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Body weight support-Tai Chi footwork for balance of stroke survivors with fear of falling: A pilot randomized controlled trial

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ABSTRACT

*Background **and purpose:*** Balance impairment is the predominant risk factor for falls in stroke survivors. This study examined the effects of body weight support-Tai Chi (BWS-TC) footwork on balance control among stroke survivors with fear of falling (FOF).

Materials and methods: Twenty-eight stroke survivors with FOF were randomly allocated to either control or BWS-TC groups. Those in BWS-TC underwent Tai Chi training for 12 weeks. Outcomes were assessed in all participants by evaluation of the limits of stability test, modified clinical test of sensory integration of balance, fall risk index, and Fugl-Meyer assessment of lower limbs at baseline and 12 weeks.

Results: The BWS-TC group displayed significant enhancement in dynamic control and vestibular and somatosensory integration.

Conclusion: BWS-TC may enhance dynamic control and sensory integration of balance and reduce the risk of fall in stroke survivors with FOF.

1. Introduction

Stroke is a leading cause of long-term incapacity amongst middle-aged and elder adults worldwide [1]. An epidemiological study from the China National Stroke Screening Survey reported that incidence of the first stroke in adults aged 40–74 years has increased from 189/100,000 in 2002 to 379/100,000 in 2013, an overall yearly increase of 8.3% [2]. In addition, 70–80% of stroke survivors develop functional disabilities [3,4]. Falling is one of the common complications of stroke survivors [5]. Approximately 23–73% of stroke survivors fall once or more 4–6 months after stroke [6]. Moreover, the number of patients with disability due to stroke is expected to increase in the coming decades due to older age and lifestyle modifications [7].

Balance impairment is the predominant risk factor for falls in stroke survivors [8]. Postural control is critical to maintaining balance and avoiding falls [9]. Both reduced dynamic control and posture preservation in stroke survivors are associated with maximum excursion along with directional control [10], increased sway of centre of gravity (COG) [11], diminished voluntary weight-shift [12], reduced sensory integration [13], and extreme dependence on visual input [14]. Furthermore, falls also lead to fear of falling (FOF) [15,16].

Tai Chi (TC) is an ancient form of exercise, meditation, and self-defence widely practiced in China [17]. It is a low-impact moderate-intensity exercise that focuses on controlling the stability of movements, which can safely be performed by people with chronic disease or disability [18]. As a balanced-base exercise, TC increases strength, balance, and physical function and also helps to avoid falls [19,20]. A recent systematic review has suggested that TC might also increase postural control and balance of stroke survivors [4]. However, FOF and unequal load bearing might limit the ability to perform TC movements of the lower limbs.

Body weight support (BWS) training typically includes an apparatus

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that mechanically supports patients with a harness while walking on a treadmill or over ground [21]. The constraints and support provided by the BWS system help vertical alignment and trunk stability during ambulation [22]. BWS training provides benefits in improving motor function, locomotion ability, and balance in patients with nervous system injury [22–24] such as stroke [23]. BWS can provide stroke survivors the confidence to begin rehabilitation promptly after surgery or trauma to recover balance and locomotion without FOF [21]. In addition, BWS reduces lower-extremity load and, thus, speeds initiation of walking [25]. TC and BWS have exclusive benefits and the positive effect of rehabilitation in stroke survivors has been documented. However, to our knowledge, no studies have assessed the combination of TC and BWS to enhance the ability to balance properly in stroke patients with FOF.

This study examined whether BWS-TC footwork training could enhance balance capability in stroke survivors. The overall hypothesis of this study was that BWS-TC footwork training would increase dynamic control, sensory integration of balance, and lower extremity function in stroke patients and mainly due to the exercise program's emphasis on weight shifts in diverse footwork along with lower extremity control movements near the limit of stability. We further hypothesized that this training might also reduce the risk of falling in stroke survivors with FOF.

2. Materials and methods

2.1. Study design

This assessor-blinded randomized clinical trial compared the effects of 12-week of exercise between BWS-TC and control groups. Patients in the control group received conventional rehabilitation therapies, while patients in the BWS-TC group received a combination of BWS-TC footwork training and conventional rehabilitation therapies. All evaluations were performed within seven days before and 12 weeks after the intervention by a research assistant who was not part of the research investigation team. To avoid potential bias, the investigator was not provided any details about the study design. All evaluations and BWS-TC footwork training sessions were done in the hospital. This study was approved by the hospital institutional review board. The trial was registered with the ClinicalTrials.gov (ChiCTR1900020758).

2.2. Study participants

Study participants were recruited through flyers, posters, and referrals from neurologists or physical therapists between March 2016 and September 2017. The participants were mainly recruited from Seventh People's Hospital and nearby community centres (Gaoqiao, Gaohang, Pudong District, Shanghai, China). Potentially eligible participants underwent in-person evaluations.

The inclusion criteria comprised a clinical diagnosis (computed tomography/magnetic resonance imaging [CT/MRI]) of cerebral haemorrhage or infarction; FOF based on positive responses to the question: "Are you afraid of falling?" [16,26]; 30–75 years of age; adequate cognition to follow commands; score of greater than 24 on the Mini-Mental State examination; able to stand unaided and walk without an assistive device; and no prior experience with TC. The exclusion criteria included current involvement in any other clinical study or instructor-directed exercise program; vision disorders; severe hypertension or cardiopulmonary diseases; and lower extremity joint or muscle injuries.

2.3. Sample size

The sample size was calculated using G*power software (v3.1.9.2) based on a comparison of outcome measures between the BWS-TC and control groups, represented by improvement in dynamic balance in the limits of stability (LOS) as the main effect indicators. Our preliminary test data indicated that the means and standard deviations of the score were 9.62 and 4.16 points, and 5.05 and 4.62 points in the BWS-TC and control groups, respectively. According to the non-inferiority clinical trial method, with a power of 0.80, an alpha level of 0.05, and fall case rate of 10%, an estimated 36 participants were required for this study.

2.4. Randomization and allocation concealment

The participants were screened through self-assessment and in-person evaluation to determine if they met the inclusion and exclusion criteria. After completing baseline testing, each participant received a sealed envelope containing a random allocation sequence number to either the intervention or control group. The sequence numbers were generated by an independent statistician using Excel (Microsoft). The statistician was not involved in the study recruitment, intervention, or evaluation. Group allocations and interventions were not disclosed to the outcome evaluators and data analysers.

2.5. Interventions

The TC intervention applied in this study was chiefly based on BWS training. As shown in Fig. 2, each patient was asked to wear a harness and a specific percentage of their body weight was supported by an overhead suspension system (LiKorall™, 250 ES, Hill-Rom, Sweden). The TC intervention was developed based on the 24-form simplified TC promoted by the State Sports General Administration of China [27]. The footwork is the foundation and precursor of TC exercise. From the 24 forms of the simplified TC, we selected seven step forms, i.e., forward steps, backward steps, shuffle steps, empty steps, lunge steps, single-leg support, and turning around (Fig. 3). These seven typical step forms comprise most TC movements.

In this study, two martial art coaches were hired to teach the BWS-TC footwork. These two coaches had National Second-level Athlete Certifications from the National Traditional Sports Major of Shanghai University of Sports. All patients were required to undergo a 40-min TC session three times per week for 12 weeks. Each session incorporated a 5-min warm-up sequence at the beginning, a 5-min cooldown sequence at the end, and 30 min of BWS-TC footwork training in between with rest periods if required. Previous studies had shown a significant decrease in energy cost and quadriceps activation at a BWS of 40% [28,29]. As the level of BWS increased, lower extremity load and muscle activity progressively decreased. Therefore, in this study, the initial BWS was set 40%. During the 12-week of the program, a gradual easy-to-difficult progression was followed, which was divided into five stages corresponding to BWS: week 1: 40%; weeks 2–3: 30%; weeks 4–6: 20%; and weeks 7–12: 0%.

The BWS-TC footwork training rehabilitation program was designed to maximize the benefit for stroke patients with FOF. We wanted to provide benefits to their insufficient support capacity to preserve their motor function as well as posture balance control. This was achieved by asking the patients to implement both symmetric and diagonal movements, including weight shifts, controlled displacement of the centre of gravity (COG) over their base of support, ankle sways, and anterior-posterior and lateral stepping. Hence, the training process did not focus on the movements of upper limbs; we mainly emphasized endurance among different movements as well as weight shifts.

Patients in the control group were involved in typical conventional rehabilitation programs including personalized Bobath therapy, proprioceptive neuromuscular facilitation, sitting and standing balance training, and walking. The BWS-TC group also had similar frequencies and training time as those in the control group.

2.6. Outcome measures

The collected demographic and clinical characteristics of the participants included age, sex, side of hemiparesis, category of stroke, and

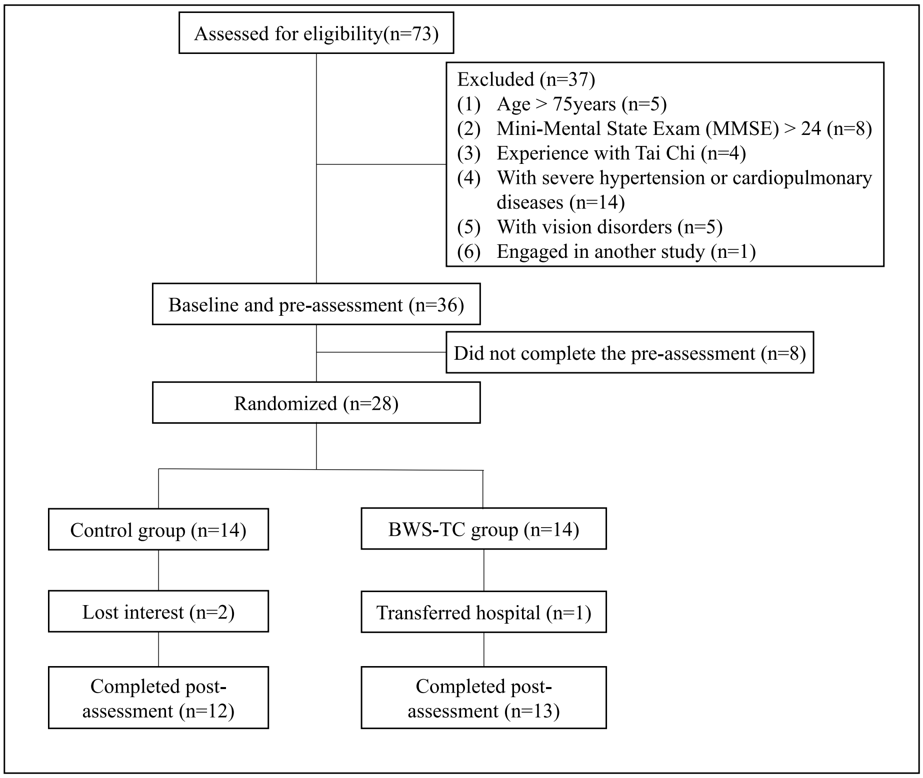

Fig. 1. Flowchart illustrating the process of participant recruitment and retention.
Note: BWS-TC: Body Weight Support-Tai Chi; MMSE: Mini-Mental State Examination.

time elapsed since the stroke. The participants were evaluated on four outcome measures at baseline and at 12 weeks. The primary outcome was dynamic balance in LOS, as measured by computerized dynamic posturography (Biodex Balance System, BBS, USA). The secondary outcomes included the Modified Clinical Test of Sensory Integration of Balance (m-CTSIB), Fall Risk Index (FRI), and Fgul-Meyer Assessment (FMA) of the lower limbs. A single evaluator with many years of assessment experience performed the evaluations to eliminate variability in assessment results and to ensure assessment accuracy.

LOS test. The LOS were defined as the farthest distance in eight different directions a subject can lean from an upright position within their base of support without taking any steps [30,31]. Li et al. [31] and Ibrahim et al. [32] have demonstrated the LOS test to be a sensitive measure of dynamic balance control, with higher scores indicating better balance or control. Moreover, previous studies established the reliability of evidence using the Biodex Balance System (BBS) and the test protocol, showing moderate test-retest reliability for directional control [33]. These dynamic balance tests were done at the easy level (=50% LOS). All BBS procedures were done as per the manufacturer's guidelines. The BBS tests the subject's ability to follow the quick movement of an indicator to a sporadic target from their COG within their base of support. The results were quantified by calculating the ratio of the linear distance from the COG to the target point to the actual path length; scores for both measures range from 0 to 100%. All participants were trained for 1 min to adapt to the machine. Furthermore, only one successful trial was collected to disregard learning effects and avoid muscle tiredness.

Sensory Integration of Balance test. The m-CTSIB provided a general evaluation of the participant's capability to assimilate numerous senses with regards to balance as well as compensation when one or more of those senses does not act properly during four conditions using the BBS [34]. Freeman et al. [35] suggested that the m-CTSIB may be a valid and clinically meaningful measure of sensory organization. The four conditions include: (1) Eyes open while on a firm surface: this baseline condition incorporates visual, and vestibular plus somatosensory inputs; (2) eyes closed while on a firm surface: this condition removes visual input to assess vestibular plus somatosensory inputs; (3) eyes open while on a foam surface: this condition is used to assess somatosensory interaction with visual involvement; and (4) eyes closed while on a foam surface: this condition is used to assess somatosensory interaction by means of vestibular input. In this test, the patients were trained to maintain the vertical projection with their COG in the centre of the platform by watching a perpendicular screen situated 30 cm anterior to their face. The sway indexes of the COG were recorded during the four conditions, with higher values indicating a more unstable posture. Each evaluation lasted 20 s, with a 10-s rest during the evaluation.

Fall Risk Index assessment. FRI assessment using the BBS was used to quantify the fall risk in stroke patients from the perspective of physiological function. The FRI was chosen as an outcome measure because Prometti et al. [36] had shown it to be a sensitive measure of fall risk, with higher values indicating a larger fall risk. The BBS induces joint stress, providing a stimulus for a muscular response allowing maximal stimulation of the mechanoreceptors of the ankle joint [37]. Mechanoreceptors provide information on various environmental and physiological conditions that affect a person's ability to maintain equilibrium and prevent falls [36]. The patients were asked to stand shoeless on the platform with eyes open with the BBS set to continuous instability (level 8). Each evaluation lasted 20 s with a 10-s rest during the evaluation. The average value of three evaluations was obtained.

Assessment of lower limb motor function. Motor function was measured by simplified Fugl-Meyer motor function assessment scale, which has demonstrated excellent interrater and intra-rater reliability and construct validity [38] and is often used in stroke rehabilitation research [39,40]. This test was used to evaluate the measurements of the lower limbs such as lower extremity plus coordination along with an aggregate score of 34. Each element was scored using a 3-point rating scale, with higher scores indicating less motor damage.

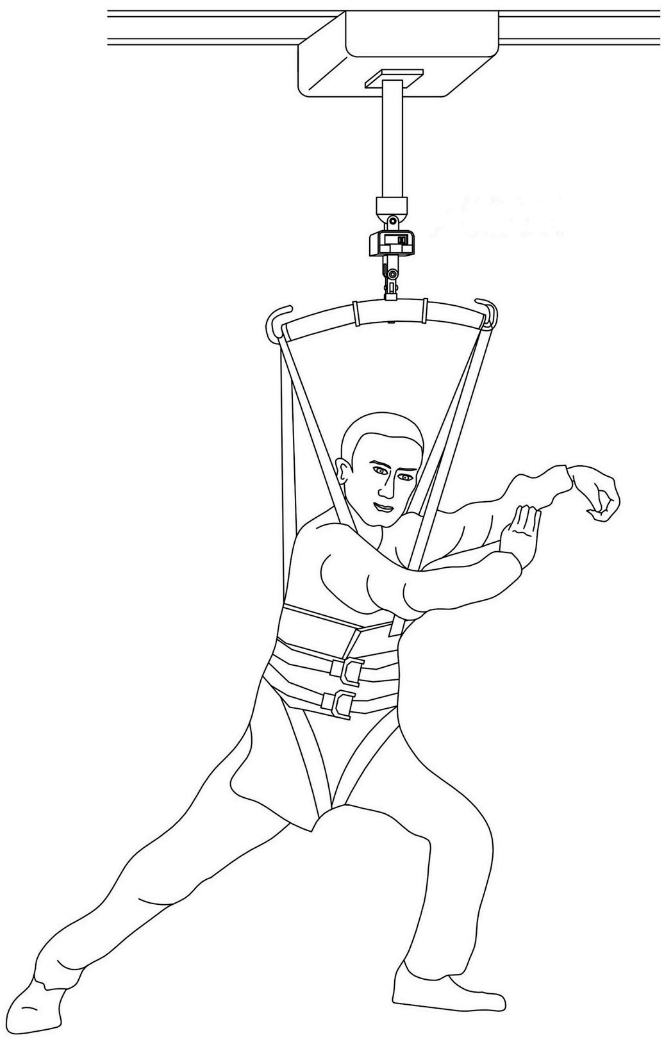

Fig. 2. Schematic diagram of body weight support with Tai Chi.

2.7. Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA). The primary and secondary analyses were done on an intention-to-treat basis. To assess between-group differences in demographic and baseline variables; one-way analysis of variance (ANOVA) and Chi-square tests were used for continuous variables and categorical variables, respectively. A two-way ANOVA repeated measures with group as a group (BWS-TC vs. control) factor and time (pre/post-intervention) factor was used to calculate the effects of the interventions on all outcome measures [41,42]. Bonferroni correction was conducted where the time × intervention interaction effect was statistically significant. An alpha level of 0.05 was considered as statistical significance.

3. Results

3.1. Participant characteristics

We screened a total of 73 stroke survivors to determine their eligibility. Of these 73 patients, 37 did not meet the inclusion criteria. The remaining 36 patients further participated in the pre-assessment. Of these 36 participants, 8 did not complete the pre-assessments; thus, the remaining 28 participants were arbitrarily allocated to two groups. Another three participants withdrew from the study after having participated because one was transferred to a different hospital and two lost interest in the study (Fig. 1). Thus, 25 participants were included in the analysis.

We recorded both demographic and clinical characteristics of the participants at baseline, as shown in Table 1. There were no statistically noteworthy differences between the two groups ($P > 0.05$). During the study duration, there were no adverse events.

3.2. Comparisons of dynamic control at baseline and 12 weeks

The primary outcome measures at baseline and 12 weeks are described in Table 2. We observed substantial group × time interactions in both forward and left directional control in the dynamic balance test ($P < 0.05$). Moreover, there were no noteworthy changes pre-intervention between groups as per the simple effect test result of the group factor. However, there were significant changes between groups post-intervention. We also observed significant between-group changes in scores in dynamic control overall and in the forward, left, and right directions ($P < 0.05$). However, there were no significant between-group differences in the time required to complete the test and other indexes of dynamic control. Additionally, the magnitude of the change in these index scores in the BWS-TC group was greater than those in the control group. We also found a significant time effect in all indexes of dynamic control between the two groups both pre- and post-intervention ($P < 0.05$).

3.3. Comparisons of m-CTSIB at baseline and 12 weeks

To examine the effect of BWS-TC on sensory integration of balance at baseline and after 12 weeks, BBS was used to assess the influence of COG during conditions 1 (baseline condition), 2 (somatosensory and vestibular integration), 3 (vision and vestibular integration), and 4 (vestibular). As shown in Fig. 4, a significant group × time interaction effect was observed in conditions 1, 2, and 3. There were significant differences post-intervention between groups in conditions 1, 2, and 3. Additionally, substantial between-group changes were also seen after 12 weeks in condition 2. There were no significant changes in condition 4 (vestibular evaluations).

Fig. 3. Seven step forms of Tai Chi footwork (a. Forward steps; b. Backward steps; c. Shuffle steps; d. Lunge steps; e. Empty steps; f. Turn around; and g. Single leg support).

Table 1
Demographic and clinical characteristics of the participants at baseline.

Characteristic	Control (n = 14)	BWS-TC (n = 14)	F/χ^2	P
Age (years)	59.93 ± 9.96	62.21 ± 9.74	0.377	0.544
Body mass (kg)	66.71 ± 7.42	68.14 ± 8.37	0.229	0.637
Time after onset (Months)	10.50 ± 4.24	11.36 ± 4.91	0.245	0.625
Sex (M/F)	10/4	12/2	0.648	0.324
Hemiparesis side (L/R)	7/7	5/9	0.704	0.352
Stroke type (Hae/Isc)	8/6	9/5	1.000	0.500

Note: Continuous variables are presented as mean ± SD. The chi-square test (categorical variables) and one-way ANOVA (continuous variables) were done. There were not any significant differences among both groups. Abbreviations: BWS-TC = Body weight support-Tai Chi; F = female; M = male; L = left; R = right; Hae = haemorrhagic stroke; Isc = ischemic stroke.

3.4. Comparisons of FMA and FRI at baseline and 12 weeks

The comparisons of FMA and FRI at baseline and 12 weeks are shown in Table 3. We observed substantial group × time interactions in FMA and FRI. Moreover, there were no significant differences pre-intervention according to the simple effect test of the group factor. However, there were significant differences post-intervention between the two groups. Additionally, there were no significant group differences in FMA and FRI (F = 0.956, P = 0.338; F = 1.177, P = 0.289). However, patients in the BWS-TC group showed a mean increase of 39.2% points in FMA along with a mean reduction of 33.1% points in FRI between baseline and 12 weeks. Similarly, the time effect remained significant for FMA and FRI.

4. Discussion

The main aim of this study was to assess if BWS-TC footwork training might enhance balance aptitude and also decrease the risk of fall in stroke survivors with FOF. To our knowledge, no studies have focused on rehabilitation programs to enhance the balance of stroke survivors with inadequate support capability and FOF. The results of our study demonstrated that a 12-week BWS-TC footwork training rehabilitation program (three times/week) was beneficial in enhancing static/dynamic balance, lower limbs function, and sensory integration of balance in stroke survivors with FOF compared to those in the control group. The substantial reduction in FRI indicated that this program might be beneficial for preventing fall in stroke survivors.

Stability is important for daily activities. It helps to maintain postural stability and orientation [43,44]. We observed significant between-group differences in dynamic control scores in the forward, overall, right, and left directions. Though common changes were not observed in other index of dynamic control, the magnitude of the change in index score in the BWS-TC group was greater than that in the control group. These results suggested that 12-week of BWS-TC footwork training was further beneficial and effective in increasing dynamic balance in stroke survivors. Previous studies have also reported similar findings [34,45]. The increase in dynamic control capability in the present study might be attributed to the TC footwork within the foundation of weight support as well as addressing the FOF. The rehabilitation program in the present study involved various aspects such as organized movements combined with enhanced balance control at the LOS, while executing heel-to-toe (forward), toe-to-heel (backward), left-to-right, right-to-left, single-leg support, and turn-around movements to improve lower-extremity function and weight-shift ability.

Damage to the sensory integration system rather than motor impairment while standing might lead to more falls in stroke survivors [13]. Niam et al. [46] reported that the postural influence was associated with proprioception of the ankle in stroke, signifying a vital part of the somatosensory system in maintaining balance in stroke survivors. This study used BBS to assess the sensory integration of balance. After completing the 12 weeks of BWS-TC footwork training, the participants had improved sensory integration of balance under conditions such as baseline condition, somatosensory and vestibular integration, and vision and vestibular integration compared to the control group. While practicing the BWS-TC footwork, the subjects depended on joint movement to conserve dynamic balance near the LOS, and constant dragging of the proprioceptors was advantageous for improving balance sensory integration.

Au-Yeung et al. [34] evaluated the effect of a 12-week modified TC program on the sensory integration of stroke survivors using a BBS, reporting improvement in standing equilibrium at three levels: visual and vestibular integration, vestibular integration with visual sensory deprivation, and higher-level vestibular integration when visual input conflicted with somatosensory input. Nevertheless, there were no significant between-group changes in vestibular condition in the present study. This might be because that the BWS-TC intervention emphasized

Table 2
Comparisons of dynamic control at baseline and 12 weeks.

Index	Group	Pre	Post	Change (%)	Group effect	Time effect	Group × time	Simple effect	
								Pre	Post
Overall	Control	28.17 ± 10.02	32.75 ± 12.61	30.34	F = 5.686	F = 10.751	*N.S.*	*N.S.*	*N.S.*
	BWS-TC	30.15 ± 7.53	46.08 ± 13.65	61.02	P = 0.026	P = 0.003			
Time to complete	Control	65.25 ± 11.67	49.75 ± 7.45	−21.87	*N.S.*	F = 31.291	*N.S.*	*N.S.*	*N.S.*
	BWS-TC	66.08 ± 14.27	44.69 ± 10.61	−28.90		P = 0.000			
Forward	Control	38.33 ± 11.77	44.67 ± 13.43	24.72	F = 4.845	F = 29.030	F = 4.942	*N.S.*	F = 7.801
	BWS-TC	41.69 ± 6.28	56.92 ± 8.07	38.92	P = 0.038	P = 0.000	P = 0.036		P = 0.010
Backward	Control	16.33 ± 5.58	20.08 ± 6.57	48.57	*N.S.*	F = 12.182	*N.S.*	*N.S.*	*N.S.*
	T BWS-TC	17.62 ± 5.65	26.23 ± 8.90	65.51		P = 0.002			
Left	Control	36.67 ± 17.17	39.25 ± 13.86	28.29	F = 4.419	F = 10.758	F = 5.608	*N.S.*	F = 11.959
	BWS-TC	38.62 ± 9.55	54.62 ± 7.74	49.58	P = 0.047	P = 0.003	P = 0.027		P = 0.002
Right	Control	37.67 ± 19.62	40.67 ± 11.31	54.76	F = 5.432	F = 6.944	*N.S.*	*N.S.*	*N.S.*
	BWS-TC	35.46 ± 13.82	57.08 ± 9.12	93.69	P = 0.029	P = 0.015			
Forward/left	Control	44.83 ± 8.41	48.33 ± 17.69	12.62	*N.S.*	F = 6.336	*N.S.*	*N.S.*	*N.S.*
	BWS-TC	41.54 ± 11.22	55.08 ± 6.40	42.76		P = 0.019			
Forward/right	Control	47.33 ± 8.60	52.33 ± 15.52	14.03	*N.S.*	F = 5.077	*N.S.*	*N.S.*	*N.S.*
	BWS-TC	45.38 ± 9.24	55.77 ± 10.93	28.04		P = 0.034			
Backward/left	Control	18.83 ± 6.22	25.42 ± 9.92	41.54	*N.S.*	F = 16.765	*N.S.*	*N.S.*	*N.S.*
	BWS-TC	20.77 ± 7.59	33.15 ± 9.32	80.29		P = 0.000			
Backward/right	Control	23.33 ± 8.37	27.08 ± 5.33	30.33	*N.S.*	F = 9.955	*N.S.*	*N.S.*	*N.S.*
	BWS-TC	22.85 ± 7.46	33.15 ± 13.36	52.17		P = 0.004			

Note: Values are presented as means ± SD; BWS-TC: Body Weight Support-Tai Chi; *N.S.*: no statistically significant difference; Pre: pre-assessment; Post: post-assessment.

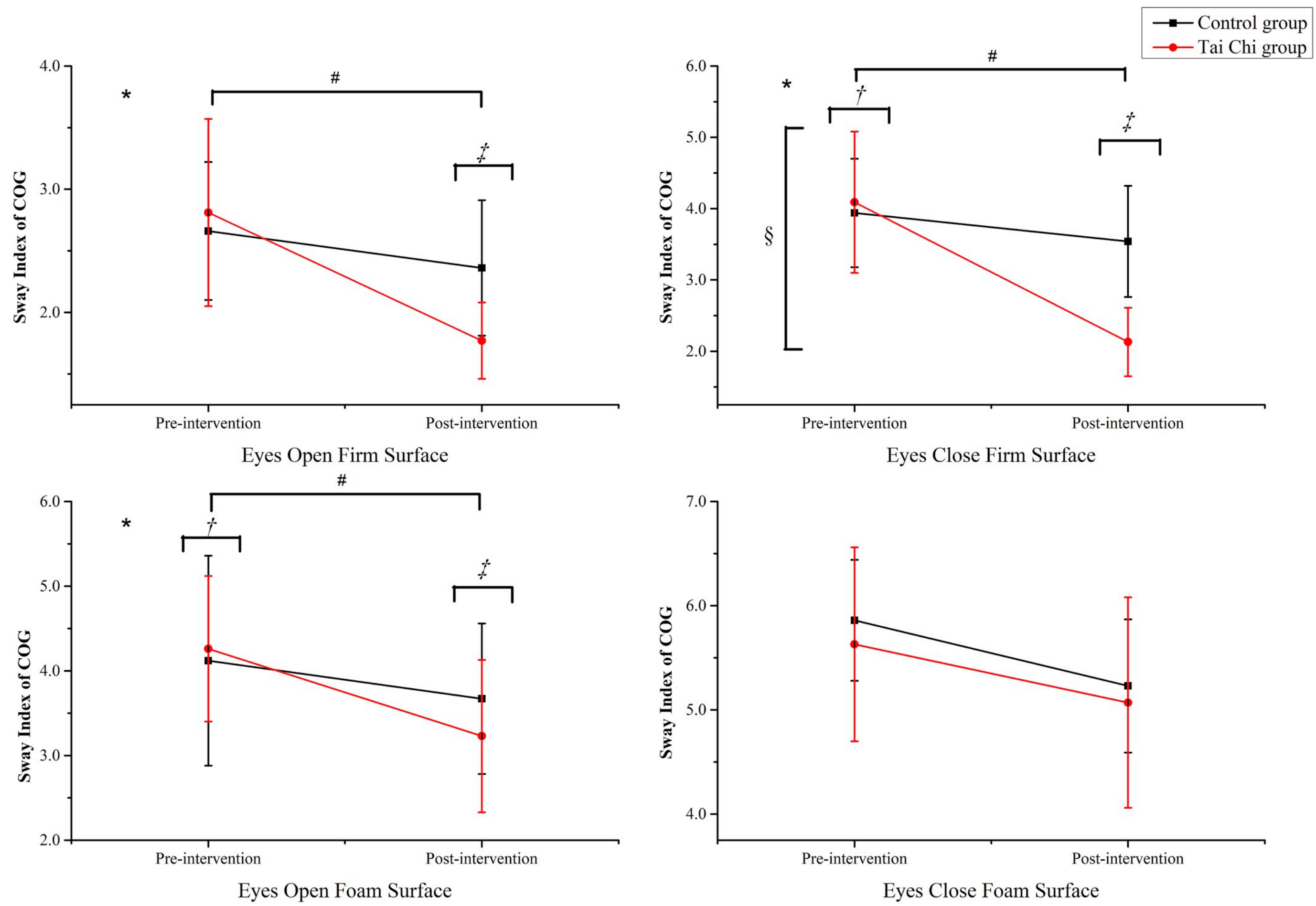

Fig. 4. Comparison of Modified Clinical Test of Sensory Integration of Balance (m-CTSIB) at baseline and 12 weeks. Note: COG: centre of gravity. *Statistically significant interaction between intervention and time; †Statistically significant group difference in the pre-assessment based on simple effect test; ‡Statistically significant group difference in the post-assessment based on simple effect test; #Statistically significant time difference; §Statistically significant group difference.

Table 3
Comparisons of FMA and FRI at baseline and 12-weeks.

Index	Group	Pre	Post	Change
FMA*‡#	Control	23.17 ± 4.04	25.50 ± 3.58	12.2%
	BWS-TC	21.92 ± 5.12	29.31 ± 2.56	39.2%
FRI*‡#	Control	3.67 ± 1.04	3.32 ± 0.72	6.4%
	BWS-TC	3.86 ± 0.73	2.54 ± 0.42	33.1%

Note: Values are presented as means ± SD. Abbreviations: FMA: Fugl-Meyer assessment of lower extremities. FRI: Fall Risk Index; BWS-TC: Body Weight Support-Tai Chi; Pre: pre-assessment; Post: post-assessment. *Statistically significant interaction between intervention and time; †Statistically significant group difference in the pre-assessment based on simple effect test; ‡Statistically significant group difference in the post-assessment based on simple effect test; #Statistically significant time difference; §Statistically significant group difference.

steadiness during multiple movements as well as weight-shifts. Additionally, the intervention did not emphasize synchronized eye-head-hand and movements of upper limbs.

After experiencing a stroke, patients would consider fall to be a general clinical problem [5,47]. Falls may lead to the development of FOF in these patients [15]. Furthermore, diminished lower extremity function was associated with fall in stroke survivors [48]. The results of the present study demonstrated that BWS-TC footwork training may increase lower extremity function. Moreover, a meta-analysis showed a significant difference in lower extremity function between the TC and control groups [49]. This might be mainly due to the fact that while performing TC, patients are required to perform a large number of concentric, eccentric, and isometric contractions as well as coordination between muscle groups while maintaining a specific knee posture and hip flexion.

Depending on the enhancement of dynamic control, sensory integration of balance, and muscle function described above, we observed BWS-TC footwork training reduced the FRI. These outcomes were comparable to those in the available literature on interventions based on TC exercise reporting that a reduced risk of falls due to TC in stroke survivors. We demonstrated that BWS-TC footwork training provides a novel rehabilitation strategy for stroke survivors unable to perform regular exercise due to FOF and bearing asymmetry. This strategy will also help to reduce accidents related to falling during rehabilitation in stroke survivors.

Although we could not eliminate the effects of uncontrolled factors, we ensured the quality of the trial by setting inclusion and exclusion criteria. Since participants were randomly assigned to two groups, they should be comparable in clinical characteristics and other related factors. Compared to the control group, any improvement in the BWS-TC group could be attributable to the BWS-TC footwork training as long as there were no other potential independent variables.

This study also had some limitations. First, this study had a small sample size. Thus, additional studies with larger sample size are required to confirm the outcomes of this study. Next, we used only routine rehabilitation treatment as control and did not investigate any other types of exercise interventions. Third, this study did not compare FRI findings to those of previous studies. While different studies have addressed the need for assessment of the risk of falls, few have used the BBS. Although there is a recognized need for consensus, measurement indexes for FRI in stroke survivors are not yet standardized. Prometti et al. [36] reported that assessment of FRI using the BBS constituted a novel and valid tool for evaluating stroke survivors. Lastly, previous literature has recommended that stroke patients self-practice either with their family or in their community once the interventions complete [34, 50]. However, due to the lack of BWS equipment in these locations, our study did not conduct any follow-up after the interventions were completed. Nevertheless, the findings of our study suggest that BWS-TC footwork training is useful for improving dynamic balance and reducing the risk of falling in stroke survivors with FOF.

5. Conclusion

Twelve weeks of BWS-TC footwork training improved dynamic balance control, sensory balance integration, and lower extremity functions and reduced the fall risk in stroke survivors with FOF. Additional research using brain imaging is essential to understand the neurological mechanism of fall prevention.

Conflicts of interest

The authors reported no conflicts of interest.

Ethical approval

The study protocol was approved by the Ethics Committee of the Shanghai Seventh People's Hospital. The Chinese Clinical Trial Registration Number is ChiCTR1900020758.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ctcp.2019.101061.

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