016/j.gaitpost.2015.10.021

79. Meyer G, Ayalon M. Biomechanical aspects of dynamic stability. *Eur Rev AgingPhys Act*. 2006;3(1):29-33. doi:10.1007/s11556-006-0006-6

80. Morgan DL, Morgan RK. Single-participant research design: Bringing science to managed care. *American Psychologist*. 2001;56(2):119-127. doi:10.1037/0003-066X.56.2.119

81. Scalzo PL, Flores CR, Marques JR, Robini SC de O, Teixeira AL. Impact of changes in balance and walking capacity on the quality of life in patients with Parkinson's disease. *Arquivos de Neuro-Psiquiatria*. 2012;70(2):119-124. doi:10.1590/S0004-282X2012000200009

82. Stack E, Ashburn A. Early development of the Standing-start 180° Turn Test. *Physiotherapy*. 2005;91(1):6-13. doi:10.1016/j.physio.2004.07.003

83. Schlachetzki JCM, Barth J, Marxreiter F, et al. Wearable sensors objectively measure gait parameters in Parkinson's disease. Toft M, ed. *PLoS ONE*. 2017;12(10):e0183989. doi:10.1371/journal.pone.0183989

84. El-Gohary M, Pearson S, McNames J, et al. Continuous Monitoring of Turning in Patients with Movement Disability. *Sensors*. 2013;14(1):356-369. doi:10.3390/s140100356

85. Dobkin BH. Wearable motion sensors to continuously measure real-world physical activities: *Current Opinion in Neurology*. 2013;26(6):602-608. doi:10.1097/WCO.0000000000000026

86. Conradsson D, Löfgren N, Nero H, et al. The Effects of Highly Challenging Balance Training in Elderly With Parkinson's Disease: A Randomized Controlled

Trial. *Neurorehabil Neural Repair*. 2015;29(9):827-836. doi:10.1177/1545968314567150

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