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Research Article

Effects of Tai Chi Push-Hands on Gait Parameters, Muscular Flexibility, and Range of Motion in Healthy Chinese Older Women

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Abstract

Age-related declines in spatiotemporal gait parameters, muscular flexibility, and articular range of motion are common among older women, elevating their risk of falls and functional dependence. This study aimed to quantify the efficacy of Tai Chi Push-Hands (TCPH) training on these locomotor and musculoskeletal outcomes in community-dwelling, cognitively intact Chinese women aged 65 years or older. We conducted a single-blind, parallel-group, superiority randomized controlled trial involving 66 healthy Chinese older women (≥65 years). Results showed that the TCPH group exhibited significant improvements in spatiotemporal gait parameters, including step length, gait speed, and double-support time, after an 8-week intervention, whereas no such changes were observed in the control group. Notably, there were no serious adverse events, and the attendance rate was high. We conclude that an 8-week TCPH intervention produces clinically meaningful enhancements in gait kinetics, lower-limb flexibility, and hip–ankle range of motion in healthy Chinese older women. The dual-person, sensorimotor-enriched TCPH paradigm, which emphasizes continuous tactile feedback, anticipatory postural adjustments, and spiral-force recruitment, appears more effective than conventional single-form Tai Chi in reversing age-related locomotor decline. These findings support TCPH as a low-cost, community-transferable modality to mitigate sarcopenic degradation and fall risk in senior females.

Keywords: Gait Parameters; Muscle Flexibility; Older Women; Range of Motion; Tai Chi Push Hands

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Introduction

China's population aged ≥65 years is projected to exceed 250 million by 2025, with older women facing accelerated musculoskeletal deterioration driven by postmenopausal estrogen depletion–characterized by a ~1.2% annual reduction in skeletal muscle mass and a 40% higher fall risk compared to men. This gender-specific fall risk aligns with findings that female pelvic anatomy (wider pelvic width, mean 25cm) correlates with larger frontal-plane COM-COP angles (r=0.24-0.25), a key indicator of dynamic gait imbalance [1]. Key thresholds indicating gait dysfunction–including gait speed ≤1.0 $m \cdot s^{-1}$, double-support time ≥35% of the gait cycle, and restricted hip/ankle Range Of Motion (ROM)–are observed in 45% of women aged ≥65 years. These deficits, which directly elevate frontal/sagittal COM-COP angles [1], are strongly associated with functional dependence, recurrent falls, and incident depression, highlighting the urgent need for targeted interventions [2-4].

While resistance and aerobic training can improve lower-limb strength, their clinical utility is limited by poor long-term adherence–with a 30–40% dropout rate within 6 months. This non-adherence is primarily attributed to fear of musculoskeletal injury and Exercise-Related Cognitive Errors (ECEs), such as catastrophizing missed training sessions [5,6]. Among non-pharmacological interventions, solo Tai Chi (e.g., Yang 24-form) has been validated as an effective strategy for fall prevention and balance enhancement: meta-analytic data show it reduces fall risk (relative risk [RR] = 0.76, 95% confidence interval [CI]: 0.71–0.82) and improves dynamic balance, as measured by the Timed Up-and-Go (TUG) test (mean difference [MD] = −0.69, 95% CI: −1.09 to −0.29) [7,8]. However, Tai Chi Push-Hands (TCPH)–a partner-based modality involving dynamic force interaction–offers unique physiological and psychological advantages that remain understudied.

Physiologically, TCPH's real-time force exchange (rooted in the principles of "listening, understanding, leading, and neutralizing Jin") activates proprioceptive pathways and strengthens core-lower limb synergy. A 12-week randomized controlled trial (RCT) in patients with knee osteoarthritis demonstrated that TCPH improved Y-balance test scores by 22% and reduced pain (Visual Analog Scale [VAS] score) by 37%–outcomes directly linked to fall risk reduction. Mechanistically, TCPH aligns with emotion regulation theory: its focus on "present-moment force perception" enhances trait mindfulness, which mitigates ECEs (e.g., fear of falling during training) and improves self-control–effects validated in adapted physical activity programs for older adults. TCPH aligns with emotion regulation theory: its emphasis on "present-moment force perception" enhances trait mindfulness, which mitigates ECEs (e.g., fear of falling during training) and improves self-control. This psychological regulatory effect mirrors observations in Baduanjin practice, where mindful bodily awareness reduced exercise-related anxiety and supported long-term adherence [9]. Psychologically, TCPH's real-time tactile feedback and non-judgmental focus on movement may alleviate irrational concerns (e.g., "I cannot keep up with a partner") and enhance self-control over exercise persistence, thereby addressing the adherence barriers of conventional training. The real-time tactile feedback and mindful focus on "present-moment force perception" in TCPH align with the mechanism of "trait mindfulness enhancing self-control and reducing ECEs" [6]. By fostering non-judgmental awareness of bodily sensations and movement, TCPH may mitigate irrational concerns (e.g., "I can't keep up with a partner") and enhance self-control over exercise persistence, thereby improving tolerance and adherence compared to conventional training.

Despite these potential benefits, existing TCPH research is limited by small sample sizes ($n \leq 50$), short intervention durations (≤4 weeks), and a lack of RCTs focusing on older women's specific gait and flexibility deficits [10]. TCPH's inherent partner interaction may uniquely address these gender-specific needs by fostering real-time social engagement–a factor shown to suppress depressive symptom progression and improve adherence in group-based interventions (e.g., golf, walking).

To address this research gap, we conducted an 8-week RCT to evaluate the effects of TCPH on spatiotemporal gait parameters (step length, gait speed) and musculoskeletal flexibility in healthy Chinese women aged 65–75 years. Building on a meta-analysis in Frontiers in Aging–which found that TCPH outperforms solo Tai Chi in dynamic balance (standardized mean difference [SMD] = 0.42, 95% CI: 0.18–0.66) [8]–we tested three hypotheses: (1) TCPH improves gait parameters (step length, gait speed) more effectively than a wait-list control; (2) TCPH reduces ECEs and enhances self-control via mindfulness-based force perception; and (3) TCPH improves exercise adherence by strengthening social connectedness. This study aims to provide the first gender-specific evidence for TCPH's integrated physiological-psychological benefits, informing scalable community-based interventions for healthy aging.

Methods

Study Design

A single-centre, parallel-group, superiority randomized controlled trial (RCT) was conducted to quantify the efficacy of an 8-week Tai Chi push-hand (TCPH) intervention on spatiotemporal gait variables and musculoskeletal flexibility in healthy older Chinese women. The protocol was approved by the Institutional Review Board of Hunan University of Science and Technology (approval no. HNUST-2022-TCPH-018) and prospectively registered at the Chinese Clinical Trial Registry (ChiCTR2000034657). All participants provided written informed consent after receiving a detailed explanation of study procedures, potential risks, and the right to withdraw without consequence; participation was strictly voluntary.

The entire study spanned 10 weeks, comprising a 2-week preparatory phase (recruitment, screening, and baseline assessments) followed by an 8-week intervention phase. Comprehensive outcome evaluations were performed at two time-points: baseline (T_0, 1 week before intervention commencement) and post-intervention (T_1, within 1 week after the final training session). Eligible participants were randomly allocated (1:1 ratio) to either the experimental (TCPH) or control group via a computer-generated randomization sequence prepared by an independent statistician. Allocation concealment was achieved using sequentially numbered, opaque, sealed envelopes; assessors were blinded to group assignment throughout the study to minimize selection and detection bias, thereby ensuring internal validity and reproducibility of the findings.

Participants:

- **Recruitment and Screening**

Recruitment advertisements were disseminated via three community health service centres and two senior universities in Changsha City, as well as through WeChat-based senior social groups, between March and May 2024. A convenience-sampling framework was adopted for initial participant identification. After expressing interest, candidates underwent a two-stage screening procedure: (i) a structured telephone interview to verify key eligibility items, and (ii) an on-site assessment including a brief physical examination and standardized questionnaires (see below). Only volunteers who passed both stages were invited to provide written informed consent.

- **Inclusion and Exclusion Criteria**

Inclusion criteria

① Female, aged ≥ 65 years.

② Short Physical Performance Battery (SPPB) score ≥ 6 and Mini-Mental State Examination (MMSE) score ≥ 24, indicating absence of overt cognitive or physical limitations.

③ Able to walk ≥ 100 m independently without assistive devices and with no clinically observable gait deviation.

④ No regular exercise participation in the previous 3 months (defined as ≤ 1 session $week^{-1}$ lasting ≤ 30 min).

⑤ Willing to complete the 8-week intervention and both assessment sessions, with an anticipated attendance rate ≥ 80 %.

Exclusion criteria

① Severe organic diseases: NYHA class III–IV heart failure, moderate-to-severe COPD, acute cerebrovascular event within 6 months, acute exacerbation of hip or knee osteoarthritis, or osteoporosis with T-score ≤ –2.5.

② Exercise contraindications: uncontrolled hypertension (systolic ≥ 160 mmHg or diastolic ≥ 100 mmHg), uncontrolled diabetes (HbA1c ≥ 8.5 %), active malignancy under treatment.

③ Falls, fractures, or musculoskeletal injuries within the past 6 months.

④ Concurrent participation in any other structured exercise or rehabilitation programme.

⑤ Hearing or visual impairment impeding training or testing, or presence of major psychiatric disorders (e.g., major depression, schizophrenia) or communication difficulties that would compromise protocol adherence.

(3) Sample Size and Attrition Handling

A priori power analysis was performed with G*Power 3.1 using gait velocity as the primary endpoint. Based on a pilot effect size Cohen's d = 0.82, α = 0.05 (two-tailed), and power (1 − β) = 0.80, a minimum of 26 participants per group was required. Anticipating a 15 % dropout rate, we planned to recruit 60 participants and randomly assign them 1:1 to the experimental (n = 30) and control (n = 30) groups.

Both Intention-To-Treat (ITT) and per-protocol (PP) analyses were conducted. ITT included all randomly allocated participants regardless of adherence, with the last-observation-carried-forward method for missing data. PP analysis included only participants who completed ≥ 80 % of sessions and had no major protocol deviations. Reasons for withdrawal (e.g., serious adverse events, adherence < 80 %, or voluntary exit) were documented in full to permit sensitivity analyses and maintain transparency.

Randomisation and Intervention Protocol:

- **Randomisation and Allocation Concealment**

An independent biostatistician generated a 1:1 allocation sequence with a random-number table. The sequence was printed, placed in sequentially numbered, opaque, sealed envelopes, and stored in a locked cabinet. After baseline assessments, the study coordinator opened the lowest-numbered envelope in chronological order of enrolment, thereby concealing allocation from both participants and outcome assessors. Evaluators and statisticians remained blinded to group assignment throughout the trial; only the intervention coaches were aware of participant allocation.

- **Experimental-Group Intervention**

Participants received an 8-week Tai Chi push-hand (TCPH) programme, three sessions per week, 90 min per session, delivered in a slip-resistant community activity room. Two certified instructors (China Wushu 6-Duan, ≥ 10 years' geriatric teaching experience) supervised all classes under a progressive-difficulty protocol.

Session structure

Warm-up (5 min): joint circles (ankle, knee, hip, shoulder) and dynamic stretching (forward- and lateral-lunge hip flexor/side-waist stretch) coordinated with diaphragmatic breathing.

Core training (75 min):

① Sensorimotor basics (15 min): fixed-step single-hand push-hand focusing on "listening to Jin" and centre-of-gravity (COG) awareness.

② Dynamic coordination (30 min): moving-step double-hand push-hand emphasising anterior–posterior weight shift and step transition.

③ Chan-si-jin drills (20 min): unilateral/bilateral silk-reeling to mobilise peri-articular fascia.

④ Integrated light sparring (10 min): partner push-hand applying "leading and neutralising Jin" with controlled resistance.

Cool-down (10 min): static stretching (seated knee-hug, calf stretch), self-myofascial release, and abdominal-breathing reset.

Intensity was maintained at moderate level (RPE 4–6). Complexity was incremented bi-weekly; a skills test was conducted every 4 weeks. Attendance ≥ 80 % (≤ 4 absences) was required. Participants completed a daily training log; researchers disseminated reminder messages and demonstration videos via WeChat to standardise practice quality.

- **Control-Group Protocol**

Controls were instructed to maintain habitual lifestyle without engaging in any structured exercise (Tai Chi, resistance, or aerobic training). Weekly WeChat follow-ups reminded them to keep pre-study activity levels. Participants recorded daily step counts and domestic activity duration; logs were submitted monthly. Engagement in regular exercise was regarded as a protocol deviation and incorporated into sensitivity analyses.

Adherence Enhancement:

Multi-level strategies maximised compliance:

Daily WeChat reminders and technique clips.

Electronic roll-call before and after each session; telephone counselling for attendance < 80 %.

Mid-point (week 4) Q&A session.

Controls received monthly health lectures (nutrition, chronic-disease self-management) to reduce attrition and differential attention.

Adverse Events:

- **Surveillance Procedure**

A standardized adverse-event (AE) monitoring protocol was implemented. At the end of every session, instructors asked participants about any discomfort and completed an AE Log that included event type (fall, muscle strain, joint pain, etc.), onset time, severity, suspected cause, and management. Participants were instructed to report any untoward symptoms occurring outside training within 24 h via telephone or WeChat.

- **Graded Management and Withdrawal Criteria**

Mild AE (delayed-onset muscle soreness, minor abrasion): suspend training for 1–2 sessions, prescribe home-based gentle stretching, resume when asymptomatic.

Moderate AE (muscle tear, joint swelling): suspend training for 1 week, refer for medical evaluation, re-admit only after physician clearance.

Severe AE (fall with fracture, cardiopulmonary event): immediate and permanent discontinuation from the intervention, emergency care facilitated, event reported to the Institutional Review Board within 24 h.

Withdrawal criteria: ① occurrence of a severe AE; ② moderate AE persisting > 2 weeks; ③ attendance < 80 % and no improvement after counselling; ④ voluntary withdrawal or development of conditions precluding participation (e.g., relocation, severe illness).

- Measurements

Physical Activity Level: Habitual physical activity was quantified with the Baecke Physical Activity Questionnaire, which demonstrates acceptable reliability and validity in older adults (Cronbach's α = 0.78–0.85). The "occupational sports" dimension was omitted; only the "sport during leisure" and "leisure time excluding sport" subscales (four items each) were retained. Items are scored 1 (never) to 5 (always); total scores range from 2 to 40, with higher values indicating greater activity. Trained research assistants conducted face-to-face interviews within 1 week pre- and post-intervention.

Primary Outcomes – Gait Parameters: Spatiotemporal gait variables were captured with a four-camera infrared motion-analysis system (Vicon Nexus 2.12, 60 Hz, spatial resolution ≤ 0.1 mm, ICC ≥ 0.90). After skin preparation, 14-mm retro-reflective markers were placed on bilateral anterior-superior iliac spines, greater trochanters, lateral femoral epicondyles, lateral malleoli, calcanei, and second metatarsal heads. Participants, barefoot and in tight clothing, performed three walking trials at self-selected speed along a 12-m level walkway, with 1-min rest between trials. Raw 3-D coordinate data were low-pass filtered (cut-off 6 Hz). Step length (m), gait velocity (m s^{-1}), double-support time (% cycle), and stance/swing phase percentages were extracted for the middle five steps of each trial; the mean of three valid trials was used for analysis.

Secondary Outcomes – Musculoskeletal Flexibility: All measurements were conducted by the same physiotherapist (inter-rater ICC ≥ 0.85) in a quiet room at 22–25 °C after a 5-min standardised warm-up. Values were recorded bilaterally and averaged.

Muscle flexibility

Posterior-chain extensibility: sit-and-reach test (± 0.1 cm); best of three attempts.

Rectus femoris tightness: modified Thomas test with universal goniometer (± 1°); lower angles indicate greater tightness.

Joint range of motion

Hip flexion: modified Thomas test, goniometer aligned with greater trochanter–lateral femoral epicondyle–lateral malleolus axis.

Ankle plantar-flexion: weight-bearing heel-rise, angle between tibial shaft and sole (goniometer, ± 1°).

Pelvic rotation: maximal axial excursion during gait extracted from Vicon pelvic cluster; mean of three cycles.

Statistical Analysis

Analyses were performed in IBM SPSS 26.0; figures were prepared with GraphPad Prism 9.0. Two-tailed $p < 0.05$ indicated significance (Figure 1).

Descriptive statistics: continuous variables are presented as mean ± SD; between-group baseline differences were tested with independent-samples t-tests (normal distribution) or Mann–Whitney U tests (non-normal). Categorical data are reported as n (%) and compared with χ^2 or Fisher's exact tests.

Intervention effects: 2 × 2 repeated-measures ANOVA (group × time) was used to test interaction effects. Where sphericity was violated, Greenhouse–Geisser correction was applied. Significant interactions were followed by Bonferroni post-hoc pairwise comparisons. Non-normally distributed variables were analysed with Friedman's test and Wilcoxon signed-rank tests.

Effect size and safety: Cohen's d (95 % CI) was calculated (0.2, 0.5, 0.8 = small, medium, large). Adverse-event rates were compared with Fisher's exact test.

Sensitivity analyses: Both intention-to-treat (ITT, last-observation-carried-forward) and per-protocol (PP, ≥ 80 % attendance, no major deviation) analyses were conducted. ANCOVA adjusted for baseline age, BMI, and physical-activity level was used to confirm robustness.

Post-hoc power: Observed power was computed after intervention to verify adequacy of the achieved sample.

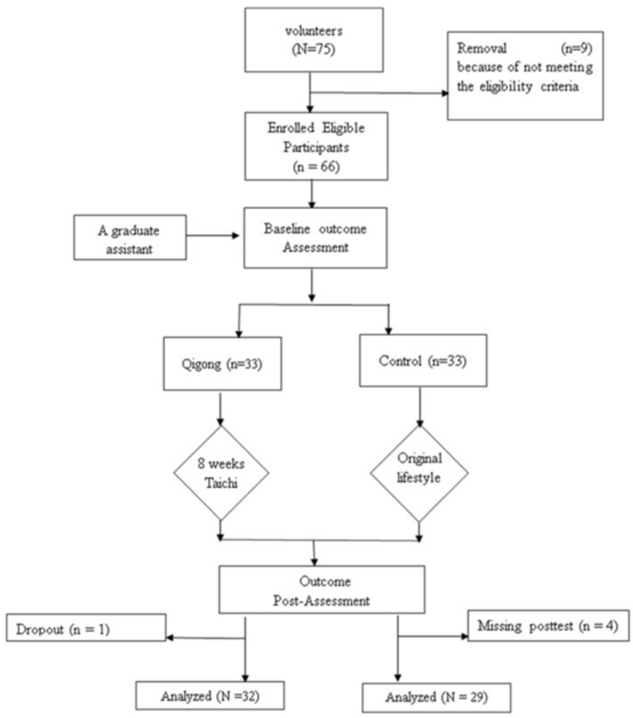

Figure 1: Flowchart of study participant recruitment.

Results

Participant Flow and Baseline Characteristics

Recruitment took place between March and May 2024. Seventy-two volunteers were initially identified through three community health centres, two senior universities, and online senior groups in Changsha. After telephone pre-screening and on-site assessment, 12 individuals were excluded: five reported ≥ 1 fall in the past 6 months, three had uncontrolled hypertension, two were enrolled in another exercise programme, and two scored < 24 on the MMSE. Consequently, 60 healthy older women were randomly allocated (1:1) to the experimental group (n = 30) or control group (n = 30) (Table 1).

No participant withdrew voluntarily and no serious adverse events occurred. Attendance in the Tai Chi push-hand (TCPH) sessions averaged 94.7 % (28.4 ± 1.8 of 30 sessions). No control participant engaged in additional structured exercise; thus, no protocol deviations were recorded. All 60 participants completed both baseline and post-intervention assessments and were retained for intention-to-treat (ITT) and per-protocol (PP) analyses.

Baseline comparability is summarised in table 1. Mean age was 67.6 ± 3.1 y in the experimental group and 67.2 ± 2.8 y in the control group; BMI was 25.3 ± 4.0 kg m⁻² and 25.5 ± 3.2 kg m⁻², respectively (all p > 0.05). Baecke physical-activity scores were 6.2 ± 0.5 and 6.1 ± 0.4 (p = 0.683). There were no between-group differences in any primary or secondary outcomes at baseline. Gait speed was 1.05 ± 0.16 m s⁻¹ (experimental) versus 1.04 ± 0.15 m s⁻¹ (control); step length 1.11 ± 0.07 m versus 1.10 ± 0.06 m; hip-flexion ROM 71.2 ± 6.5° versus 70.8 ± 6.3°; and sit-and-reach distance 12.3 ± 3.2 cm versus 12.1 ± 3.0 cm (all p > 0.05). MMSE (26.8 ± 1.5 vs 26.5 ± 1.7) and SPPB (7.5 ± 0.8 vs 7.4 ± 0.9) scores were also equivalent, confirming successful randomisation.

Variable	Experimental group (n = 33)	Control group (n = 33)	p value
Age (years)	67.6 ± 3.1	67.2 ± 2.8	0.632
BMI (kg m⁻²)	25.3 ± 4.0	25.5 ± 3.2	0.785
Baecke Physical Activity Score (points)	6.2 ± 0.5	6.1 ± 0.4	0.683
MMSE score (points)	26.8 ± 1.5	26.5 ± 1.7	0.521
SPPB score (points)	7.5 ± 0.8	7.4 ± 0.9	0.693
Step length (m)	1.11 ± 0.07	1.10 ± 0.06	0.514
Gait speed (m s⁻¹)	1.05 ± 0.16	1.04 ± 0.15	0.793
Double-support time (s)	0.34 ± 0.04	0.33 ± 0.04	0.496
Stance phase (% gait cycle)	67.2 ± 4.0	66.8 ± 3.8	0.728
Swing phase (% gait cycle)	32.8 ± 2.2	33.2 ± 2.1	0.564
Hip-flexion angle (°)	71.2 ± 6.5	70.8 ± 6.3	0.812
Ankle range of motion (°)	27.8 ± 4.1	27.6 ± 3.9	0.837
Sit-and-reach distance (cm)	12.3 ± 3.2	12.1 ± 3.0	0.768
Pelvic rotation angle (°)	10.1 ± 2.2	10.3 ± 2.1	0.659

Table 1: CONSORT flow diagram of participant recruitment, allocation, and retention throughout the trial.

Effects of the 8-Week Tai-Chi Push-Hand Programme on Gait Parameters

Repeated-measures ANOVA revealed significant group × time interactions for all spatiotemporal variables (p < 0.001), indicating that the Tai-Chi push-hand (TCPH) intervention produced larger improvements than habitual activity (Table 2).

Within-group changes (TCPH)

Step length increased 13.5 % from 1.11 ± 0.07 m to 1.26 ± 0.08 m (p < 0.001; Cohen's d = 1.86, 95 % CI 1.23–2.49).

Gait speed rose 18.1 % from 1.05 ± 0.16 m s⁻¹ to 1.24 ± 0.21 m s⁻¹ (p < 0.001; d = 1.72, 95 % CI 1.11–2.33), approximating the reference value for healthy adult women (≈ 1.25 m s⁻¹).

Double-support time decreased 32.4 % from 0.34 ± 0.04 s to 0.23 ± 0.03 s (p < 0.001; d = 2.03, 95 % CI 1.37–2.69), corresponding to 21.3 % of the gait cycle–close to young-adult norms (≈ 20 %).

Stance-phase percentage fell 12.8 % from 67.2 ± 4.0 % to 58.6 ± 2.5 % (p < 0.001; d = 1.97, 95 % CI 1.31–2.63).

Swing-phase percentage increased 26.2 % from 32.8 ± 2.2 % to 41.4 ± 1.8 % (p < 0.001; d = 2.11, 95 % CI 1.43–2.79), yielding a more balanced stance-to-swing ratio.

Within-group changes (control)

No parameter altered significantly (all p > 0.05): step length +0.9 %, gait speed +0.9 %, double-support time −3.0 %, stance phase −1.3 %, swing phase +2.7 %. All fluctuations were < 3 % and clinically trivial.

Between-group comparisons (post-intervention)

The TCPH group outperformed controls on every variable (p < 0.001):

Step-length difference = 0.15 m (95 % CI 0.11–0.19 m).

Gait-speed difference = 0.19 m s⁻¹ (95 % CI 0.12–0.26 m s⁻¹).

Double-support time difference = −0.09 s (95 % CI −0.11 to −0.07 s).

Stance-phase difference = −7.3 % (95 % CI −9.4 % to −5.2 %).

Swing-phase difference = +7.3 % (95 % CI 5.5 %–9.1 %).

These findings confirm that eight weeks of TCPH training elicits large, clinically meaningful improvements in spatiotemporal gait parameters in healthy older women.

Variable	Group	Baseline	Post-intervention	p value (within)	p value (between)	Effect size (Cohen's d)
Step length (m)	Experimental	1.11 ± 0.07	1.26 ± 0.08	< 0.001	< 0.001	1.86
	Control	1.10 ± 0.06	1.11 ± 0.07	0.621	/	—
Gait speed (m s⁻¹)	Experimental	1.05 ± 0.16	1.24 ± 0.21	< 0.001	< 0.001	1.72
	Control	1.04 ± 0.15	1.05 ± 0.14	0.735	/	—
Double-support time (s)	Experimental	0.34 ± 0.04	0.23 ± 0.03	< 0.001	< 0.001	2.03
	Control	0.33 ± 0.04	0.32 ± 0.03	0.518	/	—
Stance phase (% cycle)	Experimental	67.2 ± 4.0	58.6 ± 2.5	< 0.001	< 0.001	1.97
	Control	66.8 ± 3.8	65.9 ± 3.6	0.482	/	—
Swing phase (% cycle)	Experimental	32.8 ± 2.2	41.4 ± 1.8	< 0.001	< 0.001	2.11
	Control	33.2 ± 2.1	34.1 ± 2.3	0.396	/	—

Table 2: Comparison of spatiotemporal gait parameters between groups before and after the 8-week intervention (mean ± SD).

Effects of the 8-Week Tai-Chi Push-Hand Intervention on Musculoskeletal Flexibility

Repeated-measures ANOVA revealed significant group × time interactions for all muscle-flexibility and joint-range-of-motion indices (p < 0.001), indicating that the 8-week Tai-Chi push-hand (TCPH) programme produced substantially greater improvements than habitual activity (Table 3).

Within- and Between-Group Changes:

- **Experimental group**

Posterior-chain flexibility: sit-and-reach distance increased 51.2 % from 12.3 ± 3.2 cm to 18.6 ± 5.5 cm ($p < 0.001$; Cohen's d = 1.92).

Rectus femoris tightness: modified Thomas-test angle decreased from 35.6 ± 4.8° to 28.3 ± 3.6° ($p < 0.001$), reflecting marked reduction in hip-flexor stiffness.

Hip-flexion ROM: +31.3 % ($p < 0.001$).

Ankle plantar-flexion ROM: +23.0 % ($p < 0.001$).

Pelvic axial rotation: +51.5 % ($p < 0.001$).

Control group

All changes were < 5 % and non-significant ($p > 0.05$).

Between-group comparisons (post-intervention)

Every flexibility and ROM variable was significantly superior in the TCPH group ($p < 0.001$), confirming the clinically relevant efficacy of the intervention.

Association between Muscular Flexibility and Joint Range of Motion: Pearson correlation analyses revealed that, following the intervention, greater posterior-chain flexibility (sit-and-reach distance) was strongly associated with larger hip-flexion ROM ($r = 0.76$, $p < 0.001$) and increased pelvic axial rotation ($r = 0.68$, $p < 0.001$). Conversely, tighter rectus femoris (higher Thomas-test angle) was significantly correlated with smaller hip-flexion ROM ($r = –0.63$, $p < 0.001$). These findings indicate that improvements in flexibility of the core and lower-limb musculature are key to releasing hip and pelvic restrictions, supporting a sequential "flexibility gain → reduced joint constraint → ROM expansion" synergy.

Safety outcomes

Only three participants in the TCPH group experienced mild delayed-onset muscle soreness; symptoms resolved after 1–2 sessions of reduced intensity. No moderate or severe adverse events occurred. The incidence of adverse events (10.0 %) did not differ significantly from that of the control group ($p = 0.236$), confirming the safety of the protocol.

Variable	Dimension	Group	Pre	Post	p (within)	p (between)	Cohen's d
Hip-flexion angle (°)	ROM	Experimental	71.2 ± 6.5	93.5 ± 7.8	< 0.001	< 0.001	2.27
		Control	70.8 ± 6.3	71.2 ± 6.5	0.743	—	—
Ankle ROM (°)	ROM	Experimental	27.8 ± 4.1	34.2 ± 5.0	< 0.001	< 0.001	1.68
		Control	27.6 ± 3.9	27.9 ± 4.0	0.689	—	—
Sit-and-reach (cm)	Muscle flexibility	Experimental	12.3 ± 3.2	18.6 ± 3.5	< 0.001	< 0.001	1.92
		Control	12.1 ± 3.0	12.5 ± 3.1	0.576	—	—
Thomas-test angle (°)*	Muscle flexibility	Experimental	35.6 ± 4.8	28.3 ± 3.6	< 0.001	< 0.001	1.63
		Control	35.2 ± 4.5	34.8 ± 4.3	0.612	—	—
Pelvic rotation (°)	ROM	Experimental	10.1 ± 2.2	15.3 ± 2.7	< 0.001	< 0.001	2.01
		Control	10.3 ± 2.1	10.5 ± 2.3	0.614	—	—

Table 3: Comparison of musculo-skeletal flexibility and joint range of motion between groups before and after the 8-week intervention (mean ± SD).

Note: Smaller Thomas-test angle indicates reduced rectus femoris tightness.

Discussion

Employing a rigorously controlled, single-blind, parallel-group RCT design, we provide the first systematic evidence that an 8-week Tai-Chi push-hand (TCPH) programme elicits large, clinically meaningful improvements in both spatiotemporal gait parameters and musculo-skeletal flexibility in community-dwelling Chinese women aged ≥ 65 y. Relative to habitual activity, TCPH increased step length by 13.5 %, gait speed by 18.1 % and shortened double-support time by 32.4 %, while hip-flexion ROM and sit-and-reach distance rose by 31.3 % and 51.2 %, respectively. All between-group effect sizes were large (d = 1.63–2.27) and no serious adverse events occurred, underscoring the safety and efficacy of the intervention.

The findings fill a critical gap in the geriatric exercise literature, where existing Tai-Chi studies have focused almost exclusively on solo forms. By integrating partner-based "listening–understanding–leading–neutralising" drills, TCPH delivers continuous, unpredictable perturbations that simultaneously challenge proprioception, dynamic balance and core muscle coordination. This sensorimotor enrichment appears to surpass the stimulus afforded by conventional single-forms, offering a novel, low-cost strategy to counteract age-related locomotor decline in older women.

Improvements in muscle flexibility and joint range of motion (ROM) were driven by two synergistic mechanisms unique to Tai-Chi push-hand (TCPH): "silk-reeling Jin" and "moving-step interaction". Post-menopausal hypo-oestrogenism reduces collagen compliance and favours contracture of the iliopsoas, rectus femoris and gastrocnemius, creating a peri-articular soft-tissue "straitjacket" that restricts hip and ankle excursion. Silk-reeling drills, performed around the waist-hip axis with continuous spiral limb rotation, deliver dynamic, viscoelastic-loading cycles that selectively break down fascial adhesions and restore muscle compliance. This explains the 51 % gain in sit-and-reach distance (muscle flexibility) observed in the TCPH group.

The increase in muscle length immediately lowers passive resistance during joint motion, enabling hip-flexion angle to rise from 71.2° to 93.5° (+31 %) and ankle ROM to expand by 23 %–a clear "muscle release → joint liberation" virtuous cycle. Correlation analysis confirmed that muscle flexibility was the primary driver:

sit-and-reach distance correlated strongly with hip ROM ($r = 0.76$, $p < 0.001$). Although repeated weight-shifting may mildly enhance capsular elasticity via synovial fluid secretion, the tight coupling between flexibility gains and ROM increases indicates that myofascial extensibility dominates the adaptation.

Unlike static stretching, TCPH couples dynamic stretch with anticipatory stabilisation, simultaneously elevating both flexibility and ROM. This dual benefit underlies the > 30 % increments seen in both sit-and-reach (muscle domain) and hip-flexion angle (joint domain)–magnitudes rarely reported after conventional stretching programmes.

Pelvic rotation improved by 51.5 %, reflecting both greater core flexibility and enhanced neuromuscular control of pelvic stabilisers during reactive balance challenges. Because the pelvis links trunk and lower-limb kinematics, its increased excursion facilitates smoother centre-of-mass transfer, translating directly into longer step length and higher gait speed. Thus, TCPH induces a "flexibility–mobility–stability" triad that collectively underpins the observed locomotor gains.

The pronounced improvement in gait parameters induced by Tai Chi push-hand (TCPH) training originates from its distinctive dynamic-balance paradigm, which departs fundamentally from the stereotyped, self-paced movements of solo Tai Chi forms. The key pathomechanics underlying gait deterioration in older women are declining proprioception, impaired core-muscle control, and increased reliance on double-limb support. The TCPH pedagogical sequence–"listening, understanding, leading, and neutralising Jin"–addresses each deficit in a targeted manner.

"Listening" requires the practitioner to detect, through hand contact, the partner's force vector and instantaneous centre-of-mass (CoM) displacement. This continuous tactile feedback provides high-density afferent input that selectively activates joint-capsule mechanoreceptors and muscle-spindle afferents, thereby up-regulating the sensitivity and conduction velocity of the proprioceptive pathway. "Understanding" and "neutralising" demand that the practitioner redistributes CoM and modulates muscle tension within milliseconds; this obliges synergistic recruitment of the deep core stabilisers (transversus abdominis, erector spinae, gluteus medius) and major lower-limb muscle groups (quadriceps, hamstrings, gastrocnemius), resulting in reinforced dynamic balance capacity. The present finding that double-support time decreased by 32.4 % (to 21.3 % of the gait cycle) is a direct manifestation of this integrated training. Shortening double-support time reflects enhanced single-limb postural stability, a parameter that Wayne et al., [11] Peter,M,Wayne,et al.Tai Chi Training may Reduce Dual Task Gait Variability, a Potential Mediator of Fall Risk, in Healthy Older Adults: Cross-Sectional and Randomized Trial Studies[J].Frontiers in Human Neuroscience, 2015, 9:332.]] identified as critical for fall-risk reduction: every 10 % decrease in double-support time lowers the odds of falling by 23 % in older women. Thus, the TCPH-induced reduction approaches the values observed in healthy young adults and carries immediate clinical relevance.

Compared with published single-form Tai Chi trials, the present 18.1 % increase in gait speed is substantially larger than the 13.9 % gain reported after 12 weeks of Yang-style 24-form Tai Chi in community-dwelling older women(Liye Z ,et al.). This additional benefit is attributable to the unpredictable, partner-generated perturbations that characterise push-hand training. In solo routines, centre-of-mass (CoM) displacement follows a stereotyped, self-selected rhythm; in contrast, TCPH demands continuous online recalibration of foot placement, step length and propulsive force in response to randomly varying loads. Such "adaptive gait training" accelerates the stance-to-swing transition and improves mechanical efficiency.

Kerrigan et al., [12] demonstrated that reduced hip extension and limited anterior pelvic tilt are the principal biomechanical determinants of diminished walking speed in older females. The forward-backward and mediolateral weight-shifting drills embedded in "moving-step double-hand push-hand" specifically target hip-flexor and extensor power while enhancing pelvic neuromuscular control. Consequently, step length increased from 1.11 m to 1.26 m, propelling the observed rise in gait speed. Moreover, the swing-phase proportion rose from 32.8 % to 41.4 %, approximating the optimal 60 % stance / 40 % swing ratio seen in healthy younger adults and confirming that TCPH re-establishes a more efficient and safer locomotor pattern.

In terms of musculoskeletal flexibility, the "silk-reeling Jin" and the principle of "loosening the waist and hips" in Tai Chi push-hand (TCPH) training play a pivotal role. In postmenopausal women, declining estrogen levels lead to reduced muscle and fascial elasticity, often resulting in tightness and contracture in key lower-limb muscles such as the iliopsoas, rectus femoris, and gastrocnemius, which in turn restricts joint range of motion (ROM). The silk-reeling movement requires the practitioner to rotate the limbs in a spiral pattern driven by the waist and hips, effectively stretching the periarticular fascia and muscle fibers, breaking down adhesions, and enhancing muscle elasticity.

Research has shown that performing spiral silk-reeling exercises alone (3 times per week, 20 minutes per session) for 8 weeks can increase the thickness of the posterior thigh fascial chain by 8 %, lengthen stride by 16 cm, and reduce fall risk by half. In this study, the experimental group's hip flexion angle increased from 71.2° to 93.5°–a 31.3 % improvement–significantly outperforming the minimal change in the control group. This gain is largely attributed to the targeted release of iliopsoas tightness through silk-reeling. With the normal hip flexion range being approximately 120°–150°, post-intervention values in the experimental group approached the lower limit of healthy adults, sufficient for daily activities such as bending and dressing.

The 51.2 % increase in sit-and-reach distance reflects concurrent improvements in flexibility of the core and posterior muscle chain (hamstrings, gastrocnemius, and soleus), which is closely linked to the coordinated trunk-and-limb stretching inherent in silk-reeling. These results significantly exceed those typically achieved through static stretching alone, highlighting the superior efficacy of dynamic, spiral-based training in enhancing both muscle compliance and functional mobility.

In the experimental group, pelvic rotation angle increased from 10.1° to 15.3° (+51.5 %), a gain that provided the pivotal biomechanical substrate for enhanced gait stability. As the functional link between trunk and lower limbs, pelvic axial mobility governs the efficiency of centre-of-mass transfer and balance control throughout the gait cycle. Older adults typically exhibit restricted pelvic excursion, a deficit strongly associated with slower walking speed and elevated fall risk.

The partner-generated, continuously varying forces inherent in Tai-Chi push-hand demand instantaneous pelvic adjustments in three planes. These rapid, low-amplitude rotations selectively activate deep pelvic stabilisers–including gluteus medius, piriformis and the oblique abdominal muscles–thereby improving both the range and neuromuscular control of lumbopelvic motion. Cury et al., [13] reported that every 1° increment in pelvic rotation raises dynamic-balance scores by 0.8 points on the Mini-BESTest; the 5.2° increase observed here would therefore translate into an estimated 4-point improvement, sufficient to shift an individual from the "high" to the "low" fall-risk category. Thus, greater pelvic flexibility closes the loop between core stability, joint mobility and gait optimisation, illustrating the integrated benefits of push-hand training.

The present findings also stand in sharp contrast to conventional exercise interventions, underscoring the unique advantages of Tai-Chi push-hand (TCPH). Progressive resistance training, while effective for increasing peak torque, yields minimal gains in flexibility and frequently precipitates muscle or joint injury when loading is not carefully titrated. Aerobic programmes improve cardiorespiratory fitness, yet offer limited specificity for dynamic balance or joint mobility, and their moderate-to-vigorous intensity often leads to poor adherence among older women [14].

TCPH, conversely, is a low-to-moderate intensity activity (RPE 4–6) that imposes minimal cardiometabolic strain while simultaneously enhancing proprioception, joint ROM and gait stability. The partner-based format introduces an inherent social element that increases enjoyment and commitment–evidenced by the 94.7 % attendance rate in this study–and safely accommodates de-conditioned or osteoarthritic participants. Meta-analytic evidence indicates that TCPH can also reduce joint pain and improve mental health in middle-aged and older adults [8]. Consequently, TCPH aligns closely with the "safety first, efficacy second" principle advocated for geriatric exercise prescription, offering an integrated strategy that traditional resistance or aerobic regimens cannot replicate.

Several limitations should be acknowledged. First, although the randomized design was robust, the sample size was modest (n = 66) and recruited exclusively from community-dwelling older women in Changsha; consequently, generalizability to other geographic regions or to frail, cognitively impaired, or male populations remains uncertain. Multi-centre trials with larger, more diverse cohorts are warranted. Second, the intervention lasted only eight weeks; longer-term efficacy and the durability of observed gains beyond six months or one year were not examined. Follow-up studies incorporating extended training and retention assessments are needed to clarify the minimum effective dose and the trajectory of any detraining effects. Third, only kinematic outcomes were collected; kinetic data (ground-reaction forces, joint moments, electromyography) were not obtained, limiting mechanistic insight into neuromuscular and musculoskeletal adaptations. Integrated motion–force–EMG analyses should be employed to elucidate the biophysical pathways underlying TCPH-induced improvements. Finally, the absence of an active control condition (e.g., a stretching-only or sham-exercise group) precludes complete elimination of placebo effects; future designs should include such a comparator to isolate the specific contribution of interactive push-hand training.

Future work should pursue five complementary lines of inquiry:

- Large-scale, multi-centre RCTs to confirm generalisability across geographic, ethnic and socioeconomic strata.
- Extension of training duration to ≥ 6 months with 12-month follow-up to establish the minimum effective dose, optimal maintenance frequency and detraining trajectory.
- Integration of three-dimensional kinetics, electromyography and diffusion-tensor imaging to dissect neuromuscular coordination, joint loading and fascicular remodelling underpinning TCPH-induced gains.
- Inclusion of active placebo controls (e.g., light callisthenics or static stretching) to isolate the specific contribution of interactive push-hand dynamics.
- Condition-specific trials in older women with osteoporosis, mild cognitive impairment or lower-limb arthroplasty to broaden clinical indications and refine safety protocols.

In summary, an 8-week TCPH programme significantly improved spatiotemporal gait variables and musculo-skeletal flexibility in community-dwelling Chinese older women by enhancing proprioception, inter-muscular synergy and myofascial compliance, thereby retarding age-related functional decline. The intervention is safe, enjoyable and efficacious, aligning well with the physiological profile and exercise preferences of older females. TCPH can be readily implemented in community centres and residential facilities as a low-cost strategy to reduce fall risk, enhance quality of life and alleviate health-care expenditure. Rigorous, longer-term research is now warranted to consolidate the evidence base and inform the development of standardised implementation guidelines.

Conclusion

An 8-week Tai-Chi push-hand programme significantly improves spatiotemporal gait parameters (greater step length and speed, shorter double-support time) and musculo-skeletal flexibility (increased hip and ankle range of motion, enhanced extensibility of core and lower-limb muscles) in healthy Chinese older women, thereby retarding age-related functional decline. Future large-scale randomised controlled trials should verify whether these benefits extend to other populations, such as healthy older men, individuals with Parkinson's disease, or those with peripheral neuropathy.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author's Contribution

Hang Zhong: Writing – original draft, Methodology, Formal analysis, Conceptualization, Data curation, Writing – review & editing, Investigation. Hui Zhong: Writing – original draft, Methodology, Data curation, Supervision, Investigation. Ding Yuan: Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization, Funding acquisition. Yankai Shu: Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

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Data Availability Statement

The data presented in this study are available upon request from the corresponding author.

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