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The Examination of Dual-Tasking, Dynamic Balance, and Muscle Activity Before and After Adapted Tango in Parkinson's Disease

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Abstract

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PD postural instability results in lost static and dynamic balance. Dynamic balance involves maintaining/recovering balance in response to perturbation. Dual-tasking (simultaneous performance of two distinct tasks: one cognitive, one motor) is difficult for PD patients given increased cognitive demand. During mobility and balance tasks, abnormal muscle antagonist activity has been observed in PD. Adapted Tango (AT) improves clinical measures of PD symptoms, including static balance. Little is known about effects of dance on dual-tasking and dynamic balance. Further, neurophysiological changes underlying these improvements are yet to be determined. Our study aims to 1) examine how AT impacts dual-tasking and dynamic balance, 2) determine whether completion of AT program is associated with decreased leg muscle antagonist activity, and if this change correlates with clinical measures of balance, and 3) examine case studies for patient improvement, maintenance or regression trajectories. We recruited patients with mild-moderate PD and assigned them to AT or control. Dual-tasking (using the Serial 7 walking test) and Dynamic Gait Index (DGI) were evaluated pre-, post-, and 4 weeks postintervention. Differences were evaluated using ANOVA and t-tests. Muscle activity modulation (ability to activate and inhibit muscles appropriately according to perturbation direction) was quantified using modulation indices (MI) derived from minimum and maximum EMG activation levels observed across perturbation directions). At baseline, there was a difference between the AT and Control group dual-task cost for correct number of subtractions ($p = 0.003$), so no between groups comparison was done on this variable at posttest. At posttest, Control had a lower ($p = 0.04$) dual-task cost for speed. Within group, at posttest, control gave fewer correct subtractions ($p < 0.0001$), had a lower rate of correct answers/second given while walking ($p = 0.0322$), and had greater dual-task cost for serial 7s calculations ($p=0.0135$); AT had a lower percent of correct subtractions ($p = 0.0391$). DGI performance improved after intervention. MI did not change significantly postintervention. The case series highlights impact of clinical characteristics on participant responses. AT may improve dynamic balance performance, but more research is needed into its effect on dual-tasking and MI.

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1. Introduction

1.1 Epidemiology of Parkinson's disease

Parkinson's disease (PD), first described in 1817 by James Parkinson (Parkinson 2002), is now the second most common neurodegenerative disease (Nussbaum and Ellis 203). A neurodegenerative disease occurs from the degeneration or death of nerve cells in the body. In the United States alone, there will be an estimated 1,238,000 individuals aged ≥45 years with PD by 2030 (Marras, et al. 2018). PD is characterized by loss of neurons in the substantia nigra, leading to a deficiency in the striatal dopamine, and α-synuclein aggregates in intracellular inclusions (Poewe, et al. 2017). PD is associated with four main motor clinical characteristics: bradykinesia (slowed movement), rest tremor, muscle rigidity, and postural instability (Shukla, et al. 2019). These cardinal symptoms do not occur until 50-60% of nigral neurons and 80-85% of striatum dopamine are gone (Marsden 1996, Wirdefeldt, et al. 2011). Non-motor symptoms, including autonomic dysfunction, sleep disorders, mood disorders, cognitive abnormalities, and pain and sensory disorders, are also recognized and often precede motor symptoms (Lee and Gilbert 2016).

1.2 Parkinson's disease affects balance adversely

While PD treatments (including pharmacotherapy and surgical interventions) successfully mitigate some motor signs (i.e. reduction of tremor and rigidity, restoration of more normal muscle activity patterns) or assist with mobility, balance remains an important, and difficult, domain to treat successfully. Postural instability worsens with PD progression; it is difficult to properly reduce postural disturbances in advanced PD (Bloem, et al. 2001, Debû, et al. 2018, Melton, et al. 2006, Schoneburg, et al. 2013). Untreated postural instability may result in higher frequency of falls and injuries, which can increase the likelihood of developing comorbidity and disability. Postural instability is also associated with sudden falls, loss of equilibrium, and a progressive loss of mobility and independence.

Previous systematic studies have shown that exercises and physiotherapy treatments may be beneficial to manage postural instability for patients with idiopathic PD (Yitayeh and Teshome 2016). Physical therapy targeting balance and gait have shown efficacy in improving clinical measures of gait and balance. These interventions include occupational therapy, treadmill training, stretching, muscle strengthening, balance, postural exercises, and cueing. Physical therapy trials for patients with PD have shown improvements consistently in measures of gait, such as step length and cadence. Dance therapy, martial arts, and other non-conventional interventions have been shown to significantly improve postural control and decrease falls. However, these interventions are heterogeneous, with no expert consensus about which is the most effective approach or how to compare the efficacies of the variety of interventions. A greater understanding of the mechanisms of improvement is needed to improve prescription and dosing of the interventions (in the clinical realm) and further development of the interventions (in the research realm) (Abbruzzese, et al. 2016, Allen, et al. 2011, Radder, et al. 2020, Speelman, et al. 2011).

1.3 Dynamic vs. Static balance

Postural instability results in a progressive loss of both static and dynamic balance, which can impact a person’s ability to sit down or stand without support (Lopes, et al. 2016). Static balance refers to one’s ability to maintain their base of support with minimal to no movement. Dynamic balance refers to one’s ability to maintain a stable position while one performs a task (Bressel, et al. 2007) or is walking. In fact, while walking, one is constantly losing and regaining balance from step to step and is therefore a great example of dynamic balance. Dynamic balance involves maintaining or recovering balance in response to disturbances, both internal and external. These disturbances may be voluntary and involve segments of the body or whole-body movements during quiet stance or movement. These disturbances also may be instabilities as a result of support surface or upper body perturbations (Steffen and Stein 2018). Measures of static balance commonly used in rehabilitation for older populations include the Berg Balance Scale and the Fullerton Advanced Balance scale, which include items involving mostly static balance, e.g., standing on one leg, in tandem stance, or in transfers between chairs. Measures of dynamic balance include the dynamic gait index (DGI), which measures how an individual modifies their gait based on the environmental context (Mehta, at al. 2019). This includes walking while turning the head to look sharply left and then right, walking and pivoting quickly, walking and stepping over an obstacle, etc. Many previous studies largely showed how physical interventions improve only static balance measures in PD patients. For example, a study using an 8-week Pilates program showed that the program significantly improved functional balance by using the Fullerton Advanced Balance Scale (Bakhshayesh, et al. 2017). Previous Hackney tango studies have often used the Berg Balance Scale, which once again is a measure of static balance. For instance, when 39 participants with mild to moderate PD were assigned randomly to either partnered or nonpartnered tango, both groups significantly improved on the Berg Balance Scale (Hackney and Earhart 2010). Incorporating measures of dynamic balance, such as the Dynamic Gait Index, to evaluate improvement is important, especially given dynamic balance's role in mobility, in daily activities like routines and chores, in locomotion, in physical fitness, and in quality of life (Marandi, et al. 2013).

1.4 Dual-Tasking

Dual-tasking refers to the simultaneous performance of two distinct tasks that both demand attention and have different goals. One task is the primary task whereas the other task is referred to as the secondary task. Dual-tasking tends to have a negative impact on task performance, which is known as the dual-task cost (Nonnekes, at al. 2020).

In patients with PD, especially the postural instability and gait disorders phenotype (PIDG), gait and balance are two key issues. Dual-task conditions, such as turning, are difficult because PD-PIGD patients already have executive-attention deficits, and tasks requiring increased cognitive engagement may lead to overload of their cognitive-motor systems (Sarasso, et al. 2021). The basal ganglia is a place of integration of separate and parallel motor and cognitive limbic loops. However, because PD patients are deficient in dopamine in the basal ganglia loops, they often exhibit disturbed integration of motor and cognitive information. Previous studies have shown that, when compared to age-matched controls, PD patients demonstrated impaired gait performance under single task conditions, but especially under dual-task conditions (Wollesen, et al. 2021).

Dual-task interference tends to deteriorate postural stability in early stage PD. Huang et al. used electroencephalography (EEG) functional connectivity to measure the effect of task prioritization on posture-motor dual-tasks in patients with Early-Stage PD. Dual-task interference can be mitigated through appropriate resource allocation. They found a compensatory use of cortical resources in high-function early stage PD patients whereas controls shared resources with subcortical structures (Huang, et al. 2022). The resource allocation finding is in line with the work by Nonnekes at al. that suggested competition for attentional resources are due to a lowered state of task preparation that result in the dual-task costs (Nonnekes, at al. 2020).

Dual-task training has also been found to have a greater effect on PD patients compared to single task training without cognitive demand. When comparing PD patients that underwent dual-task training physiotherapy rehabilitation with PD patients that underwent single task training physiotherapy rehabilitation, the dual-task group improved in velocity and stride length under all conditions and assessments after training (Valenzuela, et al. 2020).

The literature has been lacking in terms of the effects of dance on dual-tasking. The systematic review by Haputhanthirige et al. is one of the first to address this gap and synthesize literature on how dance impacts dual-tasking. Their review found that cognitive dual-tasking, which was measured using dual-task Timed Up and Go (TUG) test, improved in dance groups composed of people with PD compared to controls. (Haputhanthirige, et al. 2019).

AT can be considered a form of dual-task training; it involves listening to music, dancing with a partner, paying attention to the trajectory one is going in, etc. AT has an inherent multitask nature: participants must focus on their partner, the music, the dancers around them, current and future step patterns, all while making decisions the entire time, and also requires working memory and control of attention (Hackney, et al. 2012, Romenets, et al. 2015). Therefore, it focuses on motor-cognitive integration. Our study hopes to further contribute to determine the effects of dance, specifically tango, on dual-tasking in patients with PD.

1.5 Abnormal antagonist muscle activity

As mentioned earlier, rehabilitation can result in significant clinical outcomes, specifically regarding gait and balance (Abbruzzese, et al. 2016). Most studies investigating improved gait and balance performance use clinical assessments of that performance and do not measure the potential neurophysiological changes accompanying those improvements. However, improved understanding of the mechanisms would facilitate intervention development and prescription. By understanding the impairments mediated by various interventions, these treatments can be more accurately targeted to individuals' needs and tracked to determine when an individual has attained the maximum or minimum benefit. Conversely, understanding the motor control impairments associated with illness and injury (i.e., stroke, PD) can predict differences in the functional challenges faced by individuals. Studying the neurophysiological mechanisms will help us understand how movements are generated in a healthy nervous system and in individuals with motor deficits, which can also improve clinical outcomes and guide rehabilitation development (Ting, et al. 2015).

One of these physiological mechanisms that should be further examined is abnormal antagonistic muscle activity of the lower limb, in people with PD. Antagonist muscle activity (also known as co-contraction or coactivation) refers to the simultaneous activation of the agonist and antagonist muscle groups during contractions. During maximal contractions, antagonist muscle activity can reduce test accuracy by producing a movement that opposes the moment of interest (Krishnan and Williams 2009). The moment of interest, also known as the moment of inertia, is the property of a body to resist a change in its rotational direction, such as from turning. Therefore, opposing the moment of interest would decrease the ability to maintain balance. In adults without PD, co-contraction of muscles is related to behavioral functional changes, such as increased risk of falls, increased sway, decreased functional stability boundaries, and decreased functional reach distance (Lang, et al. 2019). During changes in perturbation direction, when compared to healthy individuals, many PD patients are unable to suppress irrelevant leg muscle activity (Chong, et al. 1999). For instance, during the first trial of surface translations while sitting backwards, PD patients suppressed soleus muscle activity to a lesser extent compared to controls. PD patients were only able to lower leg muscle activity after more trials that allowed for repeated exposure to the same task (Chong, et al. 2000).

Previous studies reported earlier, longer, and larger antagonist muscle activation during reactive balance responses to support surface perturbations compared to controls (Carpenter, et al. 2004, Dimitrova, et al. 2004, Horak, et al. 1996, Lang, et al. 2019, St George, et al. 2012). This increased antagonist activity results in increased co-contraction of muscles during the reactive balance response, impairing balance response effectiveness in restoring balance.

1.6 Rehabilitation and Adapted Tango

Previous studies have shown that exercise rehabilitation is effective for improving balance and gait in patients with PD (Giardini, et al. 2018). Interventions include strength training, treadmill walking, step training, boxing, dancing, tai chi, among others and their effects on PD symptom severity reduction, muscle strength, balance, gait, and even cognition have been investigated (Allen, et al. 2011, Hackney and Earhart 2010, Hackney and Earhart 2009, Hirsch, et al. 2003, Keus, et al. 2009, McKee and Hackney 2013, Shen, et al. 2016). Of those targeting balance, typically clinical measures of balance are used, in which participants' performance of a series of tasks is rated, scored and summed. Overall, exercise training can improve gait and balance and reduce falls in individuals with PD (Shen, et al. 2016).

Dance, in particular, can be a great way to improve PD motor impairments. Some research has even shown that dance is better than exercise to improve balance and functional mobility in some patients with PD (Shanahan, et al. 2015). Dance is an effective rehabilitation program for PD patients because it involves both adapting to one's environment and dynamic balance. Dance can also address the high attrition rates of traditional exercise interventions as it is considered to be more engaging and exciting. Balance and functional mobility were found to improve in older adults who danced (Hackney and Earhart 2010).

Adapted Tango (AT) interventions improve clinical measures of PD symptoms, including balance. Tango movements may address balance difficulties because it involves rhythmic variation, initiation and cessation of movement, different speeds, and spontaneous multidirectional perturbations (Hackney and Earhart 2010). Unlike Argentine Tango seen in theatrical performances, AT does not involve difficult and complex movements, but focuses on participants being able to move rhythmically to the music to simple step combinations. Also, compared to Waltz, Foxtrot, and other partnered dances, AT has more rhythmic variation and may be more effective at improving PD symptoms (Hackney and Earhard 2010, Lötzke, et al. 2015). However, the mechanisms of balance improvement remain unclear (and whether they constitute repair or compensation is yet to be determined). Several studies have found AT yielded improvements in balance as quantified by the Berg Balance Scale (Hackney and Earhart 2010, Hackney and Earhart 2009, Hackney and Earhart 2009, Hackney, et al. 2007), Fullerton Advance Balance Scale (McKee and Hackney 2013), and miniBESTest (Duncan and Earhart 2014, Duncan and Earhart 2012, McNeely, et al. 2015). The physiologic changes underlying these functional improvements are unknown but are key to being able to prescribe the appropriate intervention and dose to individuals, thereby improving outcomes.

Our main areas of exploration include goals to: (1) Examine how AT impacted dual-tasking performance and dynamic balance, (2) Whether completion of an AT program is associated with a decrease in leg muscle antagonist activity, and is this change correlated with clinical measures of balance, and (3) examine case studies for their specific trajectories (reasons for improvement or lack of improvement) on dual-tasking and dynamic balance. We hypothesized that if AT is related to improved dynamic balance and dual-tasking, then we would see decreased leg muscle antagonist activity. We predicted that AT will improve behavioral measures of mobility and will alter associated neurophysiological underpinnings.

2. Methods

2.1 Participants

For this study, individuals with idiopathic PD were recruited in the metro Atlanta area through PD exercise classes, outreach events, and support groups from December 2013 to June 2015. Thirty-three individuals were enrolled. Twenty of these individuals were randomized to either the AT or Control arm, while the remaining participants were assigned directly to the non-contact Control arm after randomization to AT was closed. The need to have all AT participants enrolled and assessed prior to taking the AT class together necessitated this randomization approach.

Inclusion criteria were: diagnosis of definite PD, age ≥ 35, vision corrected if necessary, ability to walk ≥ 10 feet with or without an assistive device, normal perception of vibration and light touch on feet, no dance class participation within the previous 6 months, and demonstrated response to levodopa.

Exclusion criteria were: significant musculoskeletal, cognitive, or neurological impairments other than PD as determined by the investigators.

After enrollment, Figure 1 illustrates the reasons participants were excluded from analysis or lost to follow-up.

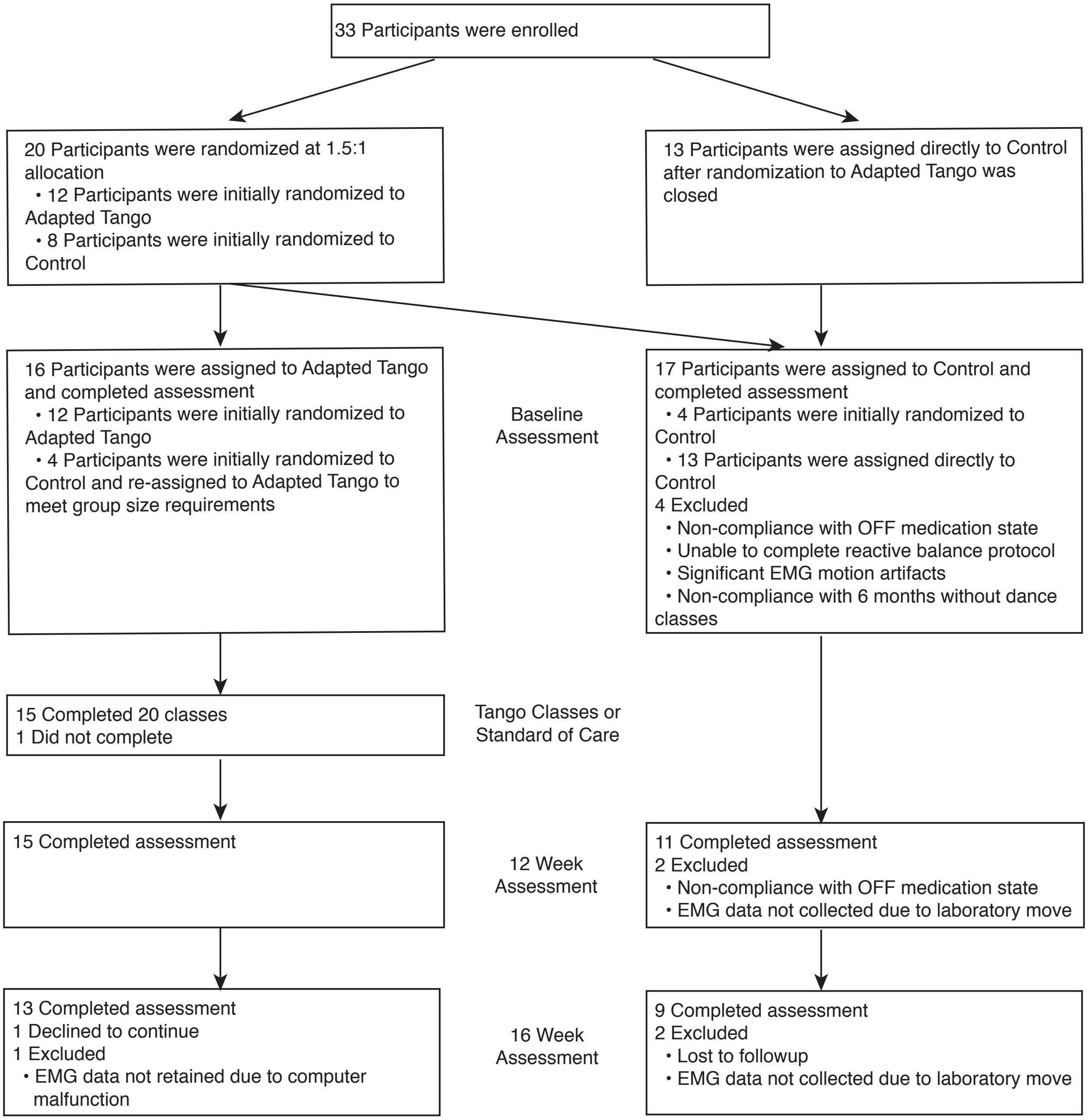

Figure 1. Consort Diagram showing progression through the trial. Twenty-two of 33 enrolled participants completed all study visits.

2.2 Adapted tango intervention

Adapted tango refers to an Argentine tango dance program adapted for PD motor impairments. Participants completed twenty, 90-minute moderate-intensity AT classes in 10-12 weeks. Classes were taught by a trained professional partnered dance instructor. Participants with PD danced with individuals without PD, holding forearms in the adapted ballroom frame, and spent equal time leading and following. In each class, participants completed standing warm-ups to upbeat music, followed by dancing to music. The skills the intervention targeted included rhythmic entrainment to the beat (i.e., tapping toes or heels or opening and closing hands), walking to various tango rhythms (more complex than typical gait), learning new steps, and completing sequences of steps to the beat. Difficulty of the classes progressed over time, and the participants could take breaks as needed, as in previous studies (Hackney and Earhart 2010, Hackney and Earhart 2009, Hackney, et al. 2007, McKee and Hackney 2013).

2.3 Measuring outcomes

At each of the three assessments, participants were observed in the 12-hour OFF medication state. The participants completed a 3-4 hour standardized protocol featuring clinical information collection and clinical and reactive balance assessment. At the baseline visit, informed consent, demographic information, and information related to inclusion/exclusion criteria that could not be assessed by phone were also obtained.

The following clinical measures were collected: Unified Parkinson's Disease Rating Scale III (UPDRS-III, by a Movement Disorders Society-certified rater (MEH) either in-person or on video); PD phenotype (tremor dominant, TD; indeterminate, ID; postural instability and gait difficulty, PIGD; calculated using standard formulae) (Stebbins, et al. 2013); Fullerton Advanced Balance Scale (FAB); Berg Balance Scale (BBS); Dynamic Gait Index (DGI); Freezing of Gait Questionnaire B (FOGQ-B); Serial 7s while walking.

2.4 Dual-tasking assessment and data

To quantify dual-task performance, we used the Serial 7 walking test. This test involved the participant walking from one side of the laboratory to the other as they would normally but counting backwards by 7 from a number the researcher tells the participant. This test measures dual-tasking as it utilizes both walking and counting. The participants' time (in seconds) and steps taken were recorded for both comfortable walking and the Serial 7 walking at both baseline and posttest. From these measures, we calculated the participants' average speed (m/s) and cadence (steps/min). The participants' number of correct and incorrect subtractions were recorded for both standing practice and the Serial 7 walking at both baseline and posttest. From these measures, we calculated the participants' correct subtractions per second and percent of correct subtractions given. For the mobility data, the comfortable walking was the control and the Serial 7 was the dual-task activity. For the cognitive data, the standing practice was the control and the Serial 7 was the dual-task activity. We calculated dual-task cost for both mobility and cognition. We calculated the average dual-task cost for speed and cadence for mobility, and the average dual-task cost for the number of correct subtractions for cognition,

To calculate the dual-task cost of each participant, we used the formula [(dual-task performance – single task performance)/singe task performance] x 100 (Manor, et al. 2016). For each measure, all the trials were averaged for a single participant and used to calculate the dual-task cost for each individual participant. The values for each measure and dual-task cost for each individual participant were then averaged to find a group average for both the control group and AT group.

2.5 Reactive balance assessment

Participants experienced support-surface translations generated by a custom platform that generated ramp-and-hold perturbations (7.5 cm peak displacement, 15 cm/s peak velocity, 0.1 g peak acceleration) (McKay, et al. 2016) (Lang, et al. 2019). Participants stood on the platform with arms crossed and feet parallel to each other (28 cm between medial aspects). They were instructed to gaze at a landscape photograph on the wall in front of them and to keep their balance with feet in place if possible. To reduce startle or "first-trial" effects, 3 forward perturbations preceded the set of multidirectional perturbations. This set featured 36 perturbations in 12 randomized horizontal directions. If possible, trials with a stepping response were repeated at the end of the block.

2.6 EMG collection and processing

As previously reported (Lang, et al. 2019), surface EMG activity was collected during reactive balance from 11 leg muscles: bilateral *soleus* (left, SOL-L; right, SOL-R), *medial gastrocnemius* (MGAS-L, MGAS-R), *tibialis anterior* (TA-L, TA-R), *biceps femoris long head* (BFLH-L, BFLH-R), *rectus femoris* (RFEM-L, RFEM-R) and right *vastus medialis* (VMED-R). EMG data were collected from silver/silver chloride disc electrodes placed 2 cm apart at the motor point (Basmajian and Blumenstein 1980) with telemetered EMG (Konigsburg, Pasadena, CA) at 1080 Hz. Vicon motion capture equipment (Oxford Metrics, Denver, CO) synchronized EMG data to kinematic data (120 Hz). EMG data were processed offline (high-pass filter, 35 Hz, de-mean, rectify, low-pass filter, 40 Hz) (McKay, et al. 2016) (Lang et al, under review).

Visual inspection identified trials with significant EMG motion artifacts and custom Matlab code (Mathworks, Natick, MA) identified trials in which vertical force dropped below 10 N, indicating a step. After excluding these trails from analysis, there were 0 to 5 trials per perturbation direction per participant, with an average of 3.0 ± 0.3.

2.7 Muscle activity modulation index (MI)

To examine muscle activity modulation, we calculated a muscle modulation index describing the ability to activate and inhibit each muscle appropriately according to perturbation direction (Lang, et al. 2019). In the multidirectional perturbation protocol used here, each muscle exhibits a continuum of activity from agonist to antagonist as a function of perturbation direction. To quantify this modulation, we calculated mean EMG levels during three time bins within each trial that encompassed the medium-(APRX) and long-latency (APRY) automatic postural response: 70-450 ms (APRX) and 175-250 (APRY) after perturbation onset (Dimitrova, et al. 2004), and subsequently assembled mean APRX and APRY EMG levels into tuning curves that described muscle activity as a function of perturbation direction (Figure 2). Then, we used the maximum and minimum values of each tuning curve for each muscle for each participant to compute the modulation index (MI) using the following equation (Figure 2):

$$MI = 100 \cdot \frac{\max\left(\overline{EMG}(\theta)\right) - \min\left(\overline{EMG}(\theta)\right)}{\max\left(\overline{EMG}(\theta)\right)} \tag{1}$$

where $\overline{EMG}(\theta)$ indicates the vector of 12 mean EMG values for the 12 perturbation directions.

2.8 Statistical analysis

Baseline differences between the AT and Control groups in demographic and clinical variables were assessed with chi-square tests, Fisher's Exact tests, and independent samples *t*-tests as appropriate.

To test whether the effect of time on muscle modulation was modified by participation in AT, we fit the following linear mixed model:

$$\begin{aligned} MI_{ijk} = &\beta_0 + \beta_{Group} \cdot Group \\ &+ \beta_{Time} \cdot TimePoint \\ &+ \beta_{Group \cdot Time} \cdot Group \cdot TimePoint \\ &+ \sum_{i=1}^{N_m - 1} \beta_{1i} \cdot Muscle_i \\ &+ \sum_{j=1}^{N_p - 1} \beta_{2j} \cdot Participant_j \\ &+ \epsilon_{ijk} \end{aligned} \tag{1}$$

and evaluated the following null hypothesis with an *F* test:

$$H_{02} : \beta_{Group \cdot Age} = 0$$

In Equation 1, β_{Group} is the beta coefficient for the fixed effect of Group (the indicator variable *Group* is 1 for the AT group and 0 for the SoC group), $\beta_{TimePoint}$ is the beta coefficient for the fixed effect of TimePoint (0, 12, or 16, with 0 as the reference group), $\beta_{Group*Time}$ is the beta coefficient for the interaction between study group and time point, β_{1i} is the beta coefficient for the fixed effect of muscle *i* (with TA as the reference group) and β_{2j} is the beta coefficient for the random effect of participant *j*. This approach was repeated to assess the effect of time on clinical outcome measures, with FAB, BBS, or DGI replacing MI as the outcome variable.

2.9 De Novo Statistical analysis

The analyses mentioned in the previous section were previously performed by Dr. Kimberly Lang. This section details analyses performed De Novo (for the first time for the purpose of this thesis).

Statistical tests were performed on the following averaged outcome measures: comfortable walking speed, dual-tasking walking speed, comfortable cadence, dual-tasking cadence, standing practice number of correct subtractions, dual-tasking number of correct subtractions, standing practice number of errors, dual-tasking number of errors, standing practice number of correct subtractions per second, dual-tasking number of correct subtractions per second, standing practice percent of correct subtractions, dual-tasking percent of correct subtractions, dual-cost task for speed, dual-task cost for cadence, and dual-task cost for number of correct subtractions.

Independent T-tests were performed between groups on baseline outcomes to determine if there were any differences prior to intervention. Independent T-tests were performed between groups on posttest outcomes to determine if there were any differences following the intervention. These tests were only performed on measures that had no baseline differences.

3.0 Case Studies Selection and Analysis

We selected 4 individuals from the AT group based on their specific results. We chose (1) a participant that improved in both DGI and mobility and cognitive dual-tasking, (2) improved in DGI and got worse in mobility and cognitive dual-tasking, (3) got worse in both DGI and mobility and cognitive dual-tasking, and (4) improved in DGI and cognitive dual-tasking but got worse in mobility dual-tasking. Mobility dual-tasking was measured by dual-task cost for speed during the Serial 7 assessment and cognitive dual-tasking was measured by dual-task cost for correct subtractions given during the Serial 7 assessment. We did not examine cases from the control group because the objective was to examine the relationship between balance ability and dual-tasking and AT outcomes.

3. Results

3.1 Participant demographics

The AT group and the control group appeared to have similar clinical and demographic characteristics. On average, the participants are about 68 years old and experienced about 12 falls within the last 6 months. Sex prevalence was matched. The participants had PD ranging from 6-10 years, with the control group having longer PD duration. Only the first 20 participants were randomized so it was important to check if there were systematic differences between groups. The participants had normal cognition according to the Montreal Cognitive Assessment test score and the Physical Activity Scale for the Elderly indicated that they were getting some physical activity. The Unified PD Rating Scale III scores indicated they had mild to moderate PD. The Hoehn and Yahr scale (hy) scores indicated most participants had mild PD with no postural instability but 1/3 had moderate PD and needed assistive devices (Table 1).

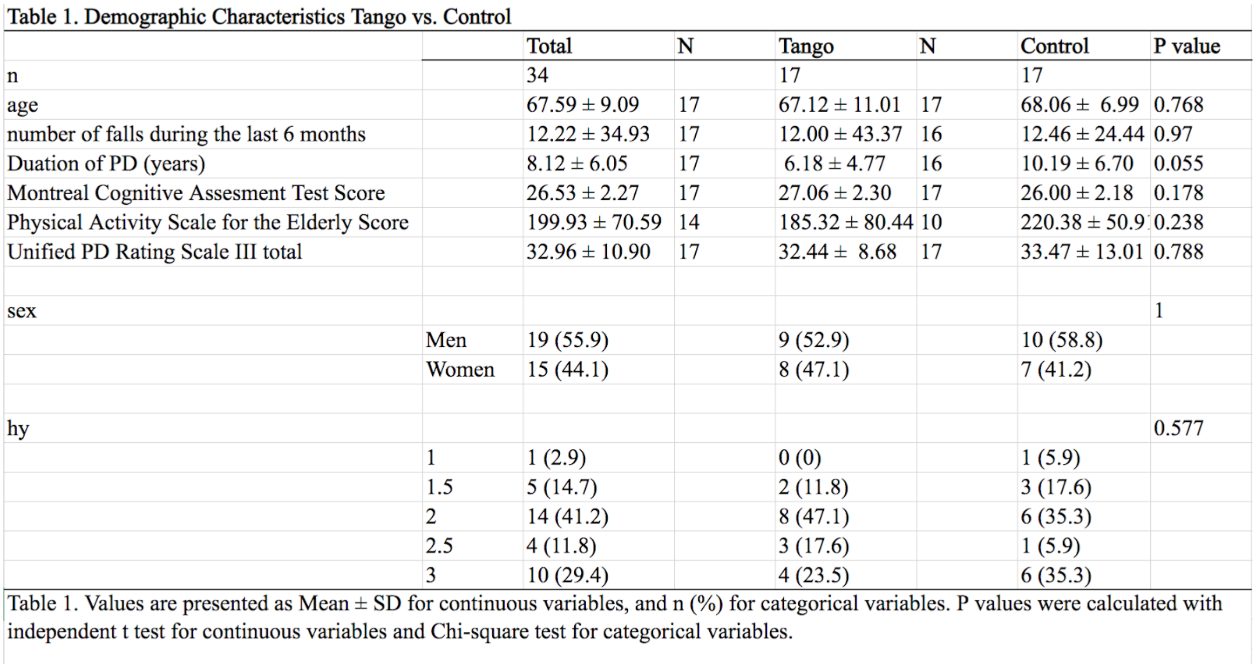

Table 1. Demographic Characteristics Tango vs. Control

		Total	N	Tango	N	Control	P value
n		34		17		17	
age		67.59 ± 9.09	17	67.12 ± 11.01	17	68.06 ± 6.99	0.768
number of falls during the last 6 months		12.22 ± 34.93	17	12.00 ± 43.37	16	12.46 ± 24.44	0.97
Duation of PD (years)		8.12 ± 6.05	17	6.18 ± 4.77	16	10.19 ± 6.70	0.055
Montreal Cognitive Assesment Test Score		26.53 ± 2.27	17	27.06 ± 2.30	17	26.00 ± 2.18	0.178
Physical Activity Scale for the Elderly Score		199.93 ± 70.59	14	185.32 ± 80.44	10	220.38 ± 50.9	0.238
Unified PD Rating Scale III total		32.96 ± 10.90	17	32.44 ± 8.68	17	33.47 ± 13.01	0.788
sex							1
	Men	19 (55.9)		9 (52.9)		10 (58.8)	
	Women	15 (44.1)		8 (47.1)		7 (41.2)	
hy							0.577
	1	1 (2.9)		0 (0)		1 (5.9)	
	1.5	5 (14.7)		2 (11.8)		3 (17.6)	
	2	14 (41.2)		8 (47.1)		6 (35.3)	
	2.5	4 (11.8)		3 (17.6)		1 (5.9)	
	3	10 (29.4)		4 (23.5)		6 (35.3)	

Table 1. Values are presented as Mean ± SD for continuous variables, and n (%) for categorical variables. P values were calculated with independent t test for continuous variables and Chi-square test for categorical variables.

3.2 *Effect of Adapted Tango on dual-tasking measures*

We studied the distributions to determine if we need to remove any outliers. After examining the data and further looking into individual participant conditions, we determined no significant outliers to remove. Sample distribution plots are shown below (Figures 2 & 3).

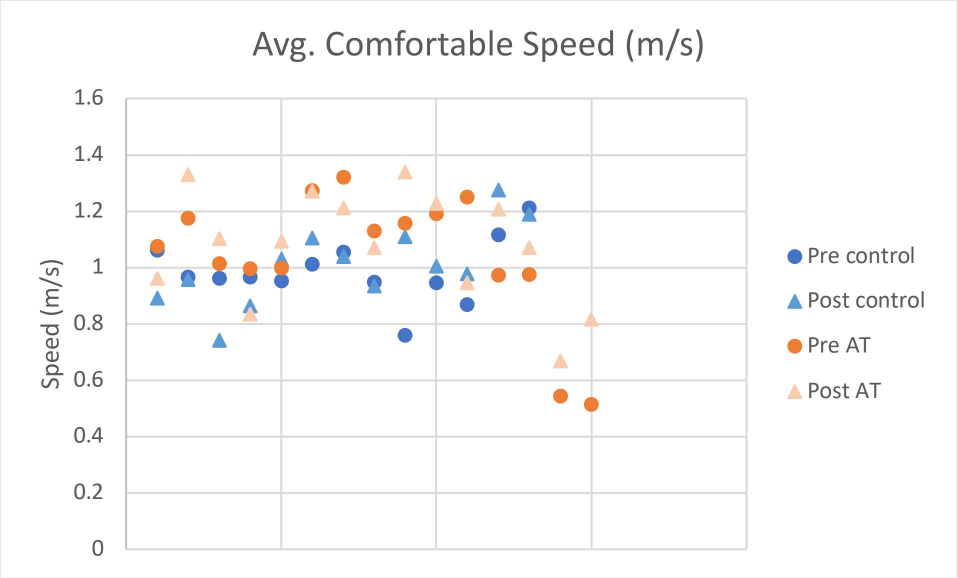

Figure 2. Scatter plot showing distribution of average comfortable speed for both AT and Control groups at baseline and post intervention. Speeds ranged from 0.5m/s to more than 1.3 m/s.

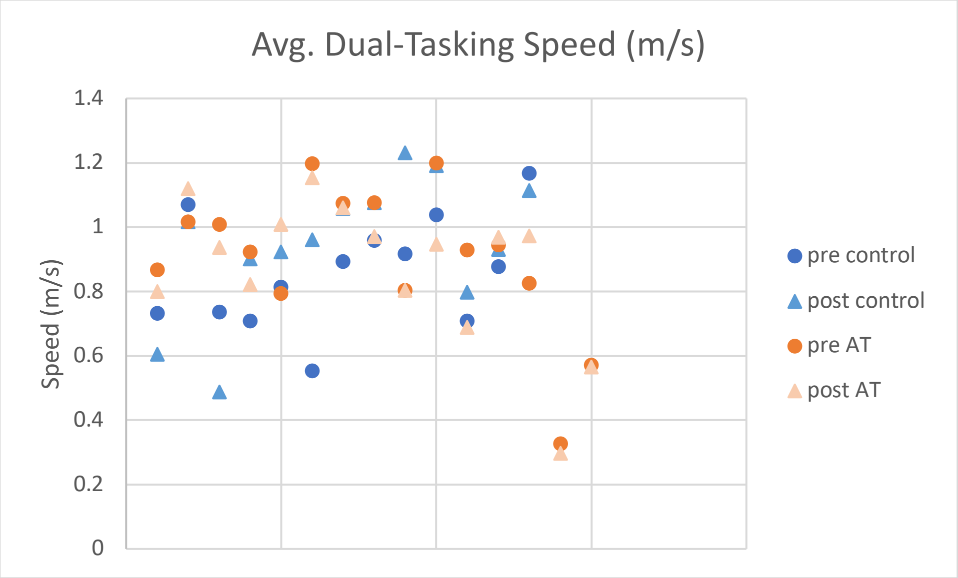

Figure 3. Scatter plot showing distribution of average dual-tasking speed for both AT and Control groups at baseline and post intervention. Speeds ranged from 0.3 m/s to a little over 1.2 m/s.

3.2.1 Between group differences at baseline

Because only the first 20 patients were randomized, we used two-sample equal variance independent t-tests to see if there were any significant differences between the AT and control groups on outcome measures at baseline. There was a significant difference (p=0.003) between the AT and control group average dual-task cost for correct number of subtractions. Therefore, we did not perform a between groups comparison on this variable using posttest values.

3.2.2 Between group differences at posttest

To test if there were any significant differences between groups at posttest, we used two-sample unequal variance independent t-tests to see if there were any significant differences. There was a significant difference (p=0.04) between the AT and control group average dual-task cost for speed at posttest. The control group had less dual-task cost for speed than the AT group; however see within group differences below for control group accuracy of performing subtractions.

3.2.3 Within group Pre to Post differences

While data were reported for all three dual-tasking timepoints, the follow-up data were not analyzed. There was a significant difference within the control group for the dual-tasking average number of correct subtractions between baseline and posttest. The control group decreased in number of correct subtractions given, going from an average of 3.64 at baseline to an average of 2.74 at posttest (Table 2).

There was a significant difference within the AT group for the dual-tasking average percent of correct subtractions between baseline and posttest. The AT group decreased in percent of correct subtractions given, going from an average of 95.78% at baseline to an average of 84.30% at posttest.

There was a significant difference within the control group for the dual-tasking average number of correct subtractions per second between baseline and posttest. The control group decreased in the number of correct subtractions per second, going from an average of 0.51 answers/second at baseline to an average of 0.45 answers/second at posttest.

Table 2. Within Group Pre to Post Differences for Dual-Tasking Measures

	Control	**Tango**	**P-values**
Comfortable avg. speed (m/s)	Pre = 0.99 ± 0.11 Post = 1.01 ± 0.14 Follow-up = 1.05 ± 0.13	1.04 ± 0.20 1.08 ± 0.20 1.10 ± 0.19	Within Control: p = 0.597 Within Tango: p = 0.385
Dual-tasking avg. speed (m/s)	Pre = 0.86 ± 0.17 Post = 0.95 ± 0.21 Follow-up = 0.90 ± 0.18	0.90 ± 0.23 0.87 ± 0.22 0.99 ± 0.25	Within Control: p = 0.106 Within Tango: p = 0.379
Comfortable avg. cadence (steps/min)	Pre = 103.21 ± 10.82 Post = 104.42 ± 10.68 Follow-up = 101.86 ± 5.98	108.60 ± 9.71 108.09 ± 10.32 108.76 ± 12.18	Within Control: p = 0.656 Within Tango: p = 0.827
Dual-tasking avg. cadence (steps/min)	Pre = 100.04 ± 18.66 Post = 104.22 ± 15.94 Follow-up = 99.07 ± 9.06	105.93 ± 12.82 103.82 ± 10.45 107.12 ± 12.98	Within Control: p = 0.195 Within Tango: p = 0.324
Standing practice avg. # of correct subtractions	Pre = 5.31 ± 3.77 Post = 5.25 ± 2.96 Follow-up = 5.25 ± 3.03	6.20 ± 2.60 5.50 ± 2.50 7.08 ± 3.40	Within Control: p = 0.309 Within Tango: p = 0.455
Dual-tasking avg. # of correct subtractions	Pre = 3.64 ± 1.97 Post = 2.74 ± 1.76 Follow-up = 3.07 ± 2.27	2.58 ± 1.12 2.42 ± 1.01 2.88 ± 1.11	Within Control: **p < .0001** Within Tango: p = 0.496

Standing practice avg. # of errors	Pre = 0.462 ± 0.78 Post = 0.458 ± 0.72 Follow-up = 0.70 ± 1.25	0.27 ± 0.46 0.43 ± 0.76 0.23 ± 0.60	Within Control: p = 0.901 Within Tango: p = 0.547
Dual-tasking avg. # of errors	Pre = 0.22 ± 0.33 Post = 0.26 ± 0.28 Follow-up = 0.39 ± 0.44	0.13 ± 0.28 0.490± 0.38 0.27 ± 0.33	Within Control: p = 0.619 Within Tango: p = 0.0689
Standing practice avg. # correct subtractions per second (answers/s)	Pre = 0.35 ± 0.25 Post = 0.35 ± 0.20 Follow-up = 0.35 ± 0.20	0.41 ± 0.17 0.37 ± 0.17 0.47 ± 0.23	Within Control: p = 0.309 Within Tango: p = 0.455
Dual-tasking avg. # correct subtractions per second (answers/s)	Pre = 0.51 ± 0.28 Post = 0.45 ± 0.30 Follow-up = 0.46 ± 0.35	0.39 ± 0.20 0.35 ± 0.19 0.45 ± 0.22	Within Control: **p = 0.0322** Within Tango: p = 0.114
Standing practice avg. % correct subtractions	Pre = 87.95 ± 21.50 Post = 90.78 ± 15.18 Follow-up = 85 ± 25.39	94.37 ± 10.55 93.27 ± 12.48 95.51 ± 11.08	Within Control: p = 0.635 Within Tango: p = 0.838
Dual-tasking avg. % correct subtractions	Pre = 93.03 ± 10.41 Post = 88.54 ± 13.19 Follow-up = 81.73 ± 25.96	95.78 ± 9.08 84.30 ± 15.20 90.57 ± 11.07	Within Control: p = 0.172 Within Tango: **p = 0.0391**

Regarding dual-task costs, there was a significant difference within the control group for the average dual-task cost for number of correct subtractions between baseline and posttest. The control group did significantly worse, going from an average of 11.80% less correct to an average of 53.59% less correct (Table 3).

Table 3. Within Group Pre to Post Differences for Dual-Tasking Measures

	Control	**Adapted Tango**	**P-values**
Avg. Dual-Task Cost for Speed (%)	Pre = -12.20 ± 19.00 Post = -6.54 ± 18.00 Follow-up = -14.70 ± 9.50	-13.00 ± 13.00 -19.60 ± 14.00 -12.30 ± 16.00	Within Control: p = 0.178 Within Tango: p = 0.0871
Avg. Dual-Task Cost for Cadence (%)	Pre = -3.25 ± 13.87 Post = -0.30 ± 9.86 Follow-up = -2.81 ± 5.40	-2.47 ± 7.23 -3.81 ± 6.63 -1.52 ± 4.51	Within Control: p = 0.319 Within Tango: p = 0.587
Avg. Dual-Task Cost for # correct subtractions (%)	Pre = -11.80 ± 51.00 Post = -53.59 ± 17.99 Follow-up = -25.42 ± 75.00	-56.70 ± 14.96 -48.59 ± 14.96 -54.92 ± 16.67	Within Control: **p = 0.014** Within Tango: p = 0.446

3.3 Effect of Adapted Tango on dynamic balance

Performance on DGI increased over time. The AT group consistently performed better on DGI at all three time points compared to the Control group (Figure 4). A group*time interaction effect was significant for DGI (Table 4).

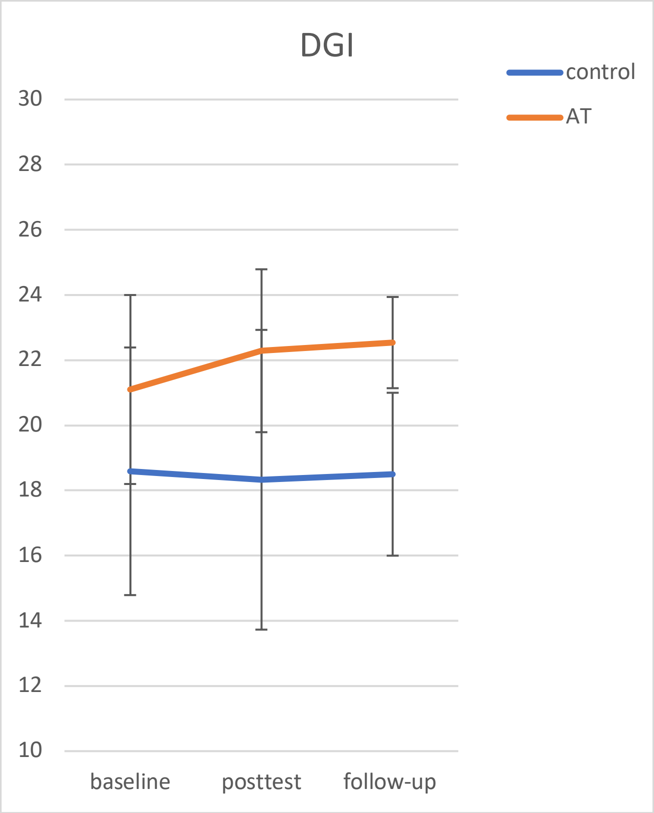

Figure 4.

Table 4. Related Measured ANOVA (Overall)

	Group			Time			Group*Time		
Outcome	*β*	95% CI	P Value	*β*	95% CI	P Value	*β*	95% CI	P Valu
DGI	-1.56	-4.38, 1.25	0.26	0.20	0.02, 0.38	0.03*	-0.14	-0.25, -0.02	0.02*

*p<0.05. Abbreviations: DGI, Dynamic Gait Index. P values are obtained by mixed effect model adjusted for PD duration.

3.4 Effect of Adapted Tango on Modulation Index

Although APRX and APRY MI was higher in the AT group and decreased with time, neither the group, time, nor group*time interaction effects were significant (Table 5). For both time bins, the effect sizes were similar.

Table 5. Associations between group and time and MI across muscles.

	Group	Time	Group*Time

Outcome	*β*	95% CI	P Value	*β*	95% CI	P Value	*β*	95% CI	P Va
MI, APRX	-1.44	-13.1, 10.2	0.81	-0.71	-1.89, 0.47	0.22	0.24	-0.63, 1.10	0.59
MI, APRY	-1.65	-12.0, 8.65	0.75	-0.57	-1.66, 0.52	0.29	0.19	-0.61, 1.00	0.64

*p<0.05.

3.5 Case Studies

To better understand the findings, we analyzed specific cases that improved or did not improve in both DGI and mobility and cognitive dual-tasking of just one of the measures to qualitatively assess clinical characteristics that may have impacted participants' responses to the AT intervention.

Table 6. Case Demographics and Clinical Characteristics

	CR1	**CR2**	**CR3**	**CR4**
Sex	Male	Male	Male	Female
Age	59	53	70	69
Race	White	White	White	White
Highest level of education	Bachelor's degree	Doctoral degree	Bachelor's degree	Some college/associate's degree
Comorbidities	Depression and thyroid issues (treated in 1999)	Vertigo (diagnosed in 2003)	high blood pressure (diagnosed in 2010)	arthritis or rheumatism and exercise induced asthma or breathing problem
PD duration (years)	6	4	12	5
Baseline medications	300mg Carbidopa-Levodopa and 1mg of a MAO-B inhibitor	300mg Carbidopa-Levodopa, 600mg Entacapone or Comtan, and 1mg of a MAO-B inhibitor	2.25mg Pramipexole or Mirapex	3mg Pramipexole or Mirapex, 300mg Amantadine, and 10mg Namenda.
Baseline FAB	37	32	35	34
Baseline MoCA	27	29	27	25
Baseline DGI	23	20	24	21
Posttest DGI	24	23	23	23

Baseline avg. dual-task cost for mobility (%)	-18.70	-13.70	-30.60	0.73
Posttest avg. dual-task cost for mobility (%)	-12.70	-15.70	-40.10	-22.90
Baseline avg. dual-task cost for correct subtractions (%)	-71.40	-55.60	-50.00	-58.30
Posttest avg. dual-task cost for correct subtractions (%)	-66.60	-66.60	-83.30	-33.00

3.5.1 Improved in DGI and mobility and cognitive dual-tasking

Case Report 1 (CR1) was a 59 year old white male. CR2's comorbidities included depression and thyroid issues (treated in 1999). His highest level of education was a bachelor's degree. At the time of the study, CR2 had had PD for 6 years. He had fallen once in the past month, and experienced freezing of gait in that last month. He left his house everyday and drove his own vehicle. He rated his quality of life a 4 (moderate). CR1's occupational status was retired. At baseline, CR1 was medicated on 300mg Carbidopa-Levodopa and 1mg of a MAO-B inhibitor. He entered the study with a high static balance level (37 on FAB out of a total of 40) and normal cognitive ability (MoCA score of 27). At posttest, CR1 reported a symptom level of 6, with 0 being worst OFF and 10 being best ON. CR2 improved by 1 point, in DGI from 23 at baseline to 24 at posttest, and improved in dual-task measures of mobility and cognition. In terms of clinical significance of changes on the DGI, the minimum detectable change is 4 points

(Marchetti, et al. 2014). The average dual-task cost for speed (mobility) decreased from 18.70% slower at baseline to 12.70% slower at posttest, so the cost of dual-tasking was less at posttest compared to baseline. The average dual-task cost for correct subtractions (cognition) decreased from 71.40% less correct at baseline to 66.60% less correct at posttest, so the cost was also less at posttest compared to baseline.

3.5.2 Improved in DGI but not in mobility and cognitive dual-tasking

Case Report 2 (CR2) was a 53 year old white male. CR1's comorbidities included vertigo (diagnosed in 2003). His highest level of education was a doctoral degree. At the time of the study, CR2 had had PD for 4 years. He had fallen 0 times in the past 6 months. He left his house everyday and drove his own vehicle. He rated his quality of life a 7 (very high). CR2's occupational status was retired and he volunteered. At baseline, CR2 was medicated on 300mg Carbidopa-Levodopa, 600mg Entacapone or Comtan, and 1mg of a MAO-B inhibitor. He entered the study with a moderate static balance level (32 of 40 on FAB) and normal cognitive ability (MoCA score of 29). At posttest, CR2 reported a symptom level of 5, with 0 being worst OFF and 10 being best ON. CR2 improved in DGI but got worse in dual-task measures of mobility and cognition. His DGI improved from 20 at baseline to 23 at posttest. The average dual-task cost for speed (mobility) increased from 13.70% slower at baseline to 15.70% slower at posttest. The average dual-task cost for correct subtractions (cognition) increased from 55.60% less correct at baseline to 66.60% less correct at posttest.

3.5.3 Lack of improvement in DGI and mobility and cognitive dual-tasking

Case Report 3 (CR3) was a 70 year old white male. CR2's comorbidities included high blood pressure (diagnosed in 2010). His highest level of education was a bachelor's degree. At the time of the study, CR3 had had PD for 12 years. He had fallen twice in the past 6 months. He left his house 3-4 times per week and drove his own vehicle. He rated his quality of life a 6 (high). CR3's occupational status was retired. At baseline, CR3 was medicated on 2.25mg Pramipexole or Mirapex. He entered the study with a moderately high static balance level (35 on FAB). He also entered the study with a normal cognitive ability (MoCA score of 27). At the time of the posttest, CR3 reported a symptom level of 3, with 0 being worst OFF and 10 being best ON. CR3 got worse in DGI and also got worse in dual-task measures of mobility and cognition. DGI decreased from 24 at baseline to 23 at posttest. The average dual-task cost for speed (mobility) increased from 30.60% slower at baseline to 40.10% slower at posttest. The average dual-task cost for correct subtractions (cognition) increased from 50.00% less correct at baseline to 83.30% less correct at posttest.

3.5.4 Improved in DGI and cognitive dual-tasking but not in mobility dual-tasking

Unlike the first three case studies, Case Report 4 (CR4) entered the study with a MoCA score that indicated potential onset of some cognitive impairment (25 on MoCA). CR4 was a 69 year old white female. CR4's comorbidities included arthritis or rheumatism and exercise induced asthma or breathing problem. She had attained some college. At the time of the study, CR4 had had PD for 5 years. She had fallen twice in the past 6 months. She left her house 3-4 times per week and drove her own vehicle. She rated her quality of life a 5 (high). CR4's worked part-time. At baseline, CR4 was medicated on 3mg Pramipexole or Mirapex, 300mg Amantadine, and 10mg Namenda. She entered the study with relatively intact static balance (34 on FAB). At the time of the posttest, CR4 reported a symptom level of 7, with 0 being worst OFF and 10 being best ON. CR4 improved in DGI, got worse in dual-task measures of mobility, and improved in dual-task measures of cognition. DGI went from 21 at baseline to 23 at posttest. The average dual-task cost for speed (mobility) increased from 0.73% faster at baseline to 22.90% slower at posttest. The average dual-task cost for correct subtractions (cognition) decreased from 58.30% less correct at baseline to 33.00% less correct at posttest.

4. Discussion

4.1 The variable impact of AT on dual-tasking

Based on previous knowledge, we expected the dual-task costs for both mobility and cognition to decrease within the AT group when compared to the control groups. A systematic review by Wollesen and Voelcker-Rehage found that in healthy older adults, dual-task performance can be improved through performance related exercises (Wollesen and Voelcker-Rehage 2014). A study by Beck et al. found that externally focused exercise for people with PD resulted in dual-task walking improvements (Beck, et al. 2018).

However, here we found that there was no significant decrease in both mobility and cognitive dual-task costs within the AT group. Although there was no improvement, because PD is a progressive neurodegenerative disease, maintenance is not looked down upon. The lack of improvement in dual-tasking may be due to potential ceiling effects, as most participants started out with moderately high to high balance and gait abilities and normal cognition. This may have left little room to improve. Additionally, one study found that high volume exercise (>180 minutes/week) improved older adults' gait speed (McKay, et al. 2016). Our study did not involve high volume exercise, which may explain the lack of improvement in measures of mobility, such as speed. We can potentially incorporate high volume AT in future studies to target this. Although the Follow-up data is currently not analyzed, it appears that the AT group decreased, although possibly not significantly, in mobility dual-task costs from Post to Follow-up, whereas the control group increased in their mobility dual-task costs from Post to Follow-up. In terms of the mobility dual-tasking measures (such as speed and cadence), even though the AT group may have gotten worse from Pre to Post, it appears as though at Follow-up, they either went back to around Pre levels or even slightly improved from Pre. This 4-week period following the intervention may have a beneficial effect on the AT group, and following significance test analysis, should be looked at further in future studies.

There was a significant difference at posttest between the control and AT group average dual-task cost for speed. We would have expected the dual-task cost for the AT group to be lower, as AT is a good form of dual-tasking training. However, at posttest, the average dual-task cost for speed for control was 6.54% slower, whereas the average dual-task cost for speed for the AT group was 19.60% slower. This means the cost was more for the AT group at posttest. Although the control group had less cost to their speed, they were also performing worse on counting backwards by 7s. The control group's average dual-task cost for number of correct subtractions went from 11.80% less correct at baseline to 56.70% less correct at posttest, meaning the cost increased from baseline to posttest for the control group. This cognitive decline is reflected in the control group significantly decreasing in the dual-tasking average number of correct subtractions given, going from an average of 3.64 at baseline to an average of 2.74 at posttest. This cognitive decline is also reflected in the control group significantly decreasing in the dual-tasking average number of correct subtractions per second, going from an average of 0.51 answers/second at baseline to an average of 0.45 answers/second at posttest. Neurodegenerative diseases such as PD are characterized by a progressive loss of structure and function of neurons in the brain; therefore, cognitive decline is expected (Yau, et al. 2014). While the control group showed their speed was less impacted by the subtractions, the reduced accuracy in subtractions, also shows a prioritization of the mobility task over the cognitive task which has been shown before (Yogev-Seligmann, et al. 2012).

The AT group significantly decreased in the dual-tasking average percent of correct subtractions given between baseline and posttest, going from an average of 95.78% at baseline to an average of 84.30% at posttest. Although the dual-tasking number of correct answers did not decrease significantly for the tango group, their percent of correct subtractions still did. This may be because they increased quite a bit, although not significantly, in their dual-tasking average number of errors made, going from an average of 0.13 at baseline to an average of 0.40 at posttest. Therefore, although the number of correct subtractions given remained around the same from baseline to posttest during the dual-tasking activity, they gave more incorrect subtractions at posttest than they did at baseline, thereby decreasing the percent of correct subtractions at posttest compared to baseline.

Some participants (like CR4 from the case study section) improved in either cognitive or mobility dual-tasking, and got worse in the other modality. This selective improvement is similar to that of the control group improving their mobility dual-task costs but not their cognitive dual-task cost. This finding may be because they prioritized or focused on one or the other. A study by Kelly et al. found that when people with PD were instructed to focus on walking, their gait speed dual-task costs decreased but their composite cognitive dual-task cost modestly increased (Kelly, et al. 2012). Dual-task prioritization may explain why these participants improved in one but got worse in the other. We can further test this by including instructions in future experiments for the participants to focus on either walking or subtractions during the Serial 7 test and see if the group that focused on walking improved only in mobility dual-tasking and if the group that focused on subtractions improved only in cognitive dual-tasking.

4.2 Dynamic balance improved as a result of AT

The AT program improved clinical measures of balance and gait, particularly, DGI. These results make sense in the context of previous literature. McKay et. al found improvement in DGI after a 3-week high volume (450 minutes/week) AT intervention for individuals with mild-moderate PD (McKay, et al. 2016). Hackney et al. found a significant improvement for older adults with visual impairments in the Tango group from pre to post to one month post in DGI (Hackney, et al. 2015).

As mentioned earlier, most previous studies mainly focused on measures of static balance to gage improvement in balance, but it is important to also incorporate measures of dynamic balance as both static and dynamic balance are progressively lost in individuals with PD. AT may be a good way to address dynamic balance issues in PD, as dynamic balance involves maintaining or recovering balance as a response to disturbances, and in dance, specifically AT, individuals move their center of mass beyond their base of support and regain their balance with each step (Hackney, et al. 2012).

Also, lower extremity strength is important in maintaining balance and preventing falls. Short-term exercise programs (8-10 weeks) targeting lower extremity training have significantly improved both the strength of the lower body and balance in older adults (DiBrezzo, et al. 2005). AT may have improved dynamic balance as it was a short-term exercise program that heavily involves movement and training of the lower extremities. Future AT studies can incorporate more targeted lower extremity training potentially during warm-ups or the dancing itself to see if there is improvement among the patients in their dynamic balance.

To further understand the relationship between AT and dynamic balance, future studies should incorporate more measures of dynamic balance in addition to DGI to validate if AT helps to improve dynamic balance.

4.3 AT did not affect modulation index

While we found that AT participants improved in clinical measures of gait and balance, specifically DGI, we did not find similar changes in MI during reactive balance. The lack of significant group by time interaction effect on MI may be due to a ceiling effect in participants' capacity for improvement or to the fact that the reactive balance task in the laboratory is not a direct replica of the balance and gait scale tasks. Additionally, the fact that MI is a recently developed measure means that this study could not be powered to detect MI change and the level of balance impairment or amount of change in balance impairment associated with a detectable change in muscle modulation is not yet clear. Further research should be dedicated to determining how long it would take to see these changes.

We observed a trend of lower MI in the control group compared to the AT group and a trend of MI decreasing with time. We know that modulation is reduced in PD compared with controls and associated with balance ability (Carpenter, et al. 2004, Dimitrova, et al. 2004, Horak, et al. 1996, Lang, et al. 2019, St George, et al. 2012), but we do not know the values the MI "cutoff score" at which one would expect impaired balance, or vice versa. Similarly, we do not know what amount of modulation change would be associated with the minimally clinically important difference (MCID) in balance scale scores.

Further research is needed to clarify the value of modulation changes in functional balance. Depending on contexts such as disease progression and severity, the same direction and magnitude of change might be associated with functional impairment or improvement (via compensation). Understanding the changes in muscle control and whether they are beneficial or harmful to balance performance is a key insight that will allow rehabilitation interventions to address balance impairments in PD more effectively.

4.4 Analysis of individual case studies

Overall, the case series we looked at here emphasizes the heterogeneity in the responses of the participants. CR1 improved in both dynamic balance and cognitive and mobility dual-tasking. It is interesting that CR1 was the one that improved in both, as he was also the only one who experienced freezing of gait in the previous month. However, falls are common. CR1 already had good static balance (37 on FAB at baseline) and dynamic balance (23 on DGI at baseline), and improved in dynamic balance. Although, it should be mentioned that previous studies have found no significant correlation between static and dynamic balance parameters (Hrysomallis, et al. 2006, Pau, et al. 2015). It is also interesting that CR1 ranked his quality of life the lowest of the four case reports but was the one that improved in both measures. It is possible that because he ranked his quality of life the lowest, he was also more actively seeking improvement compared to the other participants. Ultimately, CR1 was primed and ready to benefit from the AT intervention; he was an ideal participant with characteristics that were well suited to the AT intervention.

CR2 improved in dynamic balance but did not improve in cognitive and mobility dual-tasking. This may be because other factors that influence dual-task cost overshadowed the benefits of the inherent dual-task training from AT. Dual-task costs can be made worse and increased by a plethora of factors, such as reduced sensory inputs, concurrent visual imagery, and increased complexity of walking (Li, et al. 2018). Our AT intervention was designed to increase in complexity over time, which may have helped to improve balance but simultaneously hinder dual-tasking improvement for this participant. Additionally, CR2 was previously diagnosed with vertigo. Vertigo, dizziness, and balance disorders are associated with immobility, which may have also impacted CR2's ability to improve in his mobility dual-tasking (Regauer, at al. 2020).

CR3 did not improve in dynamic balance and dual-task measures of mobility and cognition. CR3 was the oldest of the 4 case reports and had the longest duration of PD. While it already remains difficult to reduce postural and gait disturbances, postural instability and gait difficulties worsen with PD progression (Debû, et al. 2018). Therefore, it may be the most difficult to improve the PD symptoms of patients with longer PD durations, like CR3. To further test this, we can select patients with longer PD duration and compare their results to patients with shorter PD duration. Also, a longer intervention may potentially result in greater improvement in CR3's case. It is important to add that after 3 visits, we were informed that CR3 may not have PD after all; he may have had progressive supranuclear palsy (PSP). If this is true, CR3 may not have gotten worse in both DGI and dual-task measures of mobility and cognition if he actually had PD, and this most likely justifies removal from the study for future analysis.

CR4 illustrates that a low MoCA score does not necessarily correlate with a lack of improvement in cognitive dual-tasking. In fact, out of the 4 case reports, CR4 had the lowest baseline MoCA score and the largest improvement in the cognitive dual-task measure. While improving in cognitive dual-task cost, CR4 got worse in mobility dual-task cost. This may be because CR4 prioritized improving her cognitive ability rather than her mobility. A study by Yogev-Seligmann et al. found that while participants were walking while performing a verbal fluency task and were told to focus on the motor task, there was a significant increase in gait speed (Yogev-Seligmann, et al. 2010). A study by Kelly et al. found cognitive task performance was faster when participants were told to focus on the cognitive task, and walking was faster when they were told to focus on walking (Kelly, et al. 2010).

It is also interesting to note that while CR4 had the lowest education level out of the four case reports, but still had the largest improvement in the cognitive dual-task measure. On the other hand, CR2, who had the highest education level, got worse. This could be because unlike the other case reports who were all retired, CR4 was still working part-time.

This case series gives us a preliminary understanding of PD individuals' cognitive and motor responses to AT intervention. It reminds us that it is important to account for individuals' unique backgrounds and comorbidities when considering rehabilitation intervention results and designing future studies. For example, weaker and slower adults might experience higher central processing systems loading while simultaneously performing a cognitive task and walking, which may increase dual-task cost. Additionally, individuals with visual impairments may have an even more difficult time due to the association between motor performance, loss of vision, and cognition in aging (Hackney, et al. 2015).

4.5 Conclusions

Maintenance is important in a progressive, neurodegenerative disease. The control group may have maintained their dual-tasks speed; however, the cognitive dual-tasking variables indicate that cognitive performance decreased at posttest for the control group. The improvement in mobility-dual tasking but lack of improvement in cognitive dual-tasking may indicate task prioritization on the part of the patients. Previous research has shown that patients prioritize motor tasks while other research has shown the cognitive task is prioritized (Kelly, et al. 2012). To further explore the idea of task prioritization in dual-tasking, we can include instructions in future AT studies for the participants to focus on either walking (mobility) or subtractions (cognitive) during the Serial 7 test and see if there is a significant difference in improvements in either mobility or cognitive dual-tasking. Although the AT group maintained their dual-task correct number of subtractions, their decrease in percent of correct subtractions is most likely due to an increase in the number of errors made.

AT is most likely an effective method of improving dynamic balance. To further understand the relationship between AT and dynamic balance, more measures of dynamic balance in addition to DGI should be looked at in future studies. While there was an improvement in DGI after AT, there may have been no similar improvement in MI because of it only being recently developed. To further develop the MI measure, we need more studies to best determine how to power the AT study to detect MI change and to elucidate the change in balance impairment needed for a detectable chance in muscle modulation.

Finally, the case series illustrated how clinical characteristics may potentially impact how participants respond to the AT intervention. Using these case studies, we can potentially recruit participants with clinical characteristics that would allow them to best benefit from an AT intervention, like CR1.

Altogether this research shows trends and potentially positive effects of AT for maintenance and improvements of key mobility functions in people with mild-moderate PD. Larger, better controlled randomized controlled studies are necessary to definitively determine the effects of AT in this population.

4.6 Limitations

4.6.1 Statistical Analysis

One limitation of this study is the multiplicity of outcomes in terms of the dual-tasking data, leading to the possibility of inflated type 1 error. Testing multiple hypotheses simultaneously in the same study increases the type 1 error rate. For the dual-tasking data, we only conducted independent t-tests and did not conduct multiple test analyses. Therefore, we need to potentially use multiplicity adjustments. Also, the overall significance level of the study may need to be adjusted to account for the multiplicity of outcomes (Li, et al. 2017).

Additionally, many of the variables, such as the dual-tasking average number of correct subtractions and the dual-tasking average number of correct subtractions per second, are most likely not independent and are related. These variables seem to be overlapping or potentially highly correlated. We did not account for the related variables by calculating the covariance, which may have impacted the results. Future analysis should calculate covariance.

4.6.2 Study Sample

Once again, only the first twenty participants were randomized into either the control or AT arm; the remaining participants were directly assigned to the control arm due to randomization to the AT group being closed. True randomization of the participants would have accounted for baseline differences between the control and AT groups. In subsequent studies, we should ensure all participants are randomized and have an equal chance of being assigned to either the control or AT group to make sure there are no significant baseline differences between groups.

References

A feasibility study of dual-task strategy training to improve gait performance in patients with Parkinson's disease | Scientific Reports. (n.d.). Retrieved March 23, 2022, from https://www.nature.com/articles/s41598-021-91858-0

Abbruzzese, G., Marchese, R., Avanzino, L., & Pelosin, E. (2016). Rehabilitation for Parkinson's disease: Current outlook and future challenges. *Parkinsonism & Related Disorders*, *22*, S60–S64. https://doi.org/10.1016/j.parkreldis.2015.09.005

Allen, N. E., Sherrington, C., Paul, S. S., & Canning, C. G. (2011). Balance and falls in Parkinson's disease: A meta-analysis of the effect of exercise and motor training. *Movement Disorders*, *26*(9), 1605–1615. https://doi.org/10.1002/mds.23790

Alzheimer's Disease and Parkinson's Disease | NEJM. (n.d.). Retrieved March 22, 2022, from https://www.nejm.org/doi/full/10.1056/NEJM2003ra020003

Bakhshayesh, B., Sayyar, S., & Daneshmandi, H. (2017). Pilates Exercise and Functional Balance in Parkinson's Disease. *Caspian Journal of Neurological Sciences*, *3*(1), 25–38. https://doi.org/10.18869/acadpub.cjns.3.8.25

Beck, E. N., Intzandt, B. N., & Almeida, Q. J. (2018). Can Dual Task Walking Improve in Parkinson's Disease After External Focus of Attention Exercise? A Single Blind Randomized Controlled Trial. *Neurorehabilitation and Neural Repair*, *32*(1), 18–33. https://doi.org/10.1177/1545968317746782

Bloem, B. R., Grimbergen, Y. A. M., Cramer, M., Willemsen, M., & Zwinderman, A. H. (2001). Prospective assessment of falls in Parkinson's disease. *Journal of Neurology*, *248*(11), 950–958. https://doi.org/10.1007/s004150170047

Blumenstein, R. (1980). *Electrode placement in EMG biofeedback*. Williams & Wilkins.

Bressel, E., Yonker, J. C., Kras, J., & Heath, E. M. (2007). Comparison of Static and Dynamic Balance in Female Collegiate Soccer, Basketball, and Gymnastics Athletes. *Journal of Athletic Training*, *42*(1), 42–46.

Carpenter, M. G. (2004). Postural abnormalities to multidirectional stance perturbations in Parkinson's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, *75*(9), 1245–1254. https://doi.org/10.1136/jnnp.2003.021147

Chong, R. K. Y., Horak, F. B., & Woollacott, M. H. (2000). Parkinson's disease impairs the ability to change set quickly. *Journal of the Neurological Sciences*, *175*(1), 57–70. https://doi.org/10.1016/S0022-510X(00)00277-X

Chong, R. K. Y., Jones, C. L., & Horak, F. B. (1999). Postural Set for Balance Control is Normal in Alzheimer's but not in Parkinson's Disease. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *54*(3), M129–M135. https://doi.org/10.1093/gerona/54.3.M129

Cook Shukla, L., Schulze, J., Farlow, J., Pankratz, N. D., Wojcieszek, J., & Foroud, T. (1993). Parkinson Disease Overview. In M. P. Adam, H. H. Ardinger, R. A. Pagon, S. E. Wallace, L. J. Bean, K. W. Gripp, G. M. Mirzaa, & A. Amemiya (Eds.), *GeneReviews®*. University of Washington, Seattle. http://www.ncbi.nlm.nih.gov/books/NBK1223/

Debû, B., De Oliveira Godeiro, C., Lino, J. C., & Moro, E. (2018). Managing Gait, Balance, and Posture in Parkinson's Disease. *Current Neurology and Neuroscience Reports*, *18*(5), 23. https://doi.org/10.1007/s11910-018-0828-4

DiBrezzo, R., Shadden, B. B., Raybon, B. H., & Powers, M. (2005). Exercise Intervention Designed to Improve Strength and Dynamic Balance among Community-Dwelling Older Adults. *Journal of Aging and Physical Activity*, *13*(2), 198–209. https://doi.org/10.1123/japa.13.2.198

Dimitrova, D., Horak, F. B., & Nutt, J. G. (2004). Postural Muscle Responses to Multidirectional Translations in Patients With Parkinson's Disease. *Journal of Neurophysiology*, *91*(1), 489–501. https://doi.org/10.1152/jn.00094.2003

Donaldson, I., Marsden, C. D., & Schneider, S. (2012). *Marsden's book of movement disorders*. Oxford University Press.

Duncan, R. P., & Earhart, G. M. (2012). Randomized Controlled Trial of Community-Based Dancing to Modify Disease Progression in Parkinson Disease. *Neurorehabilitation and Neural Repair*, *26*(2), 132–143. https://doi.org/10.1177/1545968311421614

Duncan, R. P., & Earhart, G. M. (2014). Are the Effects of Community-Based Dance on Parkinson Disease Severity, Balance, and Functional Mobility Reduced with Time? A 2-Year Prospective Pilot Study. *The Journal of Alternative and Complementary Medicine*, *20*(10), 757–763. https://doi.org/10.1089/acm.2012.0774

Fracture risk after the diagnosis of Parkinson's disease: Influence of concomitant dementia—Melton—2006—Movement Disorders—Wiley Online Library. (n.d.). Retrieved March 22, 2022, from https://movementdisorders.onlinelibrary.wiley.com/doi/abs/10.1002/mds.20946?casa_token=47uueOZo0agAAAAA:n7jVTE3Nn3HyWr7Zjohzinkw3rVUdqK_QR6wHzoG7fYkPLPXtdHy9kiLtt40cDozCo7DBAbesJhUqtU

Framework for understanding balance dysfunction in Parkinson's disease—Schoneburg—2013—Movement Disorders—Wiley Online Library. (n.d.). Retrieved March 22, 2022, from https://movementdisorders.onlinelibrary.wiley.com/doi/abs/10.1002/mds.25613?casa_token=d6RB8VLlQNcAAAAA:Ygfo3D6P-CJem9aENs1vbXTplM3e9EGeW5eAgnBaHUv5UpvGRxx9oC17stHPhkU7DYpbDE0mn4q_t3Q

Frontiers | Differential Effects of Tango Versus Dance for PD in Parkinson Disease | Aging Neuroscience. (n.d.). Retrieved March 22, 2022, from https://www.frontiersin.org/articles/10.3389/fnagi.2015.00239/full

Giardini, M., Nardone, A., Godi, M., Guglielmetti, S., Arcolin, I., Pisano, F., & Schieppati, M. (2018). Instrumental or Physical-Exercise Rehabilitation of Balance Improves Both Balance and Gait in Parkinson's Disease. *Neural Plasticity*, *2018*, e5614242. https://doi.org/10.1155/2018/5614242

Hackney, M. E., & Earhart, G. M. (2009). Effects of Dance on Movement Control in Parkinson's Disease: A Comparison of Argentine Tango and American Ballroom. *Journal of Rehabilitation Medicine : Official Journal of the UEMS European Board of Physical and Rehabilitation Medicine*, *41*(6), 475–481. https://doi.org/10.2340/16501977-0362

Hackney, M. E., & Earhart, G. M. (2010). Effects of Dance on Gait and Balance in Parkinson's Disease: A Comparison of Partnered and Nonpartnered Dance Movement. *Neurorehabilitation and Neural Repair*, *24*(4), 384–392. https://doi.org/10.1177/1545968309353329

Hackney, M. E., Hall, C. D., Echt, K. V., & Wolf, S. L. (2012). Application of Adapted Tango as Therapeutic Intervention for Patients With Chronic Stroke. *Journal of Geriatric Physical Therapy*, *35*(4), 206–217. https://doi.org/10.1519/JPT.0b013e31823ae6ea

Hackney, M. E., Hall, C. D., Echt, K. V., & Wolf, S. L. (2015). Multimodal Exercise Benefits Mobility in Older Adults With Visual Impairment: A Preliminary Study. *Journal of Aging and Physical Activity*, *23*(4), 630–639. https://doi.org/10.1123/japa.2014-0008

Hackney, M. E., Kantorovich, S., Levin, R., & Earhart, G. M. (2007). Effects of Tango on Functional Mobility in Parkinson's Disease: A Preliminary Study. *Journal of Neurologic Physical Therapy*, *31*(4), 173–179. https://doi.org/10.1097/NPT.0b013e31815ce78b

Hewa Haputhanthirige, N. K. (2019). *Effects of Dance on Gait, Cognition and Dual Tasking in Parkinson□s disease: A Feasibility Study* [PhD, Queensland University of Technology]. https://doi.org/10.5204/thesis.eprints.131582

Hirsch, M. A., Toole, T., Maitland, C. G., & Rider, R. A. (2003). The effects of balance training and high-intensity resistance training on persons with idiopathic Parkinson's disease11No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the authors(s) or upon any organization with which the author(s) is/are associated. *Archives of Physical Medicine and Rehabilitation*, *84*(8), 1109–1117. https://doi.org/10.1016/S0003-9993(03)00046-7

Horak, F., Frank, J., & Nutt, J. (1996). Effects of dopamine on postural control in parkinsonian subjects: Scaling, set, and tone. *Journal of Neurophysiology*, *75*, 2380–2396. https://doi.org/10.1152/jn.1996.75.6.2380

How to identify tremor dominant and postural instability/gait difficulty groups with the movement disorder society unified Parkinson's disease rating scale: Comparison with the unified Parkinson's disease rating scale—Stebbins—2013—Movement Disorders—Wiley Online Library. (n.d.). Retrieved March 22, 2022, from https://movementdisorders.onlinelibrary.wiley.com/doi/abs/10.1002/mds.25383?casa_token=4Sf7Djn6GXMAAAAA:x_0JQMvCYs16Clt_BMBAdwuw1ilvxPO4EVdTPkEEWG9G7z8O0cCAi1SoqFKOl4O0dUkKJAtb8a1-2Lo

Hrysomallis, C., McLaughlin, P., & Goodman, C. (2006). Relationship between static and dynamic balance tests among elite Australian Footballers. *Journal of Science and Medicine in Sport / Sports Medicine Australia*, *9*, 288–291. https://doi.org/10.1016/j.jsams.2006.05.021

Huang, C.-Y., Chen, L.-C., Wu, R.-M., & Hwang, I.-S. (2022). Effects of task prioritization on a postural-motor task in early-stage Parkinson's disease: EEG connectivity and clinical implication. *GeroScience*. https://doi.org/10.1007/s11357-022-00516-4

Instrumental or Physical-Exercise Rehabilitation of Balance Improves Both Balance and Gait in Parkinson's Disease. (n.d.). Retrieved March 22, 2022, from https://www.hindawi.com/journals/np/2018/5614242/

Kelly, V. E., Eusterbrock, A. J., & Shumway-Cook, A. (2012). The Effects of Instructions on Dual-Task Walking and Cognitive Task Performance in People with Parkinson's Disease. *Parkinson’s Disease*, *2012*, e671261. https://doi.org/10.1155/2012/671261

Kelly, V. E., Janke, A. A., & Shumway-Cook, A. (2010). Effects of instructed focus and task difficulty on concurrent walking and cognitive task performance in healthy young adults. *Experimental Brain Research*, *207*(1), 65–73. https://doi.org/10.1007/s00221-010-2429-6

Krishnan, C., & Williams, G. N. (2009). VARIABILITY IN ANTAGONIST MUSCLE ACTIVITY AND PEAK TORQUE DURING ISOMETRIC KNEE STRENGTH TESTING. *The Iowa Orthopaedic Journal*, *29*, 149–158.

Lang, K. C., Hackney, M. E., Ting, L. H., & McKay, J. L. (2019). Antagonist muscle activity during reactive balance responses is elevated in Parkinson's disease and in balance impairment. *PLOS ONE*, *14*(1), e0211137. https://doi.org/10.1371/journal.pone.0211137

Lee, A., & Gilbert, R. M. (2016). Epidemiology of Parkinson Disease. *Neurologic Clinics*, *34*(4), 955–965. https://doi.org/10.1016/j.ncl.2016.06.012

Li, G.; Taljaard, M.; Van den Heuvel, E. R.; Levine, M. A.; Cook, D. J.; Wells, G. A.; Devereaux, P. J.; Thabane, L. An Introduction to Multiplicity Issues in Clinical Trials: The What, Why, When and How. *Int. J. Epidemiol.* **2017**, *46* (2), 746–755. https://doi.org/10.1093/ije/dyw320.

Li, K. Z. H., Bherer, L., Mirelman, A., Maidan, I., & Hausdorff, J. M. (2018). Cognitive Involvement in Balance, Gait and Dual-Tasking in Aging: A Focused Review From a Neuroscience of Aging Perspective. *Frontiers in Neurology*, *9*. https://www.frontiersin.org/article/10.3389/fneur.2018.00913

Lopes, J. B. P., Lameira de Melo, G. E., Lazzari, R. D., Santos, C. A., Franco de Moura, R. C., Dumont, A. J. L., Braun, L. A. F., Duarte, N. A. C., Pareira, R. B., Miziara, I. M., & Oliveira, C. S. (2016). Measures used for the evaluation of balance in individuals with Parkinson's disease: A systematic review. *Journal of Physical Therapy Science*, *28*(6), 1936–1942. https://doi.org/10.1589/jpts.28.1936

Lötzke, D., Ostermann, T., & Büssing, A. (2015). Argentine tango in Parkinson disease – a systematic review and meta-analysis. *BMC Neurology*, *15*(1), 226. https://doi.org/10.1186/s12883-015-0484-0

Manor, B., Zhou, J., Jor'dan, A., Zhang, J., Fang, J., & Pascual-Leone, A. (2016). Reduction of Dual-task Costs by Noninvasive Modulation of Prefrontal Activity in Healthy Elders. *Journal of Cognitive Neuroscience*, *28*(2), 275–281. https://doi.org/10.1162/jocn_a_00897

Marandi, S. M., Nejad, V. S., Shanazari, Z., & Zolaktaf, V. (2013). A Comparison of 12 Weeks of Pilates and Aquatic Training on the Dynamic Balance of Women with Mulitple Sclerosis. *International Journal of Preventive Medicine*, *4*(Suppl 1), S110–S117.

Marchetti, G. F., Lin, C.-C., Alghadir, A., & Whitney, S. L. (2014). Responsiveness and Minimal Detectable Change of the Dynamic Gait Index and Functional Gait Index in Persons With Balance and Vestibular Disorders. *Journal of Neurologic Physical Therapy*, *38*(2), 119–124. https://doi.org/10.1097/NPT.0000000000000015

Marras, C., Beck, J. C., Bower, J. H., Roberts, E., Ritz, B., Ross, G. W., Abbott, R. D., Savica, R., Van Den Eeden, S. K., Willis, A. W., & Tanner, C. M. (2018). Prevalence of Parkinson's disease across North America. *Npj Parkinson's Disease*, *4*(1), 1–7. https://doi.org/10.1038/s41531-018-0058-0

McKay, J. L., Ting, L. H., & Hackney, M. E. (2016). BALANCE, BODY MOTION AND MUSCLE ACTIVITY AFTER HIGH VOLUME SHORT TERM DANCE-BASED REHABILITATION IN INDIVIDUALS WITH PARKINSON'S DISEASE: A PILOT STUDY. *Journal of Neurologic Physical Therapy : JNPT*, *40*(4), 257–268. https://doi.org/10.1097/NPT.0000000000000150

McKee, K. E., & Hackney, M. E. (2013). The Effects of Adapted Tango on Spatial Cognition and Disease Severity in Parkinson's Disease. *Journal of Motor Behavior*, *45*(6), 519–529. https://doi.org/10.1080/00222895.2013.834288

McNeely, M. E., Mai, M. M., Duncan, R. P., & Earhart, G. M. (2015). Differential Effects of Tango Versus Dance for PD in Parkinson Disease. *Frontiers in Aging Neuroscience*, *7*. https://www.frontiersin.org/article/10.3389/fnagi.2015.00239

Mehta, T., Young, H.-J., Lai, B., Wang, F., Kim, Y., Thirumalai, M., Tracy, T., Motl, R. W., & Rimmer, J. H. (2019). Comparing the Convergent and Concurrent Validity of the Dynamic Gait Index with the Berg Balance Scale in People with Multiple Sclerosis. *Healthcare*, *7*(1), 27. https://doi.org/10.3390/healthcare7010027

Nussbaum, R. L.; Ellis, C. E. Alzheimer's Disease and Parkinson's Disease. *N. Engl. J. Med.* **2003**, *348* (14), 1356–1364. https://doi.org/10.1056/NEJM2003ra020003.

Parkinson, J. (2002). An Essay on the Shaking Palsy. *The Journal of Neuropsychiatry and Clinical Neurosciences*, *14*(2), 223–236. https://doi.org/10.1176/jnp.14.2.223

Pau, M., Arippa, F., Leban, B., Corona, F., Ibba, G., Todde, F., & Scorcu, M. (2015). Relationship between static and dynamic balance abilities in Italian professional and youth league soccer players. *Physical Therapy in Sport*, *16*(3), 236–241. https://doi.org/10.1016/j.ptsp.2014.12.003

Poewe, W., Seppi, K., Tanner, C. M., Halliday, G. M., Brundin, P., Volkmann, J., Schrag, A.-E., & Lang, A. E. (2017). Parkinson disease. *Nature Reviews Disease Primers*, *3*(1), 1–21. https://doi.org/10.1038/nrdp.2017.13

Radder, D. L. M., Lígia Silva de Lima, A., Domingos, J., Keus, S. H. J., van Nimwegen, M., Bloem, B. R., & de Vries, N. M. (2020). Physiotherapy in Parkinson's Disease: A Meta-Analysis of Present Treatment Modalities. *Neurorehabilitation and Neural Repair*, *34*(10), 871–880. https://doi.org/10.1177/1545968320952799

Regauer, V., Seckler, E., Müller, M., & Bauer, P. (2020). Physical therapy interventions for older people with vertigo, dizziness and balance disorders addressing mobility and participation: A systematic review. *BMC Geriatrics*, *20*(1), 494. https://doi.org/10.1186/s12877-020-01899-9

Ringhof, S., & Stein, T. (2018). Biomechanical assessment of dynamic balance: Specificity of different balance tests. *Human Movement Science*, *58*, 140–147. https://doi.org/10.1016/j.humov.2018.02.004

Rios Romenets, S., Anang, J., Fereshtehnejad, S.-M., Pelletier, A., & Postuma, R. (2015). Tango for treatment of motor and non-motor manifestations in Parkinson's disease: A randomized control study. *Complementary Therapies in Medicine*, *23*(2), 175–184. https://doi.org/10.1016/j.ctim.2015.01.015

San Martín Valenzuela, C., Moscardó, L. D., López-Pascual, J., Serra-Añó, P., & Tomás, J. M. (2020). Effects of Dual-Task Group Training on Gait, Cognitive Executive Function, and Quality of Life in People With Parkinson Disease: Results of Randomized Controlled DUALGAIT Trial. *Archives of Physical Medicine and Rehabilitation*, *101*(11), 1849-1856.e1. https://doi.org/10.1016/j.apmr.2020.07.008

Sarasso, E., Gardoni, A., Piramide, N., Volontè, M. A., Canu, E., Tettamanti, A., Filippi, M., & Agosta, F. (2021). Dual-task clinical and functional MRI correlates in Parkinson's disease with postural instability and gait disorders. *Parkinsonism & Related Disorders*, *91*, 88–95. https://doi.org/10.1016/j.parkreldis.2021.09.003

Shanahan, J., Morris, M. E., Bhriain, O. N., Saunders, J., & Clifford, A. M. (2015). Dance for People With Parkinson Disease: What Is the Evidence Telling Us? *Archives of Physical Medicine and Rehabilitation*, *96*(1), 141–153. https://doi.org/10.1016/j.apmr.2014.08.017

Shen, X., Wong-Yu, I. S. K., & Mak, M. K. Y. (2016). Effects of Exercise on Falls, Balance, and Gait Ability in Parkinson's Disease: A Meta-analysis. *Neurorehabilitation and Neural Repair*, *30*(6), 512–527. https://doi.org/10.1177/1545968315613447

Speelman, A. D., van de Warrenburg, B. P., van Nimwegen, M., Petzinger, G. M., Munneke, M., & Bloem, B. R. (2011). How might physical activity benefit patients with Parkinson disease? *Nature Reviews Neurology*, *7*(9), 528–534. https://doi.org/10.1038/nrneurol.2011.107

St George, R. J., Carlson-Kuhta, P., Burchiel, K. J., Hogarth, P., Frank, N., & Horak, F. B. (2012). THE EFFECTS OF SUBTHALAMIC AND PALLIDAL DEEP BRAIN STIMULATION ON POSTURAL RESPONSES IN PATIENTS WITH PARKINSON'S DISEASE. *Journal of Neurosurgery*, *116*(6), 1347–1356. https://doi.org/10.3171/2012.2.JNS11847

Ting, L. H., Chiel, H. J., Trumbower, R. D., Allen, J. L., McKay, J. L., Hackney, M. E., & Kesar, T. M. (2015). Neuromechanical Principles Underlying Movement Modularity and Their Implications for Rehabilitation. *Neuron*, *86*(1), 38–54. https://doi.org/10.1016/j.neuron.2015.02.042

Understanding the dual-task costs of walking: A StartReact study | SpringerLink. (n.d.). Retrieved March 23, 2022, from https://link.springer.com/article/10.1007/s00221-020-05817-8

Wirdefeldt, K., Adami, H.-O., Cole, P., Trichopoulos, D., & Mandel, J. (2011). Epidemiology and etiology of Parkinson's disease: A review of the evidence. *European Journal of Epidemiology*, *26*(1), 1. https://doi.org/10.1007/s10654-011-9581-6

Wollesen, B., & Voelcker-Rehage, C. (2014). Training effects on motor–cognitive dual-task performance in older adults. *European Review of Aging and Physical Activity*, *11*(1), 5–24. https://doi.org/10.1007/s11556-013-0122-z

Yau, S., Gil-Mohapel, J., Christie, B. R., & So, K. (2014). Physical Exercise-Induced Adult Neurogenesis: A Good Strategy to Prevent Cognitive Decline in Neurodegenerative Diseases? *BioMed Research International*, *2014*, e403120. https://doi.org/10.1155/2014/403120

Yitayeh, A., & Teshome, A. (2016). The effectiveness of physiotherapy treatment on balance dysfunction and postural instability in persons with Parkinson's disease: A systematic review and meta-analysis. *BMC Sports Science, Medicine and Rehabilitation*, *8*(1), 17. https://doi.org/10.1186/s13102-016-0042-0

Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2012). Do we always prioritize balance when walking? Towards an integrated model of task prioritization. *Movement Disorders*, *27*(6), 765–770. https://doi.org/10.1002/mds.24963