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Original Research

A Multi-Directional Treadmill Training Program for Improving Gait, Balance, and Mobility in Individuals with Parkinson's Disease: A Case Series

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ABSTRACT

International Journal of Exercise Science 8(4): 372-384, 2015. Treadmill training is a commonly used intervention for improving gait in people with Parkinson's disease (PD). However, little is known about how treadmill training may also influence balance and other aspects of mobility. The purpose of this case series was to explore the feasibility and possible benefits of multi-directional treadmill training for individuals with PD. Four participants (62.3 ± 6.5 yrs, Hoehn & Yahr 2-4) performed 8 weeks of treadmill training 3 times per week. Weeks 1-4 included forward walking only, while weeks 5-8 included forward and multi-directional walking. Participants were tested every 4 weeks on 4 separate occasions. Outcome measures included the following: gait speed, 6-minute walk test (6MWT), instrumented Timed Up and Go, Four Square Step Test (FSST), Mini Balance Evaluation Systems Test (Mini-BESTest), Activities Specific Balance Confidence scale (ABC) and the 39-item Parkinson's Disease Questionnaire (PDQ-39). Improvements were demonstrated for all gait and balance measures. Improvements exceeded minimal detectable change (MDC) and/or minimal clinically important difference (MCID) values for gait speed (3 participants), 6MWT (all 4 participants), and the Mini-BESTest (2 participants). Participants experienced greater relative improvements for most measures during the multi-directional walking portion of the program. Multi-directional treadmill training was feasible for 4 individuals with moderate to severe Parkinson's disease and may have additional benefits for gait, balance and mobility than forward walking alone. Further research may be warranted for this novel intervention.

KEY WORDS: Exercise, stride length, stability, movement

INTRODUCTION

Parkinson's disease (PD) is the second most common neurodegenerative disorder, and its prevalence is expected to increase dramatically in the near future because of a rapidly aging population (20). Pharmacological agents remain the primary treatment for symptoms such as bradykinesia, rigidity, and tremor, but these pharmacological agents are less effective in addressing balance and gait impairments associated with the disease (2, 3). Exercise is also considered an important component of managing the symptoms of PD. Several recent systematic reviews have demonstrated that treadmill training is effective for improving gait speed, stride length, and walking endurance (10, 17) and there is emerging evidence that treadmill training may also improve balance and reduce fall risk (5, 8, 23, 27). Since treadmill training has the capability of addressing multiple impairments associated with PD, it may be a particularly useful intervention warranting further investigation.

Researchers have speculated that treadmill training may achieve this benefit by driving motor output through the consistent external sensory cues provided by the moving belt (1). Additional improvements may also come from increases in aerobic fitness, better walking economy, and possible neuro-protective benefits (15). Most commonly, however, treadmill training has included only forward walking. Yet many common activities of daily living and many important balance reactions require sideways stepping and backward stepping, two motions often impaired in individuals with PD (13). Therefore, activities such as multi-directional stepping while walking on a treadmill may offer added benefits to balance and mobility than simply forward walking alone. To date, only one previous study has evaluated multi-directional treadmill training in persons with PD (23). In this study, participants performed 5-7 minutes of forward walking, 5-7 minutes of backward walking, and 2-3 minutes of side stepping in each direction. Training occurred 3 times per week for 8 weeks, and outcome measures included gait speed, cadence, stride length, balance (step test), and fall frequency—measures that were recorded during the 2 weeks before and after the intervention. Compared to the control group, which performed no training, the intervention group demonstrated increased gait speed and stride length as well as a substantial reduction in falls. While the results of this study are encouraging, it did not attempt to evaluate whether multi-directional training afforded any different or added benefits than forward walking only. Additionally, only participants with mild to moderate PD (Hoehn & Yahr 2-3) were included, and the outcome measures that were used did not evaluate a broad range of dynamic balance and mobility skills.

Considering these limitations, we conducted an 8-week progressive treadmill training program with four individuals who had mild to severe PD, a program that included 4 weeks of forward walking only, followed by 4 weeks of multi-directional walking. The primary goals of this exploratory case series were 1) to assess the feasibility of multi-directional treadmill training in individuals with varying levels of disease severity, 2) to explore potential differential benefits of a forward and multi-directional training program on variety of gait and balance measures, and 3) to provide specific training parameters that may be useful in the design of future randomized trials.

METHODS

Participants

Four participants were recruited from the local community and the Parkinson's Disease Association (Table 1). Inclusion criteria included 1) a diagnosis of idiopathic PD with a Hoehn & Yahr of 1-4, 2) written

Table 1. Participant characteristics.

Characteristics	Participant 1	Participant 2	Participant 3	Participant 4
Age	71	63	59	56
Gender	M	F	F	M
Height (cm)	193	157	165	177
Weight (kg)	103.6	63.6	72.7	93.2
BMI	27.8	25.6	26.6	29.4
Duration of PD (years)	10	2	3	18
Hoehn & Yahr Stage	4	3	2	2
UPDRS motor	32	39	17	19

UPDRS = Unified Parkinson's Disease Rating Scale; BMI = Body Mass Index

medical clearance for exercise training, 3) a Mini Mental Status Examination (MMSE) score of ≥ 24, 4) no current engagement in regular treadmill training, 5) stability on current medications for at least 4 weeks, and 5) the ability to ambulate a minimum of 10 meters without an assistive device. Individuals were excluded from the study if they had any other neurological condition or had cardiovascular, orthopedic, and metabolic conditions that would make moderate to vigorous aerobic exercise unsafe. The University of Dayton Institutional Review Board approved the study, and all participants signed an informed consent prior to participation.

Protocol

This case series used repeated measures: pre-intervention, mid-intervention, post-intervention, and follow-up (see Figure 1). After a preliminary phone screening, participants attended a screening and familiarization session to ensure that they were safe and appropriate for training. Following this initial visit, participants returned within 4 weeks to perform a pre-intervention assessment. Participants then completed 4 weeks of forward treadmill training, followed by a mid-intervention assessment. Participants next completed 4 weeks of multi-directional training, followed by the post-intervention assessment. Finally, a follow-up assessment was completed 4 weeks after the end of training.

Outcome measures were selected in order to assess different aspects of gait and balance. Unique to this study, the program included such dynamic measures of balance as the instrumented Timed Up and Go, the Four Square Step Test, and the Mini-Balance Evaluation Systems Test—all of which require rapid transitional movements and multi-directional stepping. Additionally, balance confidence and quality of life were assessed.

Prior to the pre-intervention testing, participants attended a screening and familiarization session during which demographic, anthropometric, and physiological data were collected. Participants were also scored on the Unified Parkinson’s Disease Rating Scale (UPDRS III - motor subscale,) the MMSE, and the Hoehn & Yahr Staging of Parkinson’s disease. During this session participants were also exposed to each of the gait, balance, and mobility tests in order to minimize early learning effects before the pre-intervention testing.

All participants took their PD medication as prescribed and were tested in the "on" state at the same time of day for each of the testing visits. The order in which the outcome measures were administered was the same for each testing session, with the 6-minute walk test being performed last in order to minimize the impact of fatigue on the other tests.

The 10-meter Walk Test (10MWT) was used to determine gait speed by measuring the time required to cover the middle 10 m of a 14 m walking course. Walking speed was calculated for both comfortable gait speed and fast gait speed; 3 trials at each pace were recorded and then averaged. During the fast pace walking phase, each participant was given the instructions to "walk as fast as you possibly can while remaining safe." Gait speed has been demonstrated to have excellent test-retest reliability for comfortable gait speed (ICC = .96) and fast gait speed (ICC = .97) in individuals with Parkinson's disease (26). Stride length was measured during performance of the instrumented Timed Up and Go (iTUG), as described in the following section.

The 6-minute Walk Test (6MWT) was used to determine walking endurance, measuring the distance the participant walked around a large, square 50 m course in 6 minutes. Participants were able to use their preferred assistive device and were given standardized verbal cues and encouragement each minute. The total distance covered was recorded. The 6MWT has demonstrated excellent test retest reliability (ICC = 0.95-0.96) in individuals with Parkinson's disease (26).

The instrumented Timed Up and Go (iTUG) is a test of balance and mobility that requires the participant to stand up, walk over a tape line placed 7 meters away, then walk back and sit down (24). The iTUG is an instrumented modification of the standard 3-meter Timed Up and Go (TUG) test. The iTUG is performed using 4 lightweight accelerometers worn around the sternum, ankles, and waist to track trunk movements and lower extremity movements. (Opal Sensor, Model Number 350, APDM Inc., Portland, OR) The iTUG has been established as a sensitive and reliable measure of mobility and gait in individuals with PD (24, 25). The results of the iTUG were averaged over 3 trials. Data collected from the iTUG for this study included total time to complete the task, peak turning velocity, and stride length.

The Four Square Step Test (FSST) test was selected as the measurement of dynamic balance for assessing the participants' ability to step over objects in forward, sideways, and backward motions. During FSST testing, participants are afforded one practice trial, with the best time of two subsequent trials then recorded. The participants complete the stepping sequence as fast as possible in both a clockwise and counter clockwise direction, and without their feet touching canes placed on the floor in "plus"-sign arrangement, as well as having both their feet making contact with the floor in each square. Participants are encouraged to face forward during the entire test. The FSST has previously demonstrated good to excellent test and retest reliability in individuals with Parkinson's disease (ICC = 0.78 – 0.90) (6).

The Mini-Balance Evaluation Systems Test (Mini-BESTest) (7) is a test of dynamic balance and mobility that consists of 14 physical performance tasks such as sit to stand, stepping over obstacles, pivot turns and reactive stepping. The 14 items are each scored from 0-2, with 0 signifying the lowest level of performance and 2 signifying the highest level with a maximum total score of 28. The Mini-BESTest has demonstrated excellent test retest reliability (ICC = 0.88) in individuals with Parkinson's disease (16).

The 39-Item Parkinson's Disease Questionnaire (PDQ-39) (11) was used to assess Parkinson's disease-specific health-related quality of life over the previous 4 weeks. The PDQ-39 assesses the following eight different domains: mobility, activities of daily living, emotional well-being, stigma, social support, cognitive impairment, communication, and bodily discomfort. The sum of the scores can offer a single score, as a percentage, to assess the overall quality of life, with 0% being ideal health and 100% being inferior health. The PDQ-39 has been established as a valid and reliable instrument in PD (21).

The Activities-specific Balance Confidence (ABC) Scale (22) was used to assess participants' self-perception of balance confidence. The ABC is a 16-item self-report in which participants rate their balance confidence for performing various activities without falling or experiencing a sense of unsteadiness. Each item is rated on a 0% to 100% rating scale, with 0% representing no confidence and 100% representing complete confidence. The total score is calculated by adding each item score percentage, then dividing by the total number of items. The ABC has demonstrated excellent test retest reliability (ICC = 0.94) in individuals with Parkinson's disease (26).

All training took place at the University of Dayton's Doctor of Physical Therapy research laboratory. Training was performed 3 times a week for 8 weeks, using the Biodex Gait Trainer 3 Treadmill and Biodex Unweighing System (Biodex Medical Systems, Shirley, NY). A safety harness was used for protection of participants during training; however, no body-weight support was provided. Participants were given verbal cues as needed to promote normal posture, step length, and step symmetry. Participants were allowed to use the handrails if needed, but they were encouraged to minimize such use. During all training sessions participants were encouraged to walk as fast as possible while still maintaining the following parameters: 1) reasonable gait quality, 2) a heart rate ≤ 75% of heart rate reserve (HRR) as determined by Karvonen's formula (12), 3) BP < 200/100, and 4) a perceived exertion ≤ 7 on the Borg CR 10 (4) scale. During all sessions, HR was monitored continuously using a Polar FT4 heart rate monitor with chest strap (Polar Electro Inc., Lake Success, NY), and BP was assessed at the beginning, middle, and end of each session. If the participant exceeded any of the predetermined cut-off values during training, the treadmill speed was reduced until the participant's HR, BP, or perceived exertion was within acceptable range. If a

Table 2. Treadmill training program.

Week 1-4 Forward Walking			
Week 1 *Walking time = 18 min.*	**Week 2** *Walking time = 24 min.*	**Week 3** *Walking time = 28 min.*	**Week 4** *Walking time =30 min*
5 min. warm-up	5 min. warm-up	5 min. warm-up	5 min. warm-up
4 min. Forward	7 min. Forward	9 min. Forward	10 min. Forward
3 min. Rest	3 min. Rest	3 min. Rest	3 min. Rest
4 min. Forward	7 min. Forward	9 min. Forward	10 min. Forward
5 min. Cool-down	5 min. Cool-down	5 min. Cool-down	5 min. Cool-down
Week 5-8 Multi-directional Walking			
Week 5 *Walking Time = 30 min*	**Week 6** *Walking Time = 30 min*	**Week 7** *Walking Time = 30 min*	**Week 8** *Walking Time = 30 min*
5 min. warm-up	5 min. warm-up	5 min. warm-up	5 min. warm-up
1 min. Sideways Right	1.5 min. Sideways Right	2 min. Sideways Right	2 min. Sideways Right
1 min. Backward	1.5 min. Backward	2 min. Backward	2 min. Backward
1 min. Sideways left	1.5 min. Sideways left	2 min. Sideways left	2 min. Sideways left
7 min. Forward	5.5 min. Forward	4 min. Forward	4 min. Forward
3 min. Rest	3 min. Rest	3 min. Rest	3 min. Rest
1 min. Sideways Right	1.5 min. Sideways Right	2 min. Sideways Right	2 min. Sideways Right
1 min. Backward	1.5 min. Backward	2 min. Backward	2 min. Backward
1 min. Sideways left	1.5 min. Sideways left	2 min. Sideways left	2 min. Sideways left
7 min. Forward	5.5 min. Forward	4 min. Forward	4 min. Forward
5 min. Cool-down	5 min. Cool-down	5 min. Cool-down	5 min. Cool-down

participant did not reach acceptable ranges within 1 minute, the treadmill was stopped and the participant allowed to rest until HR and BP values were within acceptable ranges. Scheduled rest periods of 3 minutes were placed throughout the training sessions but participants could rest as frequently and for as long as needed or requested. However, none of the participants required additional or longer rest periods. The parameters were chosen to elicit a "moderate to strong" level of exercise intensity as outlined by the American Heart Association and the American College of Sports Medicine (19).

Weeks 1-4 consisted of forward walking only, and walking time was systematically increased each week to achieve a total of 30 minutes by week 4. During weeks 5-8, multi-directional walking (backwards, side stepping left, and side stepping right) was initiated, and length of time was progressively increased. However, as the multi-directional walking time was increased during weeks 5-8, the forward walking time was reduced in order to maintain 30 minutes of total walking time for each session. A detailed outline of the training program and progression can be found in Table 2.

Statistical Analysis

Outcome measurement values were recorded for each participant for all testing sessions to determine changes in individual performance. Changes in an individual participant's performance were compared to known minimal detectable change (MDC) or to minimal clinically important difference (MCID) values when available. Means and standard deviations were also calculated for all four participants. Percent change values were determined for the pre-

Table 3. Gait outcome measures.

Outcome Measure	Participant	Pre	Mid	Post	Follow	% Δ Pre-Mid	% Δ Mid-Post
Normal Gait Speed (m/s)							
	P1	1.19	1.36	1.62[a]	1.75	14.3	18.9
	P2	1.31	1.39	1.41	1.46	6.3	0.8
	P3	1.11	1.26	1.46[a]	1.59	13.5	16.0
	P4	1.63	1.73	1.86[a]	1.80	5.9	7.4
	Mean	1.31	1.44	1.59[a]	1.65	10.0	10.8
	± SD	0.23	0.20	0.20	0.15	4.5	8.2
Fast Gait Speed (m/s)							
	P1	1.88	1.88	2.28	2.14	0.0	21.4
	P2	1.59	1.72	1.81	1.82	8.1	4.9
	P3	1.50	1.57	1.75	1.89	5.0	11.0
	P4	1.98	2.00	2.19	2.01	1.0	9.6
	Mean	1.74	1.79	2.01	1.97	3.5	11.7
	± SD	0.23	0.19	0.27	0.14	3.7	7.0
6-Minute Walk Test (m)							
	P1	312.1	347.0	474.6[a]	572.5	11.2	36.8
	P2	424.4	471.8	512.8[a]	477.0	11.2	8.7
	P3	404.5	422.5	514.5[a]	541.7	4.5	21.8
	P4	548.9	553.6	630.8[a]	658.3	0.9	13.9
	Mean	422.5	448.7	533.2	562.4	6.9	20.3
	± SD	97.4	86.7	67.6	75.3	5.1	12.2
Stride Length (m)							
	P1	1.50	1.48	1.57	1.63	-1.3	6.1
	P2	1.16	1.27	1.27	1.30	9.5	0.0
	P3	1.35	1.31	1.35	1.37	-3.0	3.1
	P4	1.58	1.51	1.62	1.60	-4.4	7.3
	Mean	1.40	1.39	1.45	1.48	0.2	4.1
	± SD	0.18	0.12	0.17	0.16	6.3	3.3

[a] Difference in the Pre to Post test values exceeded the known minimal detectable change (MDC) for this measure in persons with Parkinson's disease

to mid-intervention in the forward walking training period only and for the mid- to post-intervention in the multi-directional training period to compare the relative amount of change that occurred during each.

RESULTS

All participants completed the treadmill training program and the required assessment sessions. Participants completed 96% of the scheduled treadmill training sessions over the 8-week period. No adverse events were experienced during training.

All four participants demonstrated improvements in self-selected speeds and fast gait speeds, with participants 1, 2 and 3 exceeding the MDC (0.18 m/s) (26) for self-selected speed. All participants demonstrated improvement and exceeded the MDC (82 m) (26) for the 6MWT. There were small improvements in stride length for participants 1, 2, and 4 following training. There were greater improvements in all gait measures during the mid- to post-intervention period (multi-directional training) than during the pre- to mid-intervention period (forward walking only) (Table 3 and Figure 2).

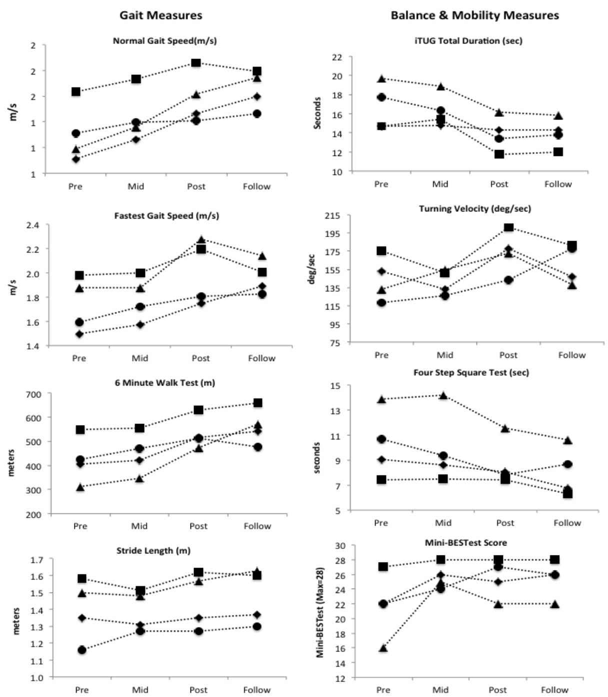

Figure 2. Graphical representation of outcomes. Pre = Pre-Intervention Assessment; Mid = Mid-Intervention Assessment; Post = Post-Intervention Assessment; Follow = Follow-Up Assessment; Participant 1 =▲; Participant 2 = ●; Participant 3 = ◆; Participant 4 = ■; meters = m; seconds = sec; meters per second = m/s.

All four participants demonstrated improvements in all of the balance and mobility measures from pre- to post-intervention, with participants 1 and 2 exceeding the MCID (4 points) for the Mini-BESTest (9). There were greater improvements in 3 of the 4 measures for the mid- to post-intervention period (multi-directional walking) than during pre- to mid-intervention period (forward walking) (Table 4).

No identifiable trends were observed, with most changes being small and variable in nature (Table 5).

DISCUSSION

The primary aim of this exploratory case series was to evaluate the possible benefits of a multi-directional treadmill-training program when added to the traditional forward-walking treadmill-training program. We also hoped to determine the program's feasibility for people who had mild to severe PD, as well as to develop specific training parameters for use in future investigations. This study used carefully selected outcome measures that assessed multiple aspects of gait, balance, mobility, and quality of life. When designing the intervention for this study, we attempted to incorporate commonly accepted principles of progressive exercise training and motor learning.

Walking speed, walking endurance (6MWT), and stride length were used to assess the effects of the training program on gait. Improvements were seen in all gait measures from pre- to post-intervention for all participants, with a continued trend for improvement at the 4-week follow-up. Three participants exceeded the MDC for self-selected gait speed of 0.18 m/s (26), and all 4 participants surpassed the MDC of 82 m (26) for the 6MWT. These findings were somewhat expected and consistent with improvements seen in previous studies on forward-walking treadmill training (17) as well as in the only previous study of multi-directional training (23).

While this study was concerned with the overall improvements seen from pre- to

Table 4. Balance and mobility outcome measures.

Outcome Measure	Participant	Pre	Mid	Post	Follow	% Δ Pre-Mid	% Δ Mid-Post
iTUG Total Duration (sec)[a]							
	P1	19.7	18.9	16.2	15.8	-4.1	-14.3
	P2	17.7	16.3	13.4	13.8	-7.9	-17.8
	P3	14.7	14.8	14.3	14.3	0.7	-3.4
	P4	14.7	15.4	11.7	12.0	4.8	-24.0
	Mean	16.7	16.4	13.9	14.0	-1.6	-14.9
	± SD	2.4	1.8	1.9	1.6	5.5	8.7
Turning Velocity (deg/sec)							
	P1	133	155	173	138	16.5	11.6
	P2	118	126	143	178	6.8	13.5
	P3	153	133	178	147	-13.1	33.8
	P4	175	151	201	181	-13.7	33.1
	Mean	144.8	141	173.8	161	-0.9	23.0
	± SD	24.7	14.0	23.9	21.7	15.0	12.1
4-Square Step Test (sec) [a]							
	P1	13.9	14.2	11.6	10.6	2.2	-18.5
	P2	10.7	9.4	7.8	8.7	-12.2	-16.3
	P3	9.1	8.6	8.0	6.8	-5.1	-6.6
	P4	7.4	7.5	7.4	6.3	0.8	-0.8
	Mean	10.3	9.9	8.7	8.1	-3.6	-10.6
	± SD	2.7	2.9	1.9	1.9	6.5	8.3
Mini-BESTest Score							
(Max = 28)	P1	16	25	22 [b]	22	56.3	-12.0
	P2	22	24	27 [b]	26	9.1	12.5
	P3	22	26	25	26	18.2	-3.8
	P4	27	28	28	28	3.7	0.0
	Mean	21.8	25.8	25.5	25.5	21.8	-0.8
	± SD	4.5	1.7	2.6	2.5	23.7	10.2

iTUG = Instrumented Timed Up and Go; Mini-BESTest = Mini-Balance Evaluation Systems Test
[a] A negative change for these timed items indicates an improvement in performance.
[b] Difference in Pre to Post test values exceeded the known minimal clinically important difference (MCID) for this measure in persons with Parkinson's disease.

post- intervention, it was also interested in the relative amount of change experienced during the forward walking only (pre to mid intervention) and multi-directional (mid to post intervention) training periods. This was evaluated by calculating percent change values for each period so that the relative contribution of each could be explored. Based on this data, the study showed that there were greater mean improvements for each of the gait measures during the multi-directional walking portion of the training. This was especially apparent for fast walking velocity and the 6MWT. For fast walking velocity there was a mean improvement of 3.5% during weeks 1-4 (forward walking only) and an 11.7% improvement during weeks 5-8 (multi-directional walking). For the 6MWT there was a mean improvement of 6.9% during weeks 1-4 (forward walking only) and a 20.3% improvement during weeks 5-8 (multi-directional walking). These findings indicate that the addition of the multi-

Table 5. Quality of life and balance confidence outcome measures.

Outcome Measure	Participant	Pre	Mid	Post	Follow	% Δ Pre-Mid	% Δ Mid-Post
ABC (%)							
	P1	59.3	54.1	52.2	57.5	-5.2	-1.9
	P2	82.5	77.5	84.4	85.0	-5.0	6.9
	P3	85.6	85.0	80.6	85.0	-0.6	-4.4
	P4	79.1	88.0	75.0	77.4	8.9	-13.0
	Mean	76.6	76.2	73.1	76.2	-0.5	-3.1
	± SD	11.8	15.3	14.4	13.0	6.6	8.2
PDQ-39 (%)[a]							
	P1	30.7	28.0	32.7	36.0	-2.7	4.7
	P2	19.3	17.3	16.7	17.3	-2.0	-0.7
	P3	10.0	9.3	18.0	10.7	-0.7	8.7
	P4	31.3	35.3	38.0	40.7	4.0	2.7
	Mean	22.8	22.5	22.6.3	26.2	-0.3	3.8
	± SD	10.2	11.5	10.6	14.4	3.0	3.9

ABC = Activities Specific Balance Confidence Scale; PDQ-39 = 39-Item Parkinson's Disease Questionnaire
[a] A negative change for PDQ-39 indicates an improvement in quality of life.

directional walking may have accelerated improvements in these gait measures since total training time remained relatively constant.

Because individuals with PD have a higher fall risk, a primary interest of this study was to evaluate the effects of the training program on balance and mobility. Few previous studies have investigated the effects of treadmill training on balance and falls in individuals with PD. Cakit et al. (5) measured the effects of an 8-week progressive forward walking program on balance using the Berg Balance Test (BBS) and Dynamic Gait Index and found significant improvements in each of these measures following training. Ganesan et al. (8) evaluated the effects of partial weight-supported treadmill training (PWSTT) on the BBS, the Tinetti Performance Oriented Mobility Assessment (POMA), and dynamic posturography. Following 4 weeks of PWSTT there were significant improvements in all of the balance measures. In a study most closely resembling the present investigation, Protas et al. (23) performed multi-directional treadmill walking and step training and reported a reduction in the number of falls experienced during the 2 weeks following the intervention compared to the 2 weeks before the intervention. While it appears that both forward and multi-directional treadmill training can have positive effects on balance, the designs of these studies did not elucidate whether one affords more or different benefits than the other. Although our study was only an exploratory case series, it is the first to investigate possible differential benefits between forward and multi-directional treadmill training.

We hypothesized that multi-directional training would lead to greater improvements in balance and mobility than forward walking only, and our results seem to support this. There were greater relative improvements for iTUG duration (14.9%), turning velocity (23%), and the FSST (10.6%) during weeks 5-8, when multi-directional training was added, compared to weeks 1-4 which only demonstrated improvements of 1.6%, 0.9%, and 3.6% respectively, when only forward walking was performed. While the Mini-BESTest showed greater improvements during weeks 1-4, this was likely because Participants 3 and 4 may have experienced a ceiling effect following the mid-intervention test and because Participant 1 had an unexpectedly large improvement during weeks 1-4, an improvement that may be partly attributed to fluctuations in PD symptoms. Overall, these findings support our hypothesis that the addition of multi-directional training would lead to greater changes in dynamic balance tests, especially those requiring activities such as rapid stepping, turning, and transitional movements.

It should also be noted that following completion of the treadmill training program some of outcome measures demonstrated a decrease in performance at the 4 week follow-up testing. In particular, turning velocity and fast gait speed showed the most obvious declines following cessation of training. However, most of the other outcome measures maintained their improvements.

Quality of life and balance confidence were assessed using the PDQ-39 and ABC respectively. Throughout the course of the intervention, changes in these measures were generally small and variable in nature. This result was not entirely unexpected for several reasons. First, the PDQ-39 assesses multiple domains of health, including areas not specific to balance and gait, and would therefore be less likely to demonstrate change as a direct result of our intervention. Second, since we continued to progressively challenge our participants and expose their balance deficits, they may not have perceived improvements in balance confidence that would be reflected by an increase in their ABC scores. Similarly, other researchers have noted limited or variable changes in survey measures of quality of life and balance confidence despite more notable and consistent improvements in physical performance tests (14, 18).

This study has a number of limitations. Most obviously, this was a small case series. The design of our study also does not rule out cumulative effects of training since there was no wash-out period between the forward and multi-directional training and forward walking was still a large component of the multi-directional training. Additionally, although exercise time was held constant once 30 minutes was reached during week 4 of training, participants experienced less total activity during weeks 1-4 (300 min) compared to weeks 5-8 (360 min) as exercise time was progressively increased from 18 to 30 minutes during weeks 1-4, then maintained at 30 minutes during weeks 5-8. While we acknowledge these limitations, the intervention as provided more closely mimics how this type of training would occur in the clinical setting.

The findings from this study may warrant a larger randomized controlled study that would benefit from a cross-over design and blinding of investigators. Sample size estimates were calculated for several of our key measures based on our results from pre to post intervention. Assuming a power of 0.8 and an alpha of 0.05, the following number of participants would be required to detect a moderate effect size of 0.5: normal gait speed = 5, 6MWT = 6, FSST = 17, Mini-BESTest = 9.

A progressive 8-week treadmill training program that included 4 weeks of forward walking followed by 4 weeks of multi-directional walking was safe and feasible for 4 individuals with mild to severe PD. There were improvements in nearly all gait and balance measures following training, with greater improvements experienced following the multi-directional training portion of the intervention for most measures. Future research regarding this novel intervention seems warranted.

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