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Original Article

Effects of a 12-week online Tai Chi intervention on gait and postural stability in individuals with Parkinson's disease

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ABSTRACT

Parkinson's disease (PD) affects gait and postural stability. Tai Chi (TC) is recommended for PD for management of the condition, however biomechanical understanding to its effects on gait and postural stability is limited. This study aimed to examine the effects of an online 12-week biomechanical-based TC intervention on gait and posture in people with PD. Fifteen individuals in early-stage PD were recruited (Hoehn & Yahr stages 1–2). The TC intervention program was 60 min session, three times weekly for 12 weeks. The pre- and post-intervention test in obstacle crossing, timed-up-and-go (TUG) test, and single leg standing (SLS) with eyes open (EO) and closed (EC) were conducted. Gait speed, crossing stride length, clearance height of the heel and toe, anterior-posterior (AP) and medial-lateral (ML) displacement and velocity of the center of mass (COM) and separation of the COM-center of pressure (COP) were analyzed. The participants significantly improved their pre-vs. post-TC intervention performance on TUG test ($p = 0.002$). During obstacle crossing, the participants significantly increased crossing stride length of the trailing foot, increased AP COM displacement and decreased ML COM-COP separation ($p < 0.05$); the maximal dorsiflexion angle of the leading limb significantly increased and maximal plantarflexion angle of the trailing limb significantly decreased ($p < 0.05$). A 12-week biomechanical-based online TC training was effective towards improvement of gait and postural stability among people in the early-stage of PD. The TC program and online training could be applied for management of PD.

Introduction

Postural instability and altered gait are problems reported by those with Parkinson's disease (PD).[1] Those with PD have difficulties with everyday tasks such as walking due to changes in step width and step length that can slow their gait.[2,3] Exercise has been used in conjunction with drug therapy (such as levodopa, carbidopa) as standard of care to manage the symptoms related to PD.

Tai Chi (TC) is a body-mind exercise that is recommended for management of PD.[4] Practicing TC regularly can help to improve the movement capacity of people with PD.[5,6] So far, it is unclear whether TC training could improve postural stability during a challenging locomotion task such as obstacle crossing. Furthermore, the information on how TC programs are formulated or how TC forms are selected in the reported studies is lacking. There are a variety of TC style and movement forms. The differences in the movement characteristics of exercise could results in different training effects on muscle strength and motion control.[7,8] Moreover, application of the research's findings is important on for the development future program for PD.

Obstacle crossing is a daily activity that is especially difficult for those with PD. It has been used to examine dynamic postural stability in the healthy and PD population by analyzing the displacement and velocity of center of mass (COM), and COM-center of pressure (COP) separation distance.[9] In order to understand the impacts of TC on gait and dynamic postural stability for people with PD, this study aimed to examine the effects of an online TC intervention program developed based on the biomechanics of the TC forms. It was hypothesized that following the 12-week TC intervention, the PD participants will improve gait indicated by an increased gait speed, step length, and toe and heel clearance distance during obstacle crossing, and improved dynamic postural stability indicated by altering COM velocity and displacement, and COM-COP separation distance. They will also improve static postural stability indicated by better scores on the single leg stance test (SLS) with eyes opened (EO) and closed (EC). This study would advance the understanding of the effects of TC training on gait and posture in people with PD.

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Abbreviation

AP	Anterior-Posterior
COM	Center of Mass
COP	Center of Pressure
EO	Eyes Opened
EC	Eyes Closed
H&Y	Hoehn and Yahr
ML	Medial-Lateral
MoCA	Montreal Cognitive Assessment
PD	Parkinson's disease
SLS	Single Leg Stance
TC	Tai Chi
TUG	Timed-Up-and-Go
UPDRS-III	Unified Parkinson's disease Rating Scale (motor subsection)

Methods

Participants

Seventeen participants aged 50 to 75 with early-stage idiopathic PD (Hoehn & Yahr [H&Y] 1 to 2, mean: [1.4 ± 0.6]; disease duration: [7.1 ± 5.7]) were recruited (age: [71.7 ± 6.6] years, weight: [67.8 ± 16.0] kg, height: [171.2 ± 10.5] cm, Montreal Cognitive Assessment [MoCA]: [26.1 ± 2.9]). The study began January 2021 and ended December 2021. The participants in the early-stage of PD were classified by 1) increased tremor, rigidity, slowness, paucity in their movements; and/or 2) stiffness (rigidity) in truncal muscles, postural abnormalities, stooping, and generalized slowness.[10] The participants were recruited from referrals from local medical clinics (i.e., physician/neurologist offices) and local support groups that are associated with *Parkinson's Canada*. They had regular exercise on average (52.4 ± 13.7) min/session, (4.1 ± 1.1) days weekly. The participants had no neuromuscular injuries in the last two years and were able to stand and walk unassisted. Exclusion criteria of the participants included impaired mobility, dementia, cardiovascular disease, poorly controlled hypertension, or if the participant were currently on medications known to impair balance. The participants were tested in the "ON" medication state approximately 1–2.5 h after their last medication dose. Informed consent from the participants were obtained. This study has been approved by the university's research ethics review board and conformed to the World Medical Association Declaration of Helsinki.

Tai Chi intervention program

A biomechanical-based TC intervention program that include seven Yang-style forms was developed based on the TC theory and movement analysis of TC.[11,12] The participants were enrolled into an online intervention that taught the TC program. The participants met online via ZOOM for 60 min, 3 times weekly for 12-weeks. The class was led by TC instructors with more than four years of TC teaching experience. Each session began with 5–10 min of warm-up, 40 min of core activities, and finished with 5-min cooldown activities. The participants were instructed to attend a minimum 2 classes/week and encouraged to practice at home in the days between each class. They were asked to complete an activity log of their daily TC practice to monitor their progress. The TC instructor and TC expert were present at each session to monitor participants' progress and to make sure that movements were being performed correctly.

Data collection

The data was collected at the Human Movement Biomechanics Laboratory before and after the 12-week TC intervention. The physical activity and/or exercise levels and health backgrounds of the participants were obtained through telephone communication. Their general cognitive function was assessed using the MoCA.

Obstacle crossing test: Motion capture data collection for gait during obstacle crossing were conducted. The three-dimensional motion capture was performed using a ten-camera VICON system at 200 Hz. Thirty-nine reflective markers were attached to the skin or over the participants' clothing in accordance with the Plug-in-Gait marker set (Oxford Matrices), as modified from the Helen Hayes marker set.[13] Ground reaction forces were recorded using four force plates at 2 000 Hz (models 9286AA, Kistler Instruments Corp, Winterthur, Switzerland; FP 4060-08, Bertec Corporation, Columbus, OH, USA) that were embedded in the middle of the walkway. The participants crossed a 20-cm-high obstacle that was set up in the middle of an 8-m walkway at their self-selected comfortable pace and with their self-select limb as the leading limb and with their comfortable shoes. Data from five successful trials of obstacle crossing were collected.

SLS and timed up and go (TUG) tests: For the SLS test, the participants were asked to stand on either the left or right leg for as long as possible with their hands placed on their hips. This test was performed three times with the EO and three times with the EC; the best time of each condition was recorded. A coin toss was used to determine the order of the stance leg. The TUG test measured the participant's time (in seconds) to stand up from a chair, walk 3 m (9.8 ft), turn around, walk back to the chair, and sit down, with a shorter time indicating better mobility.[14] The participants performed both tests with their shoes on.

Data processing and analysis

The studied variables and their definitions are listed in Table 1.[15,16] To obtain the above-mentioned variables, the captured motion data was reconstructed and labelled in VICON Nexus software 2.8.0 (Oxford, UK). The crossing motion of both the left and right limbs were analyzed. The force plates data were filtered using a 4th order Butterworth filter with a cut-off frequency of 6 Hz.[17] A three-dimensional reconstructed model of

Table 1
Summary of the definitions for studied variables.

Variables	Definition
Gait variables	
Crossing stride length	The anterior-posterior (AP) displacement between the heel strike (initial contact) of the TF before the obstacle to heel strike of the TF after the obstacle.[12]
Crossing step length	The AP displacement between the heel strike (HS, initial contact) of the TF before the obstacle to the HS of the leading foot (LF, or crossing limb) after the obstacle.[13]
Crossing width	The medial-lateral (ML) displacement between HS (initial contact) of the TF before the obstacle to heel strike of the LF (crossing limb) after the obstacle.[13]
Gait speed	The speed between HS (initial contact) of the LF before the obstacle to HS of the TF after the obstacle.
Crossing speed	The speed of the crossing stride.[12]
Obstacle clearance variables	
Toe and heel clearance	The displacement between the toe and heel, respectively, of the LF to the top of the obstacle.
Pre-horizontal distance	The horizontal distance between toe marker on the TF and the obstacle prior to crossing.[12]
Post-horizontal distance	The horizontal distance between heel marker on the LF and the obstacle after crossing.
Dynamic postural stability variables	
COM displacement at AP & ML	The change in position of the center of mass (COM) during one crossing stride.
COM velocity at AP & ML	The velocity of the COM during one crossing stride.
COM-COP separation at AP & ML	The displacement between COM and center of pressure (COP) during one crossing stride.

the participant was created using the Plug-in-Gait model. VICON Nexus and MATLAB software were used to analyze the data. Differences in demographic variables between the two groups were tested using chi-square and independent-sample t tests depending on the variable's type after testing for normal distribution. After confirming that the data is normally distributed, paired-sample t tests were used to compare the difference between the pre- and post-intervention effect for all studied variables. A p value of less than 0.05 was considered statistically significant. All statistical operations were performed using SPSS software (version 20).

Results

Fifteen participants completed the intervention (15/17, 88% completion), one participant discontinued due to (unrelated) back pain before starting. All participants completed the five trials of obstacle crossing successfully. One participant could not complete the SLS with EC test for the pre- and post-intervention sessions, their data was omitted.

Table 2

Mean and standard deviation of the clinical tests, gait, foot clearance, center of mass (COM) and center of pressure (COP) related variables from pre- and post-intervention tests ($n = 15$).

Assessment	Pre-intervention	Post-intervention	Change	p Value
Clinical				
UPDRS-III	21.1 ± 7.0	16.5 ± 8.9	−5.0 ± 7.8	0.107
Timed Up-and-Go	12.7 ± 3.3	11.0 ± 3.3	−1.6 ± 1.7	**0.002****
Single leg standing with eyes open	24.1 ± 21.3	33.3 ± 40.1	9.3 ± 31.3	0.270
Single leg standing with eyes closed	3.4 ± 2.5	8.4 ± 15.2	5.0 ± 14.9	0.214
Gait variables				
Gait speed (m/s)	0.96 ± 0.26	0.99 ± 0.24	0.03 ± 0.1	0.086
Crossing speed (m/s)	0.93 ± 0.31	0.94 ± 0.22	0.01 ± 0.25	0.797
Crossing stride length of LF (m)	1.34 ± 0.26	1.36 ± 0.28	0.01 ± 0.14	0.292
Crossing stride length of TF (m)	1.38 ± 0.25	1.41 ± 0.23	0.04 ± 0.10	**0.036***
Crossing step length (cm)	60.7 ± 16.4	61.6 ± 15.5	0.9 ± 8.9	0.358
Crossing step width (cm)	6.5 ± 4.4	7.3 ± 4.3	0.8 ± 5.5	0.263
Toe clearance distance of LF (cm)	20.8 ± 5.7	20.0 ± 5.1	−0.8 ± 3.5	0.226
Heel clearance distance of LF (cm)	19.5 ± 6.8	18.3 ± 6.2	−1.1 ± 5.1	0.286
Pre-horizontal distance of TF (cm)	25.4 ± 7.4	27.8 ± 7.0	2.8 ± 9.1	0.186
Post-horizontal distance of LF (cm)	21.8 ± 9.3	21.7 ± 9.6	−0.1 ± 9.7	0.928
COM, COP related variables				
Max AP COM displacement (cm)	139.2 ± 25.8	143.8 ± 22.6	3.0 ± 10.0	**0.03***
Max ML COM displacement (cm)	8.8 ± 4.2	9.0 ± 4.6	0.4 ± 4.8	0.503
Max AP COM velocity (cm/s)	116.0 ± 29.4	121.1 ± 23.2	3.4 ± 15.1	0.111
Max ML COM velocity (cm/s)	21.1 ± 6.5	20.5 ± 7.6	−0.1 ± 10.1	0.849
Max AP COM-COP separation (cm)	35.4 ± 11.3	33.7 ± 10.9	−3.7 ± 10.2	0.838
Max ML COM-COP separation (cm)	9.7 ± 5.0	7.6 ± 3.4	−1.6 ± 6.6	**0.03***

AP: anterior-posterior, LF: leading foot, max: maximum, min: minimum, ML: medial-lateral, TF: trailing foot, UPDRS-III: Unified Parkinson's disease Rating Scale – motor section. $^{*}p < 0.05$ & $^{**}p < 0.001$.

Unified Parkinson disease scale (motor section), SLS and TUG tests

The Unified Parkinson's disease Rating Scale – motor section (UPDRS-III), SLS with EO and EC scores pre- and post-intervention change was not remarkable. The mean TUG time of the participants was significantly faster by 1.6 s ($p < 0.02$).

Variables of gait, obstacle clearance, and joint angles

Table 2 shows the mean and *SD* of the gait measures during obstacle crossing from pre- and post-intervention tests. The mean stride length significantly increased 3.6 cm in the trailing foot ($p = 0.036$). Toe and heel clearance, and pre- and post-horizontal distance did not show significantly change (Table 2). Ankle dorsiflexion angle of the leading limb significantly increased 3.7 ° ($p = 0.03$) and ankle flexion angle of the trailing foot significantly decreased 6.8 ° ($p = 0.02$) post-intervention (Table 3).

Dynamic postural stability variables

The mean of the max anterior-posterior (AP) COM displacement significantly increased by 3 cm ($p = 0.03$); also, the mean of the max medial-lateral (ML) COM-COP separation distance significantly decreased by 1.6 cm ($p = 0.03$).

Discussion

This study showed that a 12-week online biomechanical-based TC intervention is effective toward improvement of gait and postural stability during obstacle crossing in people with early-stage PD. Significant improvements were reported on the TUG test and performance on the STS test was remarkable. The PD participants' gait significantly improved which was indicated by an increase in the crossing stride length of their trailing foot. Also, their dynamic postural stability improved which was indicated by increased maximal AP COM displacement and decreased maximal ML COM-COP separation distance.

The PD participants completed the TUG test significantly faster ($p = 0.002$). A past study reported a 1.9 s reduction on the TUG test in PD participants after 3 months of TC training ($p < 0.001$),[6] this finding is consistent with other TC intervention studies.[5,18] The findings suggest 2–6 months of TC training can help to improve movement and mobility. The current study's results for the UPDRS-III assessment were not significant. Whereas three published TC studies showed 3.3 to 6.3 points reduction in their participants' mean UPDRS-III scores after 12 and 24 weeks of training with significance.[5,6] The inconsistency with this study and published work could be related to the training intensity, in terms of training frequency and duration. The improvements in single leg stance test scores are remarkable. SLS is a challenge to perform with the EC for this population. To perform this, core muscles such as the internal oblique and the dominant side multifidus and proximal medial gastrocnemius muscles are activated to maintain stability.[19] The improvement of the SLS were not significant but the test scores are impressive.

The PD participants significantly increased crossing stride length of the trailing foot ($p < 0.05$). This finding was similarly reported in the older adults who regularly practiced TC.[20] Researchers report that people with PD reduced their stride length during obstacle crossing.[21] Furthermore, weakness in their dorsiflexor muscles could potentially lead to a trip on the obstacle or a fall.[22] Stride length increased after TC training; this would suggest that strength in the dorsiflexor muscles have improved.[22,23] The participants increased their pre-horizontal distance from the obstacle and decreased slightly their heel clearance but maintained the same toe clearance height. From the reported findings, the participants appear to be less cautious as they did not need to position the foot closer to the obstacle before crossing.[24] Those who practice TC regularly crossed a 15-cm and 23-cm high obstacle with significantly faster and longer step length and significant higher toe clearance than the

Table 3
Mean and standard deviation of the joint angles and range of motion (ROM) of the lower limb in the during obstacle crossing from pre- and post-intervention tests ($n = 15$).

Joint	Session	Obstacle Crossing											
		Leading Limb						Trailing Limb					
		Angles				ROM		Angles				ROM	
		Flex (°)	Ext (°)	Add (°)	Abd (°)	Flex-Ext (°)	Add-Abd (°)	Flex (°)	Ext (°)	Add (°)	Abd (°)	Flex-Ext (°)	Add-Abd (°)
Hip	Pre-	68.9 ± 11.1	8.0 ± 12.3	7.1 ± 4.8	8.0 ± 6.7	76.9 ± 12.6	15.1 ± 5.0	46.1 ± 7.8	8.2 ± 13.0	5.4 ± 5.7	8.3 ± 5.1	55.0 ± 10.1	13.7 ± 3.9
	Post-	70.0 ± 9.4	6.0 ± 10.8	6.7 ± 4.4	8.5 ± 6.0	76.1 ± 13.5	15.2 ± 5.3	47.9 ± 8.2	6.7 ± 8.7	4.5 ± 5.6	9.0 ± 5.9	54.6 ± 10.9	13.5 ± 4.2
	p-Value	0.996	0.251	0.549	0.857	0.299	0.895	0.745	0.414	0.857	0.532	0.515	0.991
Knee	Pre-	94.7 ± 35.0	6.8 ± 40.9	35.4 ± 27.4	6.7 ± 16.4	101.5 ± 26.0	42.1 ± 20.6	111.2 ± 21.8	−0.3 ± 8.7	35.9 ± 23.5	7.3 ± 18.1	111.4 ± 26.1	42.6 ± 18.6
	Post-	107.3 ± 27.6	0.0 ± 8.6	49.6 ± 28.0	4.4 ± 15.5	107.3 ± 31.4	54.0 ± 21.9	106.0 ± 24.3	2.4 ± 5.9	40.3 ± 23.8	5.7 ± 17.6	108.4 ± 24.7	46.0 ± 19.1
	p-Value	0.145	0.471	0.153	0.412	0.127	0.287	0.171	0.103	0.370	0.338	0.413	0.614
Ankle	Pre-	21.8 ± 7.9	16.0 ± 11.6	5.8 ± 7.8	3.1 ± 6.8	37.8 ± 13.0	8.9 ± 7.4	22.4 ± 14.0	15.5 ± 16.5	6.2 ± 4.8	6.4 ± 11.4	37.9 ± 22.5	12.6 ± 11.4
	Post-	18.6 ± 7.5	19.7 ± 11.3	7.4 ± 8.9	2.9 ± 7.6	38.3 ± 12.3	10.3 ± 6.5	15.6 ± 22.7	17.8 ± 24.9	4.6 ± 21.5	6.9 ± 21.3	33.4 ± 9.7	11.5 ± 6.3
	p-Value	0.272	**0.026***	0.655	0.994	0.210	0.601	**0.021***	0.324	0.361	0.816	0.586	0.501

A “+” represents flexion or dorsiflexion; “–” represents extension and abduction. Abd: abduction, Add: adduction, Ext: extension, Flex: flexion. *$p < 0.05$, **$p < 0.001$.

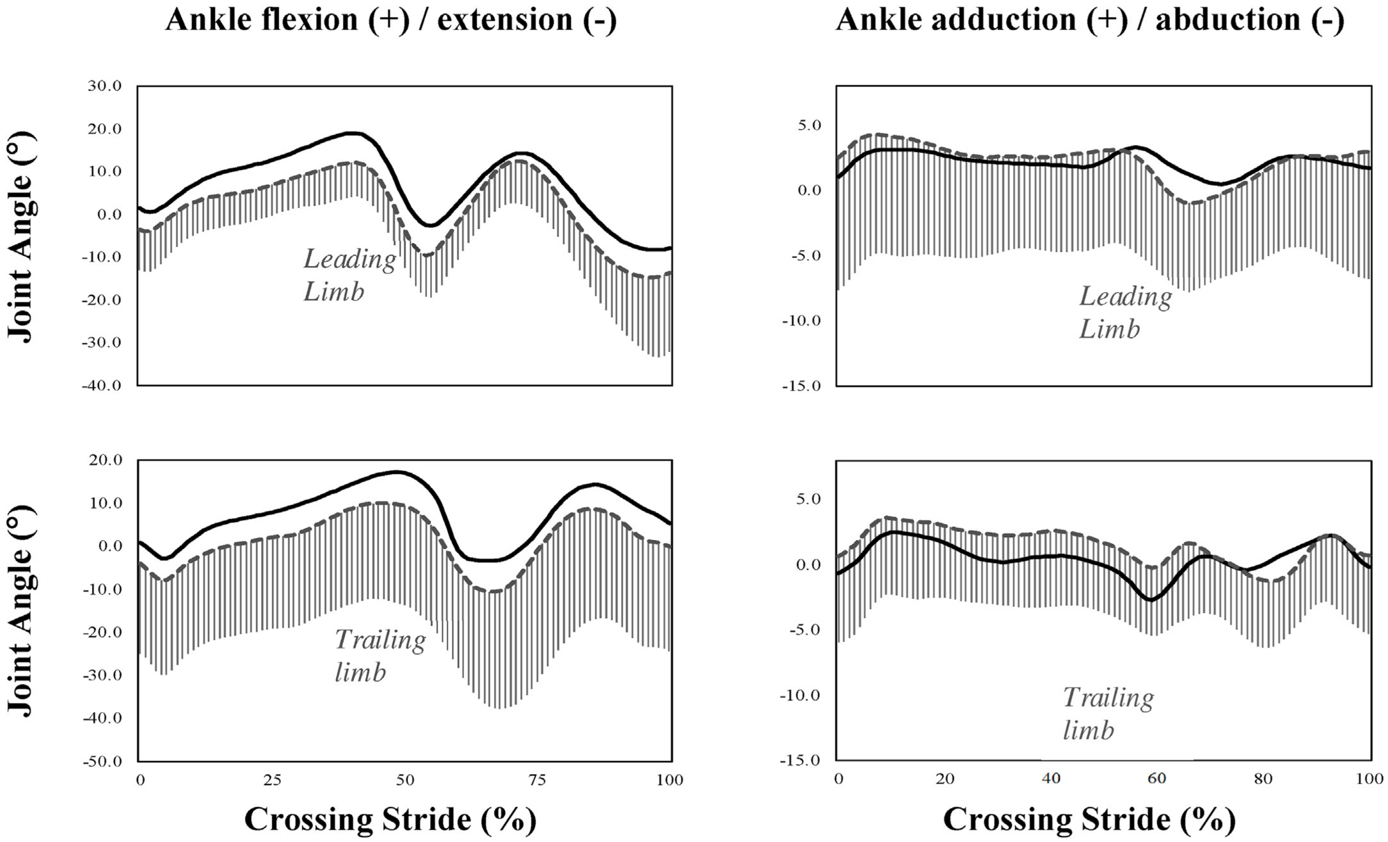

Fig. 1. Angular displacement of the hip flexion-extension (left) and abduction-adduction (right) of the leading (top) and trailing (bottom) during obstacle crossing in pre- (solid line) and post- (dashed line) 12-week Tai Chi intervention. The angle data has been time normalized to one crossing stride from heel strike (initial contact) before the obstacle to heel strike after the obstacle.

age- and exercise volume-matched older adults,[25] suggest that they have better movement and postural control capacities. When the obstacle is 20-cm higher, older adults who regularly practice TC crossed with lower heel and toe clearance heights.[26] This finding was consistent with the current study. The PD participants achieved a lower clearance height compared to the measures of before TC training implying that their sensory processing has improved.

The PD participants' dorsiflexion angle significantly increased 3.7 ° in their leading limb and plantarflexion angle significantly decreased 6.8 ° in the trailing limb ($p < 0.05$) (Table 3). In Fig. 1, the joint angle curve for the ankle was smoother post-intervention, the peaks were diminished, and the joint angle pattern in AP and ML directions were more like the data of healthy age- and sex-matched controls from a previous study.[21] The significant changes at the ankle joints in both limbs indicate an alteration in the participants' gait. Compared to the study findings from healthy older adults, the plantarflexion angles for the PD participants were larger after TC training (14.4° and 19.7°, respectively).[21] The trailing limb's plantarflexion angles of the participants were smaller compared to the healthy participants' angle during obstacle crossing from the mentioned study (15.6° and 20.7°, respectively).[21] The difference in plantarflexion angles could be related to their changed postural stability. People with PD had poor sideward weight shifting abilities of their COM while standing; their toe clearance is increased ("over-lifted") during obstacle crossing.[22] The participants appeared to use ankle strategy during obstacle crossing. TC training appears to have changed the hip and ankle joint angles as well as increase stride velocity and stride length.[27,28] Whereas older adults will adapt a "swing hip" flexion strategy to achieve a higher leading toe clearance, young adult and experienced TC practitioners rely on ankle strategy.[27] The low toe clearance height observed after TC training would suggest that they have good sensory awareness and control of their foot's position.

The PD participants' ML COM-COP separation distance significantly decreased while AP COM displacement significantly increased. This suggest that dynamic postural stability has been altered. The COM-COP separation distance represents the interaction between the COM and COP.[9,29] Greater ML COM motion indicates poor dynamic control and reflect the individuals' sensation of instability during obstacle crossing.[29] A smaller ML COM-COP separation distance is thought to be a conservative strategy used during obstacle crossing. Older adults with postural instability exhibit greater and faster ML COM displacement than healthy older adults due to poor postural stability in the frontal plane.[9] PD patients demonstrate greater ML excursion of their COM during obstacle crossing compared to healthy controls.[30] They tend to keep their COM close to their COP during obstacle crossing and reduce the maximum AP COM-COP separation distance compared to healthy older adults.[24] The changes occurring after the 12-week online TC intervention could be related to an improved capacity of the PD participants to control their body's motion and posture.

Regular TC practice benefits muscle strength, postural control, and balance.[6,31,32] For the PD population, significant improvements were reported on the Berg Balance Scale after 12 weeks of TC training,[6,32] another study showed improvements in TUG performance after 24 weeks of TC training.[33] After 12 weeks of TC training, AP and ML COP displacement significantly increased during obstacle crossing as well.[34] This study's findings are consistent with the published work.[24,34] Both the AP COM displacement and AP COM velocity increased while AP COM-COP separation distance decreased. The increase in AP COM displacement indicated that trunk motion had increased, whereas AP COP displacement indicated that movement in the lower limbs was altered. This study did not show a significant change in ML COM displacement, but a significant decrease in ML COM-COP separation distance during obstacle crossing. Poor dynamic instability is linked to reduced ML postural control and a large ML COM-COP separation during obstacle crossing.[29,35] By maintaining a small ML COM-COP separation, this would be less demanding on their body and therefore would be a safer option for people with PD as they step over the obstacle.

A limitation would be for the TUG test. For this test, the participants were asked to walk at their own "comfortable" speeds. Some variability could have been introduced between the laboratory sessions. Alternatively, if they were asked to walk as fast as possible, this may not truly reflect the actual changes in their walking speed. The participants were allowed to engage in other forms of exercise such as boxing during the intervention period; this ensured that the participants enjoyed the intervention setup and that enough participants could be recruited for the study. There is limited research evidence on this topic, it is unknown whether the participants' engagement in other forms of exercises during the TC intervention could impact the measures. Only one intervention group was recruited, no control group could be included due to the COVID-19 pandemic which restricted in-person laboratory data collection and access to the lab and offices.

Conclusion

The biomechanical-based 12-week online TC intervention could help to improve postural stability and gait in individuals with early-stage PD. The TC training could improve gait and postural stability, particularly dynamic postural stability by increasing their stride length of their trailing limb and increasing ankle dorsiflexion in their leading limb as well as improvement of their control in COM and COP motion in AP and ML direction during challenged locomotion, obstacle crossing. The biomechanical-based 12-week online TC intervention program could be recommended to people with PD for improvement of their gait and postural stability.

Authors' contributions

Dr. Li contributed to the conception and principal guidance to the study. Mr. Law contributed to the data collection and data processing. Both authors contributed to drafting of the manuscript. Both authors have read and approved the final manuscript.

Submission statement

The manuscript has not been published and is not under consideration for publication elsewhere.

Ethics approval statement

The study was approved by the human ethics committee of the University of Ottawa. The participant was a volunteer, without a monetary incentive and were informed about the use of their information. Informed consent from the participant was obtained.

Conflict of interest

Jixian Li is an editorial board member for Sports Medicine and Health Science and was not involved in the editorial review or the decision to publish this article. The authors have no conflicts of interest to report.

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