Balance, Body Motion, and Muscle Activity After High-Volume Short-Term Dance-Based Rehabilitation in Persons With Parkinson Disease: A Pilot Study

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Background and Purpose: The objectives of this pilot study were to (1) evaluate the feasibility and investigate the efficacy of a 3-week, high-volume (450 minutes per week) Adapted Tango intervention for community-dwelling individuals with mild-moderate Parkinson disease (PD) and (2) investigate the potential efficacy of Adapted Tango in modifying electromyographic (EMG) activity and center of body mass (CoM) displacement during automatic postural responses to support surface perturbations.

Methods: Individuals with PD (n = 26) were recruited for high-volume Adapted Tango (15 lessons, 1.5 hour each over 3 weeks). Twenty participants were assessed with clinical balance and gait measures before and after the intervention. Nine participants were also assessed with support-surface translation perturbations.

Results: Overall adherence to the intervention was 77%. At posttest, peak forward CoM displacement was reduced (4.0 ± 0.9 cm, pretest, vs 3.7 ± 1.1 cm, posttest; $P = 0.03$; Cohen's $d = 0.30$) and correlated to improvements on Berg Balance Scale ($\rho = -0.68$; $P = 0.04$) and Dynamic Gait Index ($\rho = -0.75$; $P = 0.03$). Overall antagonist onset time was delayed (27 ms; $P = 0.02$; $d = 0.90$) and duration was reduced (56 ms, ≈39%, $P = 0.02$; $d = 0.45$). Reductions in EMG magnitude were also observed ($P < 0.05$).

Discussion and Conclusions: Following participation in Adapted Tango, changes in kinematic and some EMG measures of perturbation responses were observed in addition to improvements in clinical measures. We conclude that 3-week, high-volume Adapted Tango is feasible and represents a viable alternative to longer duration adapted dance programs.

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INTRODUCTION

Balance problems are common in Parkinson disease (PD) and are challenging to treat.[1,2] Improvements on clinical measures of balance and gait have been demonstrated after several rehabilitative exercise programs for individuals with PD,[3-6] including Adapted Tango dance.[7,8] Adapted Tango elicits clinically measured balance improvements that are superior to exercise,[9] nonpartnered dance,[7] other dance-based and martial arts–based interventions,[10,11] no intervention,[8,11] and health education.[12] Recently, the importance of rehabilitation volume has received increased attention.[13,14] In PD, high-volume rehabilitation may be particularly effective, as individuals exhibit superior increases in gait speed after higher-volume/low-intensity exercise therapy (12 weeks, 150 minutes per week, 40%-50% of heart rate reserve) compared with lower-volume/high-intensity exercise therapy (12 weeks, 90 minutes per week, 70%-80% of heart rate reserve) with comparable overall work.[14] Furthermore, exercise therapy of at least 180 minutes per week is required to improve gait speed in older adults.[15] Recently, 450 minutes per week has been demonstrated to be the upper threshold of exercise volume (ie, the sweet spot) required for lowered mortality risk (by 39%), compared with sedentary older adults.[16] Previously, individuals with PD demonstrated functional improvements after 2 weeks of high-volume (450 minutes per week) Adapted Tango training.[17] Although these improvements are promising, it is unknown if longer-term therapy (ie, 3 weeks) with similar volume is feasible and possibly more effective. Also, it is unknown whether clinical changes after Adapted Tango are associated with alterations in responses to postural perturbations assessed in a laboratory setting, a common paradigm in human neurophysiology research.[18-20]

Previous studies in populations other than PD suggest that improvements in clinical measures of balance after rehabilitation may be associated with improved kinematic and electromyographic (EMG) measures during balance and gait.[21-24] For example, 3 weeks of high-volume

(450 minutes per week) Tai Chi training advanced agonist muscle activation onset times and reduced co-contraction in response to support-surface perturbations during walking in mildly balance-impaired older adults whose balance had only slightly improved, as measured by a 2-point increase on the Berg Balance Scale (BBS).[22] In individuals with poststroke hemiparesis, agility exercise therapy (10 weeks, 180 minutes per week) improved gait speed, and reduced muscle activation onset times in response to support-surface perturbations during standing.[23] Locomotor rehabilitation also improved timing of ankle plantar flexors during gait in hemiparetic individuals (12 weeks, 120 minutes per week).[24] However, it is unknown whether changes in clinical measures after Adapted Tango, a dance-based rehabilitation, which may address PD impairments through different mechanisms than Tai Chi and agility exercise,[25] would be associated with changes in muscle activity or kinematic measures during postural responses.

Electromyographic and kinematic abnormalities during responses to support surface translation perturbations in PD[18,20] differ from those of older adults[22] and stroke survivors.[23,24] During translation perturbations of the support surface, the center of mass (CoM) is displaced and medium- ($\geq$80 ms) and long-latency ($\geq$100 ms) corrective responses are generated in leg and trunk muscles, referred to as the automatic postural response.[19] Unlike the delayed responses in balance-impaired older adults[22] and in individuals with poststroke hemiparesis,[23,24] in individuals with PD, automatic postural response onset latency is typically normal or earlier than normal in agonist muscles[18] and typically earlier than normal in antagonist muscles, leading to inappropriate co-contraction.[18,20] Parkinson disease is also associated with increased total CoM displacement during perturbation responses.[26] We initiated this investigation because, to the best of our knowledge, no studies have examined changes in postural responses in PD before and after Adapted Tango.

The primary objectives of this pilot study were to determine the feasibility and investigate the efficacy of 3 weeks of high-volume (450 minutes per week) Adapted Tango in improving clinical measures of balance and gait in community-dwelling individuals with PD. We performed a repeated-measures observational study of high-volume Adapted Tango with duration increased to 3 weeks to estimate adherence and investigate efficacy. We predicted that (1) 3-week high-volume Adapted Tango would be feasible for individuals with mild-moderate PD, as demonstrated by adherence with a 95% confidence interval lower bound of 60% or more, (2) clinical measures of balance and disease severity would improve from pretest to posttest and be retained for at least 1 month, on the basis of results from previous studies demonstrating retention for 2 months,[8,12] and (3) clinical measures would be stable over 1 month before pretest, when tested in a subset of participants.

The secondary, exploratory objectives of this pilot study were to evaluate postural responses before and after Adapted Tango to examine the feasibility of and utility of using kinematic and EMG outcome measures in this type of intervention. We allocated a convenience sample of intervention participants to receive additional perturbation response testing at pretest and posttest. Muscle onset time measurements have been demonstrated to be stable across multiple days in healthy young individuals[27] and across multiple months in individuals with PD.[28] Thus, we determined that we would consider a randomized trial to be feasible and justified if we obtained preliminary efficacy evidence, as determined by reductions in CoM displacement or in antagonist muscle onset time, duration, or magnitude. To further investigate preliminary evidence of efficacy, we also examined associations between changes in clinical measures and changes in CoM displacement or in muscle activity measures after Adapted Tango.

METHODS

Study Design

This study was a repeated-measures, observational study without a control group. A double baseline procedure was employed to improve internal validity of clinical outcomes. Multiple posttest periods were used to assess stability of observed changes in clinical outcome measures. A convenience sample of study participants was allocated to additional perturbation testing before and after the intervention.

Participants and Setting

Participants were recruited at PD outreach events, senior centers, and the Emory Movement Disorders clinic. Participants met the following inclusion criteria: Hoehn & Yahr stages I-IV, diagnosis of "definite" idiopathic PD,[29] age 35 years or greater. Exclusion criteria were deep brain stimulation, other significant comorbidities, or significant musculoskeletal impairment as determined by the investigators. Participants were observed for outcome measures on 3 separate occasions. All participants were assessed within 1 week before (pretest) and within 1 week after (posttest) the intervention. Participants recruited early in the trial (n = 7) were assessed 1 month before the beginning of the intervention (1-month pretest) to establish a double baseline for these participants and examine stability of clinical measures. Participants recruited later in the trial (n = 13) were observed in a follow-up appointment, 1 month after the intervention's cessation (1-month post). The double baseline was conducted to examine the stability of measures between 1-month pretest and pretest: a time period ($\sim$1 month) that was similar to the intervention time period of 3 weeks. The 1-month posttest (follow-up) was used to detect retention (or loss) of changes between posttest and 1-month posttest also over a period of time that was similar to the interventional time period. Adapted Tango classes and clinical assessments were performed in a large multipurpose room on a university campus. Perturbation response assessments were performed in a dedicated balance laboratory elsewhere on campus. Participants provided written informed consent according to protocols approved by institutional review boards at Emory University and the Georgia Institute of Technology.

Three-Week High-Volume Adapted Tango Intervention

Participants received high-volume, moderate-intensity Adapted Tango, taught by a professional dance instructor,[30] and were to complete fifteen 90-minute Adapted Tango sessions in 3 weeks. Classes were designed to induce expenditure of 3 or more metabolic equivalents of task (METs) per minute,

as per estimates for typical ballroom dance, which is considered light- to moderate-intensity exercise by the US Centers for Disease Control and Prevention.[31] Classes began with standing warm-ups to upbeat music and continued with dancing to commercial music selections. Participants spent equal time leading and following dance steps, performed in an adapted ballroom frame, holding forearms, and classes were progressive. (See Video Abstract, Supplemental Digital Content 1, for an example of the adapted ballroom frame.) Individuals with PD were coupled with individuals without PD. Participants spent one third of class working on rhythmic entrainment to the beat during the warm-ups, such as tapping of toes or heels, or sequentially opening and closing the hands. Furthermore, the participants spent ample time (ie, 20-30 minutes) simply walking to various tango rhythms intended to enhance their musicality, that is, the ability to control the gait cycle in a more complex rhythm than typical gait. As in previous studies,[7,9,10,12] participants were allowed to take breaks as needed throughout the classes to decrease fatigue.

Outcome Measures

Clinical Balance and Gait Measures

Assessments were administered in the same order at each evaluation to minimize the effects of fatigue on measurements. Participants were assessed for general health and were observed at each visit with clinical measures including Parkinson disease severity (Unified Parkinson Disease Rating Scale [UPDRS] motor subscale III[32]), dyskinesia (total of scores 0-4 for each limb and face), the BBS[33], Dynamic Gait Index (DGI[34]), Fullerton Advanced Balance Scale (FAB[35,36]), the 2-footed Jump test, a test of neuromuscular synergies and musculoskeletal health,[37] 6-minute walk test (6MWT[38]), functional reach (FR[39]), Single/Dual Timed Up and Go (TUG[34]), fast and preferred gait speed, and cadence were measured using a stopwatch over a 20′ path.[40] The Activities-Specific Balance Confidence questionnaire (ABC[41]) and the Freezing of Gait questionnaire (FOG[42]) were also administered. Fullerton Advanced Balance Scale was recently validated in community-dwelling individuals with PD[36] and was used to avoid BBS ceiling effects. For each participant, all assessments occurred at a standardized time of day coinciding with a self-determined optimal ON period to minimize pharmacologically related motor fluctuations. Clinical balance and gait measures were performed by an experienced rehabilitation scientist or by trained research assistants. An experienced rehabilitation scientist certified by the Movement Disorders Society administered the UPDRS-III. To minimize the variability of individual UPDRS items, including the retropulsion test,[43] the same rehabilitation scientist administered the examination at each observation. Clinical data were entered and cross-verified by research assistants.

Response to Perturbation

A convenience sample of the study participants was allocated to receive additional perturbation response assessments within 2 weeks before (pretest) and within 2 weeks after (posttest) the intervention. These participants were assessed at a standardized time of day (either 9 AM or 1 PM) coinciding as closely as possibly to the participants' self-determined ON time. While wearing a safety harness, participants stood with each foot on a 6-axis (3D ground-reaction forces and moments) force plate (OR6-6; AMTI, Watertown, Massachusetts) embedded in a custom perturbation platform that translated in the horizontal plane. They were instructed to cross their arms over their chest, to focus on a landscape scene 3 m ahead, and to maintain balance with their feet in place but to take protective steps if necessary. Three perturbations were induced in each of the forward (displacing the CoM anterior toward the toes) and backward (displacing the CoM posterior toward the heels) directions of body sway.[19] These perturbations were induced within a set of 36 perturbations spanning all directions in the horizontal plane and delivered in random order. At pretest, 3 to 6 test perturbations were delivered to select the highest perturbation level each participant could maintain balance without stepping. These perturbations were excluded from analysis to control for startle effects.[44] Participants PR7 and PR9 ("PR" designates "Perturbation Response") used level 4 (peak displacement 10 cm; peak velocity 20 cm/s; peak acceleration 0.2 g; 700-ms total duration); all others used level 3 (7.5 cm; 15 cm/s; 0.1 g; 700 ms). Self-selected stance width was measured at pretest and subsequently enforced at posttest. (See Video Abstract, Supplemental Digital Content 1, for the video of the perturbation apparatus.)

Platform kinematics, surface EMG, and ground-reaction forces were sampled at 1080 Hz and processed in Matlab (The MathWorks, Natick, Massachusetts). Trials with stepping responses or arm movement were excluded from analysis. Ground reaction forces were low-pass filtered (100 Hz, third-order zero-lag Butterworth filter), and CoM acceleration in the medial-lateral and anterior-posterior directions was calculated by adding horizontal-plane ground reaction force components at each foot and dividing by participant mass (acceleration = force/mass).[19,45,46] Because estimates of CoM position from kinematic marker data were unreliable, we then integrated the acceleration twice, assuming zero initial velocity and zero initial displacement at the onset of the perturbation, to arrive at the displacement of the CoM.[47-51] Linear trends were removed from acceleration signals before integration to avoid introducing integration constants in velocity signals, and computed velocity and displacement signals were set to zero at perturbation onset to enforce the assumed initial conditions. Surface EMG (Konigsberg Instruments, Pasadena, California) was collected from leg and trunk muscles, high-pass filtered (35 Hz, third-order zero-lag Butterworth filter), demeaned, rectified, and low-pass filtered (40 Hz).[48,52,53] EMG was analyzed from ankle muscles *tibialis anterior* (TA) and *medial gastrocnemius* (MG), recorded bilaterally.[22,54] During backward sway, agonist TA is lengthened and antagonist MG is shortened. During forward sway, agonist MG is lengthened and antagonist TA is shortened. To minimize variability in electrode placement between pretest and posttest, silver/silver chloride disc electrodes were placed at 2-cm interelectrode distance according to standard EMG electrode placement guidelines[19,55] by the same experimenter at each assessment. Electromyographic records from each trial were normalized to the maximum value observed during each assessment after averaging across similar trials and across 50-ms bins.

Before statistical analysis, computed CoM displacement signals in the anterior-posterior direction and normalized EMG signals from each recorded muscle were averaged across similar trials for each participant at each assessment. The peak of each average CoM displacement signal was calculated. Onset and offset times of each average EMG signal were calculated with a computer program and corrected as necessary (14 records, ≈11%). For each average EMG signal, the first sample within a window between 80 and 300 ms after perturbation onset to cross a threshold of $M + 6 \times$ SD was first identified. Onset time was then determined as the last sample prior to the threshold-crossing sample for which the preceding 10 samples were all less than $M + 2 \times$ SD. Offset time was determined as the first sample subsequent to the threshold-crossing sample for which the following 10 samples were all less than $M + 2 \times$ SD. To avoid including responses to platform deceleration,[54] offset times were truncated to the earlier of 280 ms after EMG onset or 450 ms after perturbation onset. The duration of each average EMG signal was calculated as offset time − onset time. The magnitude of each average EMG signal was calculated by averaging over a window 80 to 450 ms after perturbation onset after removing background level.[18,20] After all processing, kinematic and EMG data of each participant were summarized as a data set containing 13 variables (CoM displacement, 1 variable, and 3 variables [Onset, Duration, and Magnitude] for each of the 4 muscles analyzed [TA from the left and right leg and MG from the left and right leg], for a total of 13 variables) for each level of the independent variables Time [pretest, posttest], Perturbation Direction [forward, backward], and Perturbation Level [3, 4]).

Sample Size

Sample size for the intervention (n = 26) was selected to achieve effect sizes in clinical balance and gait measures comparable with a previous 2-week intervention (conducted with n = 14)[17] after allowing for approximately 40% attrition, given the longer term of the intervention. Sample size for the group of participants allocated to postural response testing (n = 10) was selected on the basis of previous literature demonstrating the feasibility of identifying effects of interest in EMG and kinematic measurements of individuals with PD in cross-sectional[56] and longitudinal[57] studies.

Statistical Analyses

Descriptive Analyses and Effect Sizes

Descriptive statistics were calculated for all outcomes at each time point. Magnitude effect sizes representing changes from pretest to posttest were calculated with Cohen's d,[58] which describes the difference in means scaled to units of standard deviation, in this case taken from pretest.

Sampling and Stability of Clinical Measures at Pretest

To test that participants allocated to perturbation response testing represented an unbiased sample of the study population, baseline demographic characteristics were compared between perturbation response participants and the rest of the study participants with 1-way analyses of variance (ANOVAs) (Group [allocation to perturbation response testing vs nonallocation to perturbation response testing]) or Kruskal-Wallis 1-way ANOVAs on ranks for nonparametric data. To establish test-retest stability of clinical balance and gait measures in this cohort, intraclass correlation coefficients were calculated between 1-month pretest (screening) and pretest. Intraclass correlation coefficient values more than 0.75 and more than 0.40 were characterized as "excellent" and "fair to good," respectively.

Statistical Analyses of Changes in Clinical Measures Across Pretest, Posttest, and Follow-up

To investigate the efficacy of the intervention in improving clinical measures of balance and gait, repeated-measures ANOVAs (time [pretest, posttest, follow-up]), with Holms-Sidak post hoc tests determined significance of changes in clinical measures between pretest, posttest, and follow-up. Greenhouse-Geisser corrections to degrees of freedom were applied when sphericity was violated as per Mauchly's Test. The last observation was carried forward in cases of missing data. Additional paired t tests on individual UPDRS-III items and on average tremor score (the average of the scores of items III.20 and III.21; cf[59]) were performed post hoc to identify items that changed from pretest to posttest.

Statistical Analyses of Changes in Postural Responses From Pretest to Posttest

To investigate the potential efficacy of the intervention in altering CoM displacement and muscle activity during perturbation responses, separate repeated-measures ANOVAs (time [pretest, posttest], with perturbation level [3, 4] included as a covariate) were initially run. Perturbation level was entered as a covariate in these analyses to control for the potential effects of perturbation level on CoM displacement and muscle activity demonstrated in previous studies.[19,27] No statistical testing of differences between perturbation levels 3 and 4 was performed. These ANOVAs determined the significance of changes in peak CoM displacement and in onset time, duration, and magnitude of each recorded muscle (TA-L, TA-R, MG-L, MG-R) in each perturbation direction.

Changes in Postural Responses Based on Pooled EMG Data

Secondary univariate ANOVAs were also conducted on EMG variables onset time, duration, and magnitude after recoding data from individual muscles as either TA or MG, or as agonist or antagonist. In these analyses: (1) Data from TA-L and TA-R were pooled for analysis as "TA," and data from MG-L and MG-R were pooled for analysis as "MG." Secondary ANOVAs (time [pretest, posttest] × perturbation level [3, 4] × participant [1-9]; with participant as a nested factor within perturbation level, and a Time × Participant interaction term) were then conducted to determine significance of changes in onset time, duration, and magnitude of TA and MG in each perturbation direction. (2) Data from MG during forward CoM perturbations and from TA during backward CoM perturbations were pooled for analysis as "agonists," and data from TA during forward CoM perturbations and from MG during backward CoM perturbations were pooled for analysis as

"antagonists." Secondary ANOVAs (time [pretest, posttest] × perturbation level [3, 4] × participant [1-9]; with participant as a nested factor within perturbation level, and a Time × Participant interaction term) were then conducted to determine significance of changes in onset time, duration, and magnitude of agonists and antagonists.

Associations Between Changes in Clinical Measures and Changes in Postural Responses

To test whether improvements in clinical measures of balance function after Adapted Tango were associated with alterations in perturbation responses and to detect possible evidence of efficacy of the intervention in altering CoM displacement and muscle activity during perturbation responses, associations between changes on BBS, FAB, and DGI and changes in perturbation response measures were determined with Spearman correlation coefficients in a complete case analysis. Statistical analyses were performed using IBM SPSS 20 software (IBM Corp., Armonk, New York) and SAS University Edition 9.2 (SAS Institute, Inc., Cary, North Carolina). All tests were performed with 2 tails and considered significant at $P < 0.05$. Summary statistics are reported as $M \pm$ SD unless otherwise noted.

RESULTS

Participant Flow and Recruitment

A flow chart of participants through the study is presented in Figure 1. Twenty-six participants were recruited for the trial. Of these, 4 withdrew before pretest assessment (family/health issues, n = 1; lack of interest, n = 1; loss of contact/unknown, n = 1). These individuals were excluded from analyses of outcome measures as no data were available, but they were included in estimates of adherence to the intervention. Of the remaining 22 participants, 2 participants withdrew before posttest (family/health issues, n = 1; scheduling difficulties, n = 1); all others completed all planned assessments. Adherence to the intervention exceeded previously expected targets (20/26 observed vs 15/26 expected), providing evidence that 3-week high-volume Adapted Tango is feasible. Overall adherence to the intervention was 77%, with 95% confidence interval (CI: 61%-93%). Adherence was higher among those who attended at least 1 class (91% [95% CI: 78%-100%]). Posttest and 1-month posttest data were unavailable for participants who withdrew before posttest (n = 2). One-month posttest data were not collected for those (n = 7) allocated to 1-month pretest (screening) assessments. Participants who completed at least 1 clinical assessment were invited to participate in postural response assessments until the Adapted Tango intervention began and enrollment for additional testing was closed. Nine participants were enrolled in postural response testing. Demographic characteristics of the 22 participants included in the final analysis (68% female, 65.4 ± 12.8 years) are summarized in Table 1. Detailed characteristics of the 9 participants allocated to additional postural response testing are summarized in Table 2.

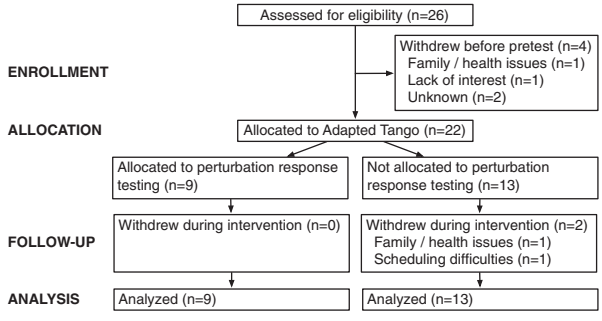


Figure 1. Diagram depicting flow of participants through the study.

During the study, no adverse events or deviations from the intervention were observed. Two small deviations from the perturbation response assessment protocol occurred. In one participant (PR1), self-selected stance width was not correctly enforced. This participant used a 9.5-cm wider stance width at posttest. These data were retained in analyses as stance width minimally affects forward and backward perturbations.[18] Because of equipment failure, only MG recorded from the right leg (MG-R) was available at posttest for participants PR4, PR5, and PR6. Adapted Tango classes and all assessments were conducted from August through October 2011.

Baseline Data

At pretest, no significant effects of group (allocated to perturbation response testing vs not allocated to perturbation response testing) were identified in age, sex, height, weight, disease duration, UPDRS-III, Hoehn and Yahr stage, or dyskinesia score. Correlational analyses showed very strong correlations between FAB and BBS ($r = 0.81$; $P < 0.001$) and between FAB and DGI ($r = 0.87$; $P < 0.001$). Test-retest analyses demonstrated that clinical measures were stable over the month before treatment, with "excellent" intraclass correlation coefficient values (>0.75) obtained for BBS (0.93), DGI (0.90), FR (0.79), ABC (0.94), and FOG (0.88) and intraclass correlation coefficients characterized as "fair to good" (>0.4) obtained for 6MWT (0.60).

Clinical Measures

Descriptive statistics, change scores, and effect sizes for all clinical measures are tabulated in Table 3. At posttest, scores increased on BBS ($P < 0.01$), FAB ($P < 0.001$), and DGI ($P = 0.01$) (Figure 2). All significant increases at posttest remained significant at 1-month posttesting in post hoc tests (BBS, $P < 0.001$; FAB, $P < 0.001$; DGI, $P = 0.04$). Participants also increased preferred and fast cadence (preferred, $P < 0.01$; fast, $P = 0.03$) and exhibited decreased UPDRS-III (motor subscale) total scores ($P < 0.01$) from pretest to follow-up. Paired t tests performed post hoc on individual UPDRS-III items identified significant improvements on postural stability (item III.30; 0.95 ± 0.58, pretest, vs 0.60 ± 0.68, posttest, $M \pm$ SD, $P = 0.03$), and speech (item III.1; 1.18 ± 0.73, pretest vs 1.00 ± 0.79, posttest; $P = 0.02$). No changes were observed on 6MWT ($P = 0.11$), FR ($P = 0.48$), ABC ($P = 0.22$), FOG ($P = 0.38$), gait speed (preferred, $P = 0.69$; fast, $P = 0.18$), Jump ($P = 0.06$), or TUG ($P = 0.30$).

Table 1. Characteristics of Participants in the 3-Week High-Volume Adapted Tango Rehabilitative Intervention

Variable	All Participants (n = 22)	Participants Allocated to Receive Perturbation Response Testing (n = 9)	Participants Not Allocated to Receive Perturbation Response Testing (n = 13)	P[a]
Age ($M \pm$ SD), y	65.4 ± 12.8	68.0 ± 14.6	63.5 ± 11.7	0.46
Sex, n (%)				0.65
Male	7 (32%)	2 (22%)	5 (38%)	
Female	15 (68%)	7 (78%)	8 (62%)	
Height ($M \pm$ SD), m	1.72 ± 0.11	1.76 ± 0.07	1.68 ± 0.12	0.06
Weight ($M \pm SD$), kg	74.3 ± 13.7	73.2 ± 11.4	75.0 ± 15.5	0.76
PD duration ($M \pm$ SD), y	6.1 ± 3.8	6.0 ± 3.9	6.2 ± 3.8	0.89
UPDRS III, $M \pm$ SD	30.4 ± 6.1	30.0 ± 4.7	30.6 ± 7.0	0.81
H & Y, n (%)				0.83
Stage 1.5	1 (4%)	0 (0%)	1 (8%)	
Stage 2	12 (55%)	5 (56%)	7 (54%)	
Stage 2.5	4 (18%)	1 (11%)	3 (23%)	
Stage 3	5 (23%)	3 (33%)	2 (15%)	
Dyskinesia score ($M \pm$ SD)	1.8 ± 2.5[b]	2.1 ± 2.5[c]	1.6 ± 2.5[d]	0.65
Tremor score ($M \pm$ SD)	0.4 ± 0.4	0.5 ± 0.7	0.3 ± 0.2	0.32

Abbreviations: H & Y, modified Hoehn and Yahr stage; PD, Parkinson disease; UPDRS III, Unified Parkinson's Disease Rating Scale Motor Subscale III.
[a]*P* values are from independent-samples *t* tests for continuous variables or Fisher exact tests for categorical variables comparing participants allocated to receive perturbation response testing with those not allocated to receive perturbation response testing. [b]n = 19. [c]n = 7. [d]n = 12.

Table 2. Detailed Characteristics of Participants in the 3-Week High-Volume Adapted Tango Rehabilitative Intervention Allocated to Receive Perturbation Response Testing

Participant	Age, y	Sex	Height, m	Weight, kg	PD Duration, y	UPDRS III (/108)	H & Y	Dysk (/20)	Medications
PR1	68	M	1.80	80.6	5	26	2	1	C/L, Ent., Rop.
PR2	79	M	1.68	68.0	3	40	2	0	C/L, Ama.
PR3	64	M	1.75	79.3	11	25	2.5	6	C/L, Ent.
PR4	81	M	1.78	83.8	3	35	3	0	C/L, Ent., Ras.
PR5	74	M	1.73	76.1	5	28	2	0	C/L
PR6	73	F	1.80	62.5	4	28	3	0	C/L, Ras.
PR7	36	M	1.83	74.7	6	29	2	4	C/L
PR8	81	F	1.65	48.9	14	31	3	4	C/L, Rop.
PR9	56	M	1.85	82.9	3	28	2	1	C/L

Abbreviations: Ama., amantadine; C/L, carbidopa/levodopa; Dysk, dyskinesia score; Ent., entacapone; H & Y, modified Hoehn and Yahr stage; PD, Parkinson disease; Ras., Rasagiline; Rop., ropinirole; UPDRS III, Unified Parkinson's Disease Rating Scale Motor Subscale III.

Postural Responses

Changes in Postural Responses From Pretest to Posttest

Descriptive statistics and effect sizes for kinematic and individual EMG measures are tabulated in Table 4. At posttest, CoM displacement was reduced during forward CoM perturbations ($P = 0.03$) and unchanged during backward CoM perturbations ($P = 0.39$) (Figure 3). Initial analyses of individual muscles revealed significant reductions in TA-L magnitude ($P = 0.02$) and MG-R magnitude ($P = 0.01$) during forward CoM perturbations and no statistically significant changes in onset, duration, or magnitude of any individual muscles during backward CoM perturbations.

Secondary Analyses Using Pooled EMG Data

Descriptive statistics and effect sizes for pooled EMG measures are tabulated in Table 5. Secondary analyses of EMG data pooled across legs revealed significant delays in TA onset time (forward CoM perturbations, $P = 0.04$; backward, $P = 0.03$), TA duration (forward, $P = 0.02$), and MG onset time (backward, $P < 0.01$). Secondary analyses of EMG data pooled across legs and across perturbation directions revealed significant delays in antagonist onset time (27 ms; $P = 0.02$), agonist onset time (10 ms, $P < 0.05$), and a significant reduction in antagonist duration (56 ms, ≈39%, $P = 0.02$).

Associations Between Clinical Changes and Changes in Postural Perturbations

Significant correlations were identified between reductions in forward CoM displacement and increased BBS scores ($\rho = -0.68$; $P = 0.04$) and DGI ($\rho = -0.75$; $P = 0.03$). No significant correlations were identified between increased BBS scores and delayed antagonist onset times ($\rho = 0.78$; $P = 0.07$), between reductions in forward CoM displacement and increased FAB scores ($\rho = -0.49$; $P = 0.19$), or between changes in backward CoM displacement and improvements in BBS ($\rho = 0.37$; $P = 0.33$), FAB ($\rho = 0.52$; $P = 0.15$), or DGI ($\rho = 0.21$; $P = 0.62$).

DISCUSSION

The low attrition observed here (2 of 22 participants who began the intervention) and improvements observed in these individuals with mild-moderate PD on clinical measures of balance, gait, and disease severity after 3-week, high-volume

Table 3. Mean Values (±SD) of Clinical Measures of Balance and Gait Before and After the 3-Week, High-Volume Adapted Tango Rehabilitative Intervention[a]

	Pretest (n = 20)	Posttest (n = 20)	Follow-up (n = 13)	Change Scores (n = 20)	Effect Size
PD severity					
UPDRS-III (/108)[b]	30.4 ± 6.1	27.5 ± 6.3	23.6 ± 5.6[c]	−2.9 ± 5.4[d]	−0.47
Dyskinesia	1.7 ± 2.1 (n = 18)	1.3 ± 2.1	1.8 ± 2.1	−0.3 ± 1.8 (n = 16)	−0.14
FOGB	5.2 ± 5.0	5.3 ± 5.2	4.9 ± 4.9 (n = 14)	−0.3 ± 1.9	−0.05
Static and dynamic balance					
BBS (/56)[b]	49.3 ± 6.4	53.1 ± 3.5[c]	54.4 ± 1.7[c]	3.8 ± 4.2[e]	0.59
FAB (/40)[b]	27.1 ± 6.6	31.0 ± 5.3[c]	31.6 ± 7.4 (n = 12)[c]	3.7 ± 3.5	0.56
DGI (/24)[b]	19.1 ± 3.5	21.2 ± 2.1 (n = 19)[c]	20.9 ± 2.6 (n = 12)[c]	1.8 ± 2.4 (n = 19)[f]	0.53
FR, m	0.30 ± 0.07	0.32 ± 0.07	0.30 ± 0.07	0.01 ± 0.06	0.14
ABC (/100)	77.0 ± 23.0 (n = 21)	79.6 ± 23.3	85.1 ± 16.4 (n = 14)	2.9 ± 12.6 (n = 19)	0.12
TUG, s	9.3 ± 3.1	8.2 ± 2.1	8.9 ± 3.6 (n = 12)	−1.0 ± 2.1	−0.31
TUG cognitive, s	12.6 ± 4.3	11.2 ± 3.7	11.0 ± 6.0 (n = 12)	−1.4 ± 3.0	−0.32
TUG manual, s	11.3 ± 3.9	10.5 ± 3.7	10.8 ± 3.8 (n = 12)	−0.6 ± 2.0	−0.16
Two-Footed Jump, m	0.50 ± 0.39	0.60 ± 0.37 (n = 19)	0.66 ± 0.47 (n = 12)	0.09 ± 0.19 (n = 19)	0.23
Gait					
6MWT, m	396.3 ± 87.7	437.1 ± 86.0	450.3 ± 93.2 (n = 12)	32.4 ± 83.0[g]	0.37
Preferred gait speed, m/s	1.19 ± 0.21	1.23 ± 0.26	1.26 ± 0.19 (n = 12)	0.02 ± 0.19[h]	0.10
Preferred cadence, steps/min[b]	109.6 ± 11.1	115.3 ± 9.7	120.2 ± 8.1 (n = 12)[c]	6.1 ± 10.7	0.55
Fast gait speed, m/s	1.67 ± 0.26	1.78 ± 0.34	1.77 ± 0.31 (n = 12)	0.09 ± 0.18	0.35
Fast cadence, steps/min[b]	136.3 ± 16.4 (n = 21)	141.9 ± 12.6	144.1 ± 15.4 (n = 12)[c]	7.6 ± 11.8 (n = 19)	0.47

Abbreviations: ABC, Activities-specific Balance Confidence Scale; BBS, Berg Balance Scale; DGI, Dynamic Gait Index; FAB, Fullerton Advanced Balance Scale; 6MWT, Six-Minute Walk Test; FOGB, Freezing of Gait questionnaire B; FR, Functional Reach; TUG, Timed Up and Go test; UPDRS, Unified Parkinson's Disease Rating Scale.

[a] Values are shown as $M \pm SD$ at each time point. Effect sizes (Cohen's d) are calculated as difference in means between posttest and pretest divided by standard deviation at pretest.

[b] Main effect of time ($P < 0.05$), repeated-measures ANOVA with Holms-Sidak post hoc tests.

[c] Significantly different from pretest. The last observation was carried forward in cases of missing data.

[d-h] Where available, Minimal Clinically-Important Differences (MCIDs) are noted. [d] MCID = 2.5 points.[60] [e] MCID (estimated from balance-impaired older adults) = 7 points,[61] Minimal Detectable Change (estimated from PD) = 5 points.[62] [f] MCID (estimated from community-dwelling older adults) = 1.9 points.[63] [g] MCID (estimated from geriatric individuals and stroke survivors) = 47 m.[64] [h] MCID (estimated from geriatric individuals and stroke survivors) = 0.10 m/s.[64]

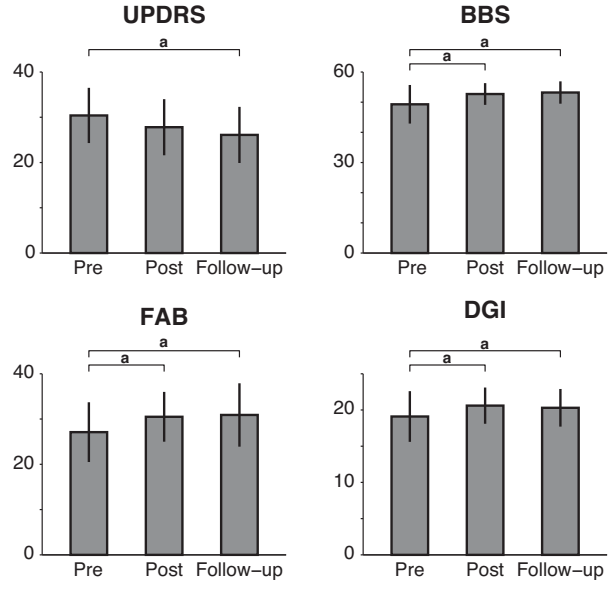


Figure 2. Clinical measures of balance and gait before and after the intervention. BBS, Berg Balance Scale; DGI, Dynamic Gait Index; FAB, Fullerton Advanced Balance Scale; UPDRS, Unified Parkinson's Disease Rating Scale, motor subscale III. Bars and error bars indicate $M \pm SD$. The last observation was carried forward in cases of missing data. All measures shown exhibited a main effect of time ($P < 0.05$) in repeated-measures ANOVA. Superscript indicators ([a]) indicate significant differences from pretest determined with Holms-Sidak post hoc tests, $P < 0.05$.

Adapted Tango demonstrate that the program volume is feasible and may have efficacy comparable with longer programs with similar total doses. This pilot study is the first to measure automatic postural responses before and after Adapted Tango. In a convenience sample of the study participants, we observed reductions in forward CoM displacement and changes in some measures of EMG magnitude and timing after Adapted Tango. On the basis of this, we consider a subsequent randomized Adapted Tango trial with kinematic and EMG outcome measures to be feasible and justified.

Benefits and Feasibility of High-Volume Exercise in Persons With PD

High-volume exercise (>180 minutes per week) is necessary to improve older adults' gait speed.[15] We observed overall adherence to the high-volume intervention of 77%, with 95% confidence interval 61% to 93%, achieving the stated primary feasibility criterion of 60% and demonstrating that 3-week, high-volume Adapted Tango is feasible in this population. After the intervention, we observed improvements in measures of disease severity and balance (changes: UPDRS, 2.9; BBS, 3.8) comparable to a previous 2-week high-volume Adapted Tango trial (UPDRS, 4.6; BBS 2.8)[17] and to 2 previous longer duration trials (ie, 20 hours over 13 weeks: UPDRS, 1.6; BBS, 3.9; 20 hours over 10 weeks: BBS, 3.6).[7,10] Minimal clinically important differences (MCIDs) have not been established for many of the outcome measures used in this population. However, clinically significant changes were observed in UPDRS-III (2.9 points vs MCID 2.5[60]) and marginally significant changes were observed in DGI (1.8 points vs MCID

Table 4. Mean Values (±SD) of Primary Kinematic and Electromyographic Measures of Perturbation Responses Before and After the 3-Week, High-Volume Adapted Tango Rehabilitative Intervention

	Pretest		Posttest		Effect Size
	n	*M* ± SD	n	*M* ± SD	
Kinematic					
CoM displacement, backward (cm)	9	4.17 ± 0.97	9	4.26 ± 1.04	0.09
CoM displacement, forward (cm)[a]	9	3.97 ± 0.93	9	3.69 ± 1.13	−0.30
Individual muscle analyses					
Backward perturbation					
TA-L onset, ms	9	124 ± 10	6	138 ± 10	1.40
TA-L duration, ms	9	243 ± 63	6	231 ± 77	−0.19
TA-L magnitude, nu	9	0.48 ± 0.08	6	0.50 ± 0.08	0.30
TA-R onset, ms	9	133 ± 14	6	136 ± 7	0.21
TA-R duration, ms	9	274 ± 19	6	259 ± 33	−0.79
TA-R magnitude, nu	9	0.50 ± 0.07	6	0.48 ± 0.11	−0.22
MG-L onset, ms	4	152 ± 14	2	153 ± 22	0.07
MG-L duration, ms	9	100 ± 121	6	85 ± 131	−0.12
MG-L magnitude, nu	9	0.14 ± 0.16	6	0.06 ± 0.16	−0.52
MG-R onset, ms	4	149 ± 10	3	161 ± 12	1.20
MG-R duration, ms	9	58 ± 91	9	34 ± 71	−0.26
MG-R magnitude, nu	9	0.12 ± 0.17	9	0.02 ± 0.17	−0.64
Forward perturbation					
TA-L onset, ms	8	137 ± 29	3	175 ± 28	1.31
TA-L duration, ms	9	203 ± 118	6	96 ± 122	−0.91
TA-L magnitude, nu[a]	9	0.11 ± 0.07	6	0.09 ± 0.09	−0.30
TA-R onset, ms	9	129 ± 40	5	167 ± 23	0.95
TA-R duration, ms	9	206 ± 108	6	154 ± 128	−0.48
TA-R magnitude, nu	9	0.11 ± 0.06	6	0.09 ± 0.08	−0.30
MG-L onset, ms	9	141 ± 36	6	141 ± 27	0.00
MG-L duration, ms	9	183 ± 90	6	174 ± 96	−0.10
MG-L magnitude, nu	9	0.34 ± 0.09	6	0.32 ± 0.16	−0.23
MG-R onset, ms	9	124 ± 20	8	143 ± 20	0.95
MG-R duration, ms	9	236 ± 89	9	216 ± 101	−0.22
MG-R magnitude, nu[b]	9	0.39 ± 0.18	9	0.34 ± 0.09	−0.28

Abbreviations: MG, medial gastrocnemius; nu, normalized units; TA, tibialis anterior.
[a] $P \leq 0.05$; [b] $P \leq 0.01$, ANOVA.

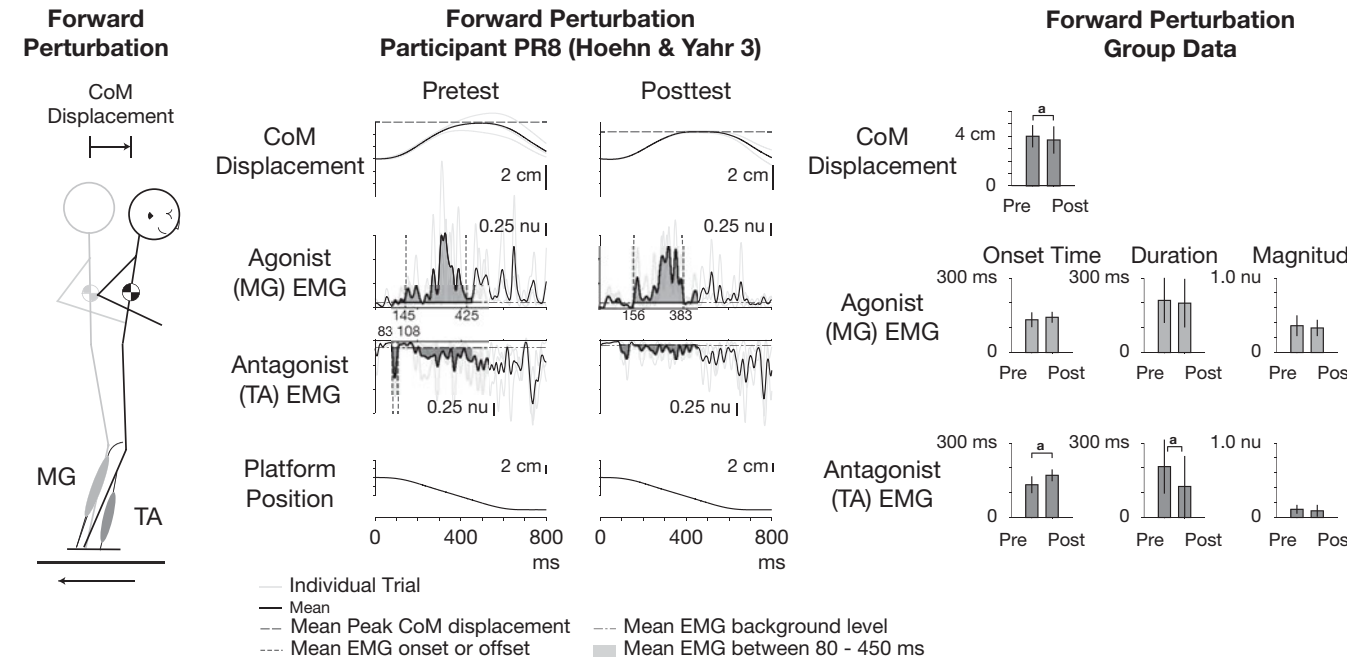
1.9 in community-dwelling older adults.[63]) While these results ostensibly support the benefits of the program, it is important to be extremely cautious in any interpretation. The results of this pilot study will require replication with a more appropriately powered sample size. Although the participants exhibited a 3.4-point improvement on BBS, this change is less than the MCID of 7 points established in older adults with balance impairments[61] and also less than the Minimal Detectable Change (MDC) of 5 points established in individuals with PD. This cohort was relatively higher functioning than the reference population for the MDCs determined for the BBS in PD (49.3 ± 6.4 vs 42 ± 11.2); therefore, there may have been some ceiling effects on this measure. Improvements were observed on the more challenging but lesser used FAB, and small improvements were observed in the postural stability UPDRS-III item (0.35 points, comparable to the difference observed in this item between the OFF and ON medication states[65]). However, clearly a similar cohort would need to be recruited and examined in comparison to a control group to make definitive conclusions about the efficacy of this high-volume but short-term dose of Adapted Tango. Vigorous ongoing exercise that increases heart rate and oxygen uptake could be neuroprotective for individuals with PD[66]; however, high-volume/low-intensity exercise therapy may be superior to low-volume/high-intensity exercise therapy for changes in gait speed.[14] We noted sustained gains 1 month after the high-volume Adapted Tango treatment ended, consistent with prior work demonstrating gains maintained over 1 month,[7] and 3 months,[12] after intervention cessation. The 3-week Adapted Tango protocol may be useful in crossover designs that can be completed in a short overall time frame, which is beneficial for academic research studies that rely on student volunteer personnel over the course of an academic semester.

Electromyographic and Kinematic Measures From Support-Surface Perturbation as Rehabilitation Outcome Measures

On the basis of the observed reductions in forward CoM displacement and changes in antagonist onset and duration, we consider a subsequent randomized trial of Adapted Tango with kinematic and EMG outcome measures to be feasible and justified. Given the limited sample size, the observed changes in muscle activity could be attributed to chance in many cases. However, average effect sizes observed in individual muscle analyses were moderate (average effect size 0.50), and generally comparable with those observed in UPDRS-III (0.47), BBS (0.59), FAB (0.56), and DGI (0.53). Particularly because effect sizes are less susceptible to the influence of small sample sizes than *P* values, we interpret these results as evidence that EMG and kinematic measures would be feasible and potentially useful when applied in a larger sample in this type of intervention. Associations between changes in clinical measures observed after the intervention and changes in kinematic measures provided additional evidence that laboratory-assessed balance measures are feasible as objective rehabilitative outcomes for Adapted Tango.

Generalizability

The feasibility results obtained here appear generalizable to subsequent controlled trials without substantial modifications to the basic protocol. We anticipate that a subsequent randomized trial would test the hypothesis that CoM displacement would be reduced and automatic postural response onset latency would be delayed from pretest to posttest after Adapted Tango, compared to standard care. The following modifications could improve the precision of subsequent studies. A reduced number of clinical outcomes, all collected at the same visit as postural response testing, would improve the precision of correlational analyses and reduce the potential for fatigue effects. The postural stability UPDRS item has known limitations in discriminating fallers from nonfallers[65] and lower interrater reliability than tests including the Push and Release test.[43] Balance outcome measures should be evaluated carefully to improve external validity and to reduce participant burden. At posttest, we did not observe reductions in backward CoM displacement, despite reductions in forward CoM displacement, altered antagonist activity, and improved postural stability as measured by the UPDRS. This may reflect the increased difficulty and fewer biomechanical strategies available to recover balance when falling backward



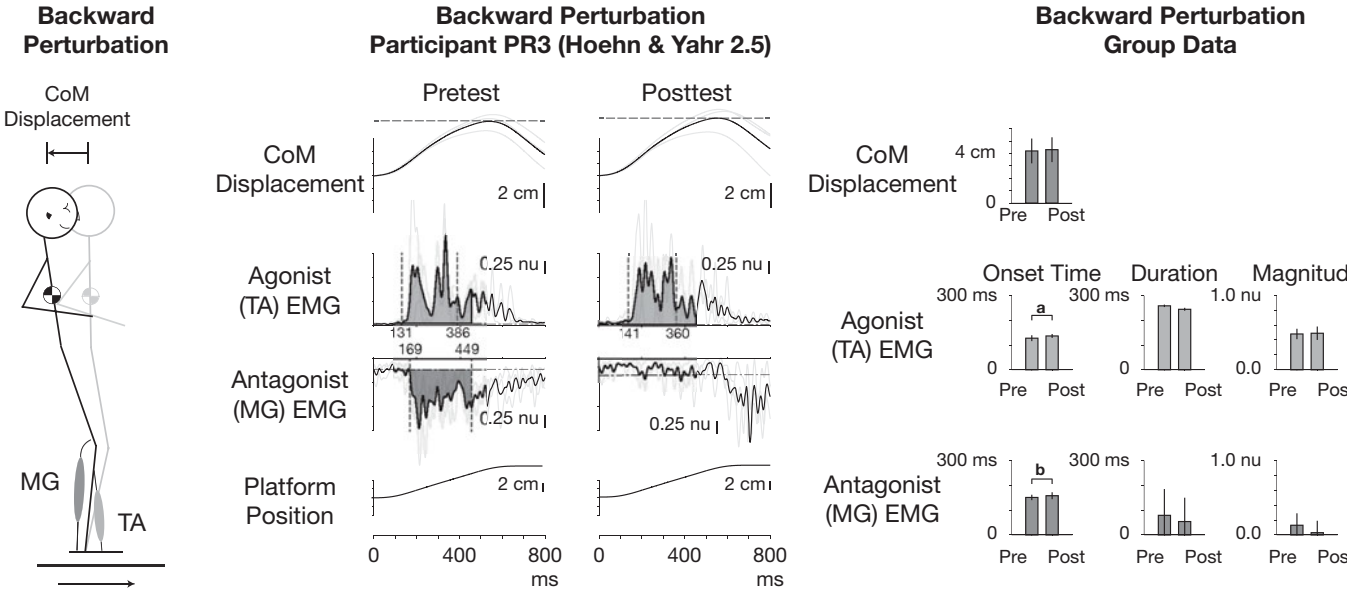


Figure 3. Examples of center of mass (CoM) displacement and muscle activity during automatic postural responses to forward (above) and backward (below) perturbations before and after the intervention. From left to right in each row, a cartoon describing perturbation direction, exemplar data of one participant at pretest and posttest, and group data across participants are shown. Shaded regions in exemplar data plots designate area under average EMG curves 80 to 450 ms after perturbation onset. Note that scale is reversed for antagonist muscles, and absolute CoM displacement is shown as positive for both perturbation directions. Bars and error bars in group data designate $M \pm$ SD. $^{a}P < 0.05$, $^{b}P < 0.01$; ANOVA.

in individuals with PD, who are particularly unstable during backward sway.[20,67] Overall, the number of trials delivered in which a foot, heel, or toe lift or arm flailing occurred was reduced from 31% at pretest to 23% at posttest, suggesting that perturbations in both directions were less challenging at posttest, possibly because of altered postural strategies that were not captured in our analyses of CoM displacement. A more complete kinematic and kinetic data set, including variables such as center of pressure and stability margin,[67] should be collected to better characterize postural strategies during perturbation responses and investigate this asymmetric response. As posterior perturbation responses and the UPDRS

Table 5. Mean Values (±SD) of Secondary Pooled Electromyographic Measures of Perturbation Responses Before and After the 3-Week, High-Volume Adapted Tango Rehabilitative Intervention

	Pretest		Posttest		Effect Size
	n	$M \pm SD$	n	$M \pm SD$	
TA, pooled					
Backward perturbation					
TA onset[a]	18	128 ± 12	12	137 ± 8	0.75
TA duration	18	259 ± 48	12	245 ± 58	−0.29
TA magnitude	18	0.49 ± 0.07	12	0.49 ± 0.09	0.06
Forward perturbation					
TA onset[a]	17	132 ± 34	8	170 ± 24	1.12
TA duration[a]	18	205 ± 109	12	125 ± 123	−0.73
TA magnitude	18	0.11 ± 0.06	12	0.09 ± 0.08	−0.31
MG, pooled					
Backward perturbation					
MG onset[b]	8	151 ± 11	5	158 ± 14	0.64
MG duration	18	79 ± 106	15	54 ± 99	−0.24
MG magnitude	18	0.13 ± 0.16	15	0.03 ± 0.16	−0.62
Forward perturbation					
MG onset	18	132 ± 30	14	142 ± 22	0.33
MG duration	18	210 ± 91	15	199 ± 98	−0.12
MG magnitude	18	0.36 ± 0.14	15	0.33 ± 0.11	−0.23
Agonist, pooled					
TA, backward; MG, forward					
Agonist onset[a]	36	130 ± 23	26	140 ± 17	0.43
Agonist duration	36	234 ± 76	27	220 ± 84	−0.18
Agonist magnitude	36	0.43 ± 0.13	27	0.40 ± 0.13	−0.19
Antagonist, pooled					
MG, backward; TA, forward					
Antagonist onset[a]	25	138 ± 30	13	165 ± 21	0.90
Antagonist duration[a]	36	142 ± 124	27	86 ± 114	−0.45
Antagonist magnitude	36	0.12 ± 0.12	27	0.06 ± 0.13	−0.52

Abbreviations: MG, medial gastrocnemius; nu, normalized units; TA, tibialis anterior.
[a] $P \leq 0.05$; [b] $P \leq 0.01$, ANOVA.

postural stability item are correlated in the practically defined 12-hour OFF,[67] but not in the ON,[68] medication state, testing should be performed in the practically defined 12-hour OFF state to improve the precision of correlational analyses[68] and the discriminatory ability of clinical measures.[65,69]

Limitations

This pilot study has several limitations that should be addressed in subsequent controlled trials. Caution should be used in interpreting these results, given the small effect sizes of most measures, the potential for Type II error, and the lack of a control group. Furthermore, the small sample size left the study underpowered. Although we provide test-retest reliability findings that demonstrate stability of clinical mobility measures within these individuals with PD, the absence of a parallel control group for EMG and kinematic measures prevents us from attributing changes in these measures to the effects of the intervention. The study used a large number of outcome measures, which increases the likelihood of chance findings. In particular, a plausible mechanism for Adapted Tango in improving speech (UPDRS-III item 1) is unknown. Parkinson disease is most often associated with hypokinetic dysarthria attributed to a decreased range of motion in the speech mechanism.[70] We observed improved preferred and fast cadence after the intervention, as well as improved speech—these changes may reflect a common underlying mechanism. However, it is also possible that this unexpected finding is spurious and should be interpreted with caution. The study also used a convenience sample of participants for postural response outcome measures. Although these participants did not differ in demographic measures from the other participants in the study, unknown selection biases may limit the generalizability of these findings. Since the Adapted Tango classes represent a form of group exercise, in future studies it would be valuable to assess changes in measures of social participation.[71]

CONCLUSIONS

These results demonstrate that a 3-week, high-volume Adapted Tango rehabilitative intervention is feasible for individuals with mild-moderate PD and that randomized Adapted Tango trials using laboratory-assessed measures of postural responses are feasible and justified.

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