

Efficacy of Tai Chi and Roliball Exercise on Balance, Mobility, and Cognitive Function in Community-Dwelling Older Adults: A Randomized Controlled Trial

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Objective: Falls are a major public health concern for older adults, and exercise is considered a key strategy for fall prevention. This study aimed to evaluate the efficacy of a novel combined intervention of Basic Tai Chi and Roliball on balance, mobility, and cognitive function in community-dwelling older adults, and to compare its effects with traditional Tai Chi programs, thereby providing a novel structured physical activity approach for localized fall prevention and control.

Patients and Methods: One hundred and thirty-five participants aged ≥ 60 years were divided equally into structured Basic Tai Chi combined with Roliball demonstration (TC+RB-D), Basic Taichi Chuan (TC) and 24-form simplified Tai Chi (24-TC). During the 12-week intervention period, participants attended three in-person sessions per week (90 minutes/session). All measures were assessed before and after the intervention.

Results: Compared with the 24-form Tai Chi group, the TC group and TC+RB-D group showed significant improvements in GS, TUG, BBS, and MoCA. The TC+RB-D group showed significant improvement on the mFES ($\beta=0.463$, 95% CI: 0.366–0.561, $p<0.001$). The TC group demonstrated a unique advantage on the EC-SLS ($\beta = 2.705$, 95% CI: 0.989–4.421, $p = 0.002$). The TC+RB-D group was not inferior to the traditional 24-form simplified Tai Chi in functional fall risk testing and cognitive function assessment.

Conclusion: This study developed a structured physical activity program rooted in Tai Chi culture. This multimodal exercise approach may have significant benefits for older adults in maintaining balance, enhancing mobility, and preserving cognitive function.

Keywords: older, Tachi, Roliball, exercise, balance, cognitive, fall

Background

The World Health Organization (WHO) identifies falls as the second most prevalent cause of global unintentional injury mortality, primarily affecting adults aged ≥ 60 years.¹ In China, falls constitute the predominant cause of unintentional injury-related deaths, accounting for 77.74% of such fatalities among adults aged ≥ 60 years,² while standardized mortality rates have shown a persistent upward trajectory through 2024,³ and population aging has significantly contributed to the marked increase in both healthcare burdens and economic costs associated with fall-related injuries.^{4,5} Existing evidence has established that falls among community-dwelling older adults are influenced by numerous predictors including age, gender, cognitive function (notably attention and executive function), balance capacity, proprioception, and environmental factors,^{6–8} and evidence-

based tailored exercise interventions significantly enhance physical performance parameters while mitigating both fall incidence rates and subsequent injury severity in geriatric populations.^{9,10}

WHO recommends at least three days per week of moderate or higher intensity exercise, particularly balance and strength training, as the most effective approach to reduce fall risks, improve balance and physical functioning, and prevent fall-related injuries in older adults.¹¹ As outlined in the UK Physical Activity Guidelines for Older People, general physical activity (eg, walking) alone shows limited effectiveness in fall prevention,^{12,13} while evidence confirms that a high-dose, multifactorial and exercise intervention program including balance, coordination, and resistance training prove most effective for this purpose.^{10,13–15} This proposition is further supported by the latest consensus guidelines on fall prevention in older adults, which recommended tailored programs emphasizing balance challenges and functional exercises of progressive intensity, backed by robust evidence of significant benefit.¹⁶ These comprehensive fall prevention exercise programs meeting the Administration for Community Living's criteria for evidence-based programs have been recommended, including “A Matter of Balance”, “Enhance Fitness”, “Healthy Steps in Motion”, and “The Otago Exercise Program”.¹⁷

Traditional Chinese mind-body exercises, particularly TaiChi Chuan (TCC) and fitness Qigong, can enhance balance function and reduce falls in older adults, with substantial supporting evidence.^{18,19} Our previous review also highlighted the benefits of Baduanjin in improving balance and preventing falls in the older population.²⁰ The Moving for Better Balance program developed by Li et al,²¹ based on Yang-style TCC, has shown positive results in large-scale controlled trials.²² Although these mind-body exercises share core principles, variations in practice styles and instructors' experience levels may lead to discrepancies.²³ For example, Lin et al²⁴ demonstrated that 24-form simplified TCC outperformed other TCC types, followed by Yang-style TCC. Notably, the 24-form routine was developed from Yang-style TCC as a standardized protocol, while Yang-style itself encompasses both traditional routines and modern variations. This indicates that the style-specific training of TCC instructors and protocol in TCC routines act as significant confounding variables in intervention outcomes, constraints research quality. This underscores the need for population-specific standardization and health-oriented guideline development in Taichi practice.²³ In response to these challenges, researchers have sought to streamline longer routines and design basic Tai Chi programs that remain effective while being more accessible for older adults. Ge et al observed that older adults practicing only the first eight movements of the 24-form still achieved measurable improvements.²⁵ Mao et al reported that Tai Chi gait practice alone produced improvements in balance and functional ability comparable to those from Li et al's simplified 8-form program.^{26,27} Similarly, BafaWubu Tai Chi, a basic form integrating eight simple techniques with five directional stepping patterns, has shown considerable potential for improving lower-limb muscle and joint function and enhancing postural control in older adults.^{28,29} TCC as a gentle form of physical activity, demonstrates unique advantages in enhancing proprioception by requiring consistent coordination between physical movements and mental focus during practice while improving balance, flexibility, and strength beyond conventional exercise.^{30,31} As a result, TCC is recognized for its significant potential in preventing falls among the older population.³²

Roliball demonstration (RB-D) is a highly representative throwing and catching sport. As a traditional Chinese sport rooted in Tai Chi principles, it features a unique “Arc-Guided Dynamic Force Redirection” mechanism that emphasizes dynamic force redirection through guided yielding. This racquet-based exercise has been implemented in over 20 countries and regions worldwide, including China, the United States, Japan, Australia, South Korea, and Singapore,³³ and particular favored by the middle-aged and older population. Research indicates that RB-D exercise is effective in improving balance function and preventing falls among middle-aged and older adults.^{34,35} Compared to TCC, RB-D not only incorporates challenging balance postures and weight shifting maneuvers but also features a faster exercise tempo along with integrated ball throwing and catching actions. However, while existing evidence supports RB-D's benefits in balance function and fall prevention,^{34,35} it shares similar limitations with TCC regarding the uncontrolled nature of exercise protocols compared with highly protocolized programmes such as the Otago Exercise Programme or A Matter of Balance. Despite offering greater variety than conventional balance-and-strength programmes, the Basic Tai Chi combined with Roliball demonstration (TC+RB-D) remains without a rigorously designed, validated structured protocol, and evidence demonstrating its effects on balance, mobility, and cognitive function in older adults is currently lacking.

This study aims to evaluate the effectiveness of a structured Basic Tai Chi combined with Roliball demonstration (TC+RB-D), Basic Tai Chi Chuan (TC), and 24-form simplified Tai Chi (24-TC) protocol on functional mobility, balance,

and cognitive function in community-dwelling older adults, with the goal of determining its potential significance for fall prevention. We hypothesize that, compared with the standard 24-TC, older adults participating in the TC program or receiving the combined TC+RB-D intervention will show significant improvements in Berg Balance Scale (BBS), Timed Up and Go (TUG), 4-Meter Gait Speed (GS), and Montreal Cognitive Assessment (MoCA) scores. Furthermore, we hypothesize that the improvements observed in the structured TC or TC+RB-D interventions will be at least comparable to those achieved with traditional 24-TC training.

Methods

Participants

Community-based open recruitment was conducted in Hongshan District, Wuhan, China. Participants were recruited through three subordinate residents' committees during a two-week online campaign. Recruitment took place from March 10 to April 15, 2025. As shown in [Figure 1](#), 142 community-dwelling older adults were initially recruited after the cutoff date and 7 individuals were excluded prior to formal intervention. Ultimately, 135 participants completed post-intervention assessments and were included in the analysis.

Following allocation, 45 participants were randomly assigned to the TC+RB-D group, 45 to the TC group, and 45 to the 24-TC group. All participants completed a 12-week intervention program involving Basic Taichi Chuan Program, 24-Form Simplified Tai Chi, or Taichi Chuan Program combination Roliball, with three in-person sessions per week (90 minutes/session). During the study, three participants were lost to follow-up due to discomfort. Of these, one participant in the TC+RB-D group and two in the TC group withdrew because of exercise-induced knee pain; clinical evaluation recommended that they discontinue participation.

Inclusion and Exclusion Criteria

Eligibility criteria included community-dwelling older adults aged 60–75 years capable of performing daily physical/cognitive activities and participating in community center programs; medically stable conditions; self-reported intact postural control with independent ambulation exceeding one city block without assistive devices; no prior TCC/RB-D training experience. Exclusion criteria were current participation in other clinical trials; receiving pharmacological agents or rehabilitative therapies potentially affecting cognition/balance; malignancy, history of neurological disorders (Parkinson's disease, multiple sclerosis, stroke), exercise-induced vertigo, severe visual impairment, or diagnosed vestibular dysfunction; Mini-Mental State examination score <24 (indicating cognitive impairment);³⁶ inability to maintain contact during the study period.

Study Design and Control Procedures

The study was reviewed and approved by the Institutional Review Board of the Ethics Committee of Central China Normal University (CCNU-IRB-202502010b), registered with the Chinese Clinical Trial Registry (ChiCTR2500105622), and reported in accordance with the item descriptions of the CONSORT 2025 checklist ([Appendix 1](#)). This study utilized an observer-blinded randomized controlled trial design to evaluate intervention outcomes, and study spanned a 14-week period for each participant, baseline measurements were assessed during the week preceding the intervention, followed by a 12-week structured exercise program. The intervention comprised three face-to-face sessions per week (90 minutes each on Wednesdays, Fridays, and Sundays), all exercise sessions were conducted at the community residents' activity plaza, with relocation to the older adults' community activity center when encountering inclement weather conditions. The post-training tests took place on week 14, baseline and outcome assessments were systematically conducted at a community-based older adult health service center. Baseline and outcome assessments were administered by 27 volunteers with sports science or medical disciplines. Specifically, functional movement assessments employed a three-member operational group (comprising guidance specialist, assessment technician, and safety supervisor).

All personnel completed three standardized training sessions incorporating protocol familiarization and inter-rater reliability calibration prior to formal data collection. To ensure adequate attention and guidance for all participants during the intervention, both the experimental and control groups were supported by a staffing configuration comprising: 1) at

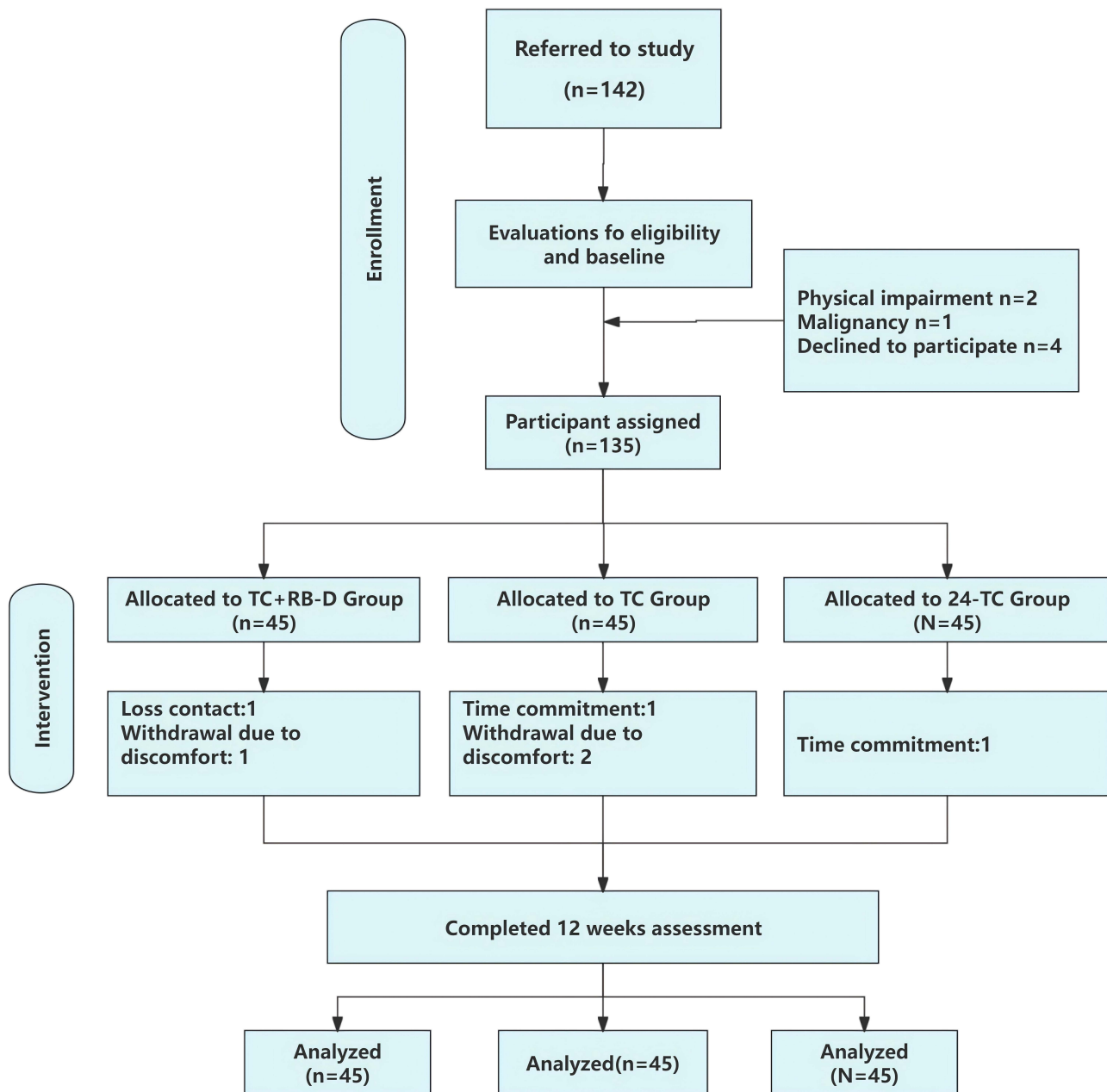


Figure 1 CONSORT (Consolidated of Standards of Reporting Trials) flow diagram.

minimum one certified exercise instructor, and 2) two sports science student volunteers who had undergone standardized pre-training sessions. This personnel structure was systematically implemented across all intervention phases. The RB-D received instruction from a RoliBall practitioner holding a Master’s degree in Sports Science, who possessed Level 1 coaching certification in RoliBall with 6 years of specialized teaching experience. The TC was guided by a TCC instructor with a Master’s degree in Sports Science, transitioning from a professional martial arts athletic career, accredited as a Level 2 Wushu athlete with 7 years of discipline-specific instructional practice.

Assignment and Blinding

This study employed a randomized controlled trial design with three parallel groups. To ensure balance in age distribution across groups, stratified randomization was conducted based on age categories. Participants were first

stratified into predefined age groups (60–65, 66–70, and 71–75 years), and within each stratum, individuals were randomly assigned in a 1:1:1 ratio to one of the three intervention groups. A computer-generated randomization list was prepared in advance by an independent statistician. Allocation concealment was maintained using sequentially numbered, opaque, sealed envelopes. The pre- and post-intervention evaluations were performed by volunteers who were blinded to the exercise treatments. Data analysis was performed with concealed experimental/control group labels.

Sample Size Estimate

This study referenced previous research on TCC, particularly comparisons between personalized TCC routines and the standardized 24-form Tai Chi, which reported effect sizes of 0.65 for TUG and 1.14 for MoCA.^{26,37} Based on a conservative approach, the present study assumed medium effect sizes (0.35) for both between-group and within-subject factors. The correlation among repeated measures was estimated to be less than 0.50, with two time points of measurement.²⁶ The Type I error rate was set at 0.05, and the statistical power at 0.80. Sample size calculations were conducted using G*Power (version 3.1.9.6; Germany), indicating that 42 participants per group were required. Accounting for a 10% attrition rate, at least 47 participants per group will be recruited.

Protocol

This community exercise program was developed based on guidance from the World Guidelines for Falls Prevention and Management for Older Adults: A Global Initiative (WG-FPM),¹⁶ the Physical Activity Guidelines for Americans 2nd Edition (PAG-A),³⁸ and the Interpreting the UK Physical Activity Guidelines: Older Adults in Transition (65+)(PAG-E).¹² According to the recommendations of PAG-A and PAG-E, older adults should engage in at least 150 minutes (2 hours and 30 minutes) of moderate-intensity physical activity weekly, with each session lasting a minimum of 10 minutes.^{12,38} However, when performing vigorous-intensity exercise, a reduced duration of 75 minutes (1 hour and 15 minutes) can achieve the recommended amount. These guidelines have been endorsed by WG-FPM, which additionally strongly advocates for the implementation of fall prevention programs consisting of at least three sessions per week sustained over a minimum 12-week period.¹⁶ Simultaneously, progressive exercise is systematically incorporated into structured intervention protocols, featuring progressive escalation in both motor task complexity and physical activity intensity. As indicated in WG-FPM, when balancing the safety and challenge of physical activities for older adults, it is necessary to adopt step-by-step approaches to guide their physical activity engagement.¹⁶ Current research shows that progressive exercise design for older adults, with step-by-step physical activity arrangements, can safely and effectively improve their physical activity capabilities.^{39,40} Therefore, our physical activity program is designed with progressive difficulty and intensity, with the 12-week intervention divided into four phases featuring continuous increments in both parameters (Figure 2). The exercise of this program consisted three principal components (Figure 3): (1) a gait drill-centered warm-up regimen, (2) core intervention components integrating TC and RB-D, and (3) a cool-down phase incorporating stretching and relaxation exercises.

Basic Taichi Chuan

TCC is primarily classified as an aerobic physical activity. Although certain variations (for example low-stance forms) incorporate bodyweight resistance to enhance muscular strength, its most robust evidence base lies in improving balance and preventing falls among older adults.^{19,23} Research specifically endorses Yang-style TCC for fall prevention benefits in geriatric populations.²³ Originating from Chen-style TCC, Yang-style emphasizes smooth and gentle movements with arm extension positioning. This distinctive approach reduces postural control demands while enhancing accessibility for learning, dissemination and safety. Consequently, the TCC component of our first-phase intervention protocol was grounded in Yang-style TCC, a choice informed by its evidence-based efficacy in geriatric populations and biomechanical adaptability for safe implementation.

Roliball Demonstration

Roliball (RB) originated in modern China and was initially developed as a rehabilitation method. As its creation was rooted in Taiji theory, it was originally named Taiji Roliball. The practice features two distinct forms: RB competition and RB-D, both

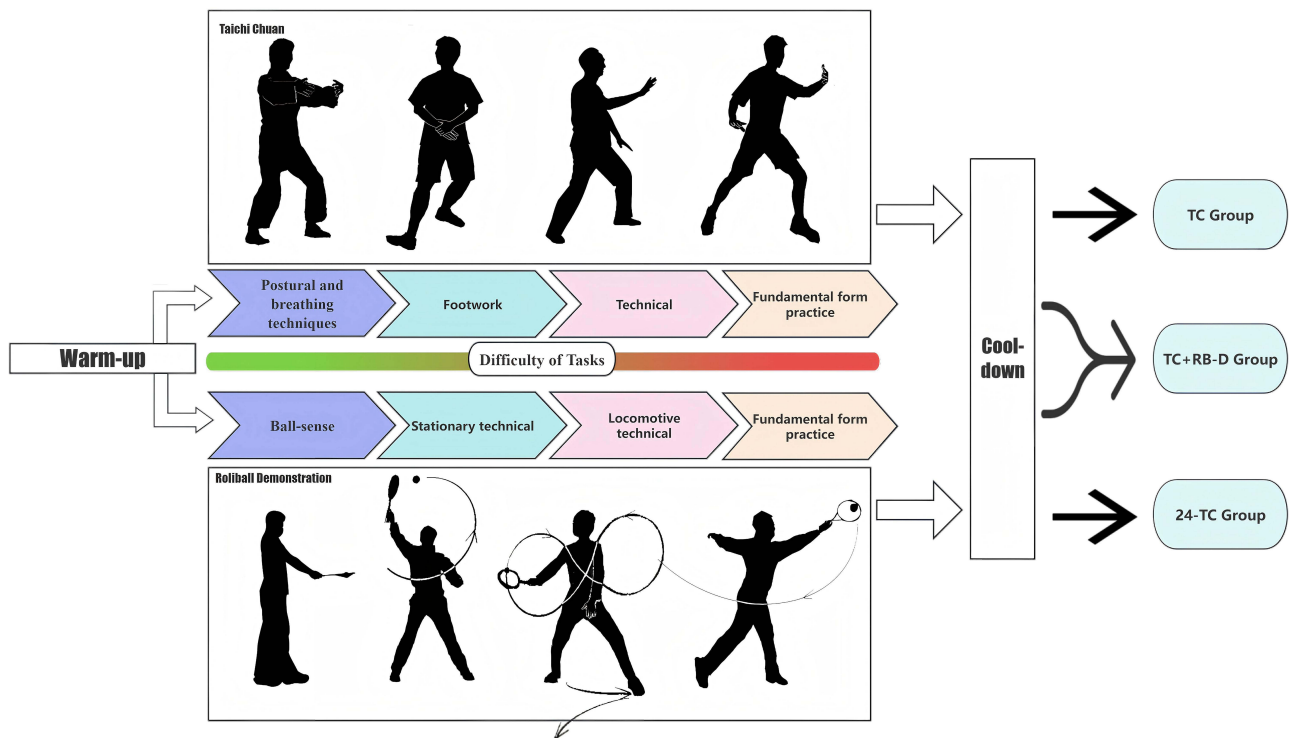


Figure 2 Design of Basic Tai Chi and Roliball Demonstration Exercises.

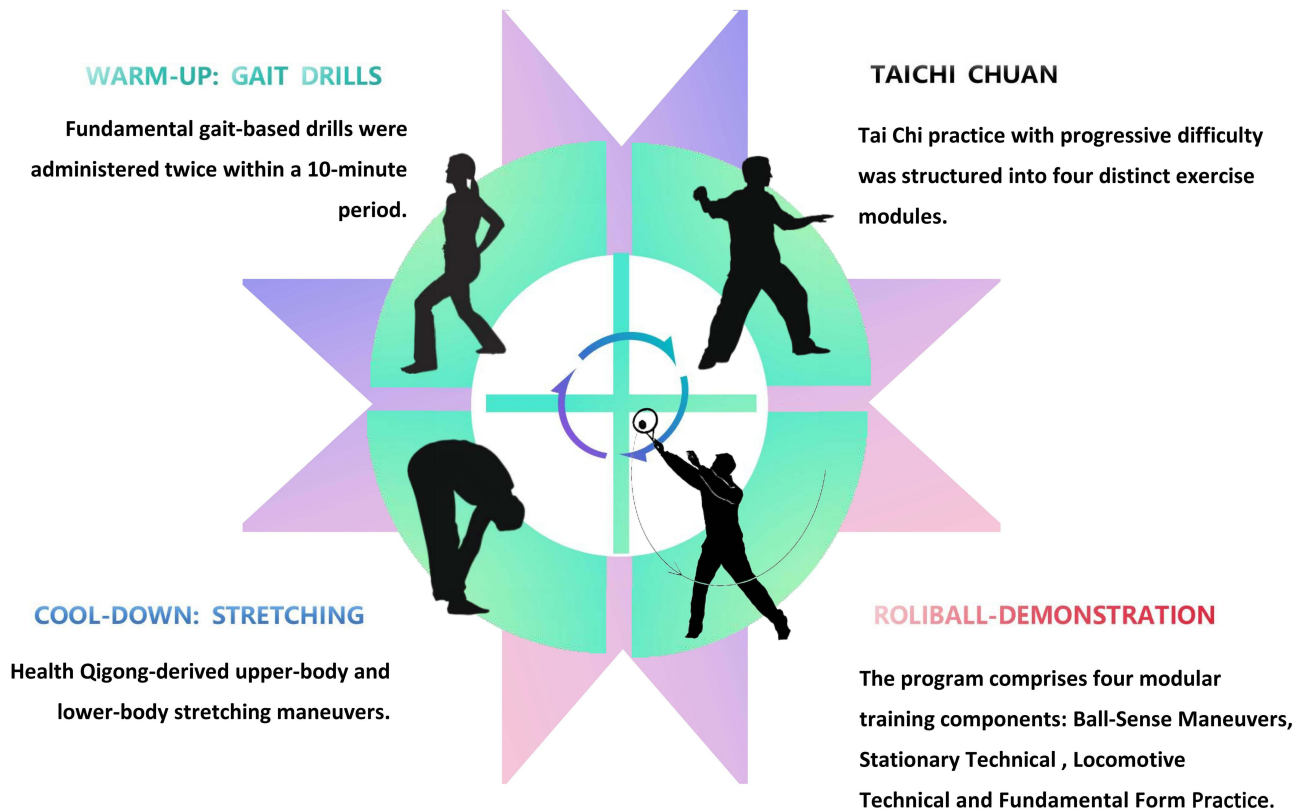


Figure 3 Basic Tai Chi Combined with Roliball Demonstration Intervention Lesson Schedule.

centered on the core technique of arc induction. However, limited evidence currently indicates potential benefits of RB-D for improving balance function and preventing falls in older adults.^{34,35} Recent studies suggest RB-D may positively influence skeletal health by increasing bone mineral density, bone mineral content, and altering bone metabolism markers in perimenopausal women.⁴¹ We selected RB-D based on the following rationale: 1) Current guidelines¹⁶ recommend considering cultural contexts when implementing exercise interventions for older adults and selecting culturally adaptive regimens and the cultural alignment requirement for exercise and fall-prevention interventions has been emphasized.⁴² RB-D originated from Taiji culture. Currently classified as an ethnic physical activity modality, it thus demonstrates inherent cultural congruence features compared to routine exercise programs. 2) Roliball competition is a competitive activity. Compared to RB-D, it imposes higher facility requirements and entails inherent safety risks. Based on the target population's characteristics and community facility availability, RB-D was selected. 3) RB-D permits the design of controlled exercise protocols that ensure research reproducibility and enhance program scalability.

24-Form Simplified Tai Chi

The 24-Form Simplified Yang-Style Tai Chi was developed in 1956 under the direction of the National Physical Culture and Sports Commission of the People's Republic of China. It draws on the key movements of the traditional Yang-style 108-form routine, streamlining and standardizing them with the goal of promoting health and making the practice more accessible to the general public. In this study, we employed a continuous-sequence format: each full run-through of the form lasted approximately six minutes, with six to seven repetitions per intervention session and rest intervals of no more than five minutes between repetitions.

This study established three groups: experimental groups RB-D+TC and TC, and a control group performing 24-TC only (Figure 3). The RB-D+TC group implemented two exercise component per session, maintaining identical content to TC with proportionally reduced durations (detailed protocols in Appendix 2 and Appendix 3). All groups followed identical warm-up and cool-down routines, along with weekly supervised practice sessions. Overall, each group received a 12-week face-to-face group exercise intervention, consisting of three sessions per week, with each session lasting 90 minutes.

Assessment

Assessments were conducted for balance, functional mobility and cognitive function. All evaluations were performed during morning hours (08:00–11:00), and before assessments began, all assessors received three protocol training sessions administered by author YG. All assessment methods used in this study are listed in Appendix 4.

Assessment of functional mobility and balance function included the following performance tests: the One-leg Standing Test (OLST),⁴³ Berg Balance Scale (BBS),⁴⁴ Chair Stand Test (CST),⁴⁵ Gait Speed (GS) and Timed Up and Go (TUG), which are recommended by WG-FPM¹⁶ as evidence for fall prediction. All performance tests were conducted twice, and the best value from the two tests was recorded. Cognitive function included the following performance tests: Montreal Cognitive Assessment (MoCA)⁴⁶ and Stroop Color and Word Test (SCWT).⁴⁷ These performance tests were completed under one-on-one guidance from trained assessors.

In addition, we conducted hand grip strength tests (HGS) and fear of falling assessment. Emerging evidence indicates the relationship between grip strength and all-cause mortality and cognitive function, while it is recommended as a routine measurement indicator for independence in older adults.^{48,49} The tests followed a standardized protocol recommended by Mehmet et al,⁵⁰ with participants comfortably seated, elbows maintained at a 90° angle to the torso. Three consecutive trials were performed per hand, each grip sustained for 3 seconds, separated by 1-minute rest intervals, using the maximum measured grip strength value. Fear of falling was assessed using the modified Falls Efficacy Scale (mFES), and the mFES was translated and validated for reliability and validity in Hao et al's study.⁵¹ The mFES is a modified version of the original Falls Efficacy Scale developed by Tinetti et al⁵² and total scores on the mFES ranged from 0 to 10 (the mean score of all items), with higher scores indicating greater confidence. These assessments were self-reported, with guidance from Community-based geriatric health center nurses as needed.

Statistical Analysis

The study employed an intention to treat analysis, beginning with an assessment of baseline characteristics. When the data satisfied the normality assumption, between group differences were compared using a one way ANOVA or Welch’s ANOVA; if the data violated the normality assumption, the Kruskal Wallis test was applied. Baseline differences were adjusted using either the Games-Howell or Bonferroni correction. This study adopted a 3 (Group) × 2 (Time) mixed-design randomized controlled trial. Given that the primary outcome variables were continuous and included a repeated-measures structure (Pre vs Post), a Linear Mixed Model (LMM) was employed for statistical analysis to adequately control for individual differences and improve estimation efficiency. In the model, “Group” was specified as a fixed between-subject factor, “Time” as a fixed within-subject factor, and “Participant ID” as a random effect to account for repeated measurements within individuals. To determine an appropriate covariance structure, we first evaluated the correlations between time points as well as the normality and homoscedasticity of residuals. An unstructured covariance structure was applied to flexibly model the variances and covariances across time points. Bonferroni correction was used for multiple comparisons. The effect size was expressed as Cohen’s d. The within-group effect size was calculated by subtracting the baseline mean from the mean at a specific time point within the same group, then dividing by the pooled standard deviation of the two time points. The between-group effect size was defined as the difference in within-group effect sizes between two groups at the same time point. The study used the Inverse Efficiency Score (IES) to account for reaction time (RT) and accuracy of SCWT, with smaller IES values indicating better overall performance under a given condition.⁵³ IES was calculated as

$$IES = \frac{\overline{RT}}{1 - ER}$$

where \overline{RT} overline is the participant’s mean reaction time in the task and ER is the error rate under that condition.

Non-inferiority analyses were performed on the primary outcomes, including the Timed Up and Go test (TUG), 4-meter gait speed (GS), Berg Balance Scale (BBS), and Montreal Cognitive Assessment (MoCA). In accordance with the methodology proposed by Mao et al,²⁶ 60% of the minimal detectable change (MDC) was adopted as the non-inferiority margin. If the confidence interval (CI) of the between-group difference fell entirely within this equivalence boundary, the effects of the TC+RB-D or TC interventions were considered statistically comparable to those of the 24-TC group. Based on previous research,^{54–57} the non-inferiority thresholds were determined as follows: 0.66 seconds for TUG (1.10 s × 60%), 0.0648 m/s for GS (0.108 m/s × 60%), 2.4 points for BBS (4 points × 60%), and 3.06 points for MoCA (5.1 points × 60%).

All statistical analyses were performed using SPSS Statistics for Windows, Version 30.0 (IBM Corp., Armonk, NY, USA).

Table 1 Baseline Characteristics of Participants

Characteristic	Basic Tai Chi + Roliball Demonstration Group (n=45)	Basic Tai Chi Group (n=45)	24 Simplified Tai Chi Group (n=45)
<i>Demographic</i>			
Female, n(%)	30 (66.7)	30 (66.7)	31 (68.9)
Mean age (SD), year	66.98(6.36)	66.87(2.98)	67.98(7.29)
Mean height (SD), cm	163.98(6.27)	163.74(6.78)	166.40(5.00)
Mean body weight (SD), kg	62.40 (10.22)	64.40 (7.91)	66.48 (7.47)
Mean Body Mass Index (SD), kg/m ²	23.13(3.00)	24.01(2.39)	23.95(1.91)

(Continued)

Table 1 (Continued).

Characteristic	Basic Tai Chi + Roliball Demonstration Group (n=45)	Basic Tai Chi Group (n=45)	24 Simplified Tai Chi Group (n=45)
<i>Balance and Mobility</i>			
Mean Timed Up and Go Test (SD), s	9.86 (1.58)	10.30 (1.43)	10.04 (1.43)
Mean Gait Speed (SD), m/s	0.7920 (0.0954)	0.7826 (0.0865)	0.7572 (0.1036)
Mean Eyes-Open Single Leg Stance (SD), s	25.59 (16.66)	25.83 (11.43)	25.34 (12.43)
Mean Eyes-Closed Single-Leg Stance (SD), s	8.85 (5.18)	9.74 (6.22)	10.76 (7.28)
Mean Berg balance scale (SD)	48.47 (4.29)	47.96 (4.23)	48.51 (3.87)
Mean 30-Second Chair Stand Test (SD), number	17.80 (4.59)	17.31 (3.53)	17.58 (3.51)
Mean Five-Times Sit-to-Stand Test (SD), s	7.68 (1.90)	6.93 (1.36)	6.90 (1.87)
Mean Modified Falls Efficacy Scale (SD), score	8.97 (0.48)	8.94 (0.44)	8.91 (0.46)
<i>Cognitive Function</i>			
Mean Montreal Cognitive Assessment (SD), score	25.51 (2.67)	25.73 (2.97)	25.87 (2.43)
Mean Hand Grip Strength (SD), kg	24.24 (6.91)	21.69 (5.42)	21.70 (6.47)
Stroop Color and Word Test			
Mean Consistency-Accuracy Rate (SD), %	96.03 (7.77)	92.95 (10.14)	95.31 (5.94)
Mean Inconsistent-Accuracy Rate (SD), %	94.32 (11.59)	93.61 (5.89)	94.12 (6.44)
Mean Consistency-Reaction Time (SD), ms	1451.86 (666.53)	1450.90 (735.22)	1465.44 (572.44)
Mean Inconsistent-Reaction Time (SD), ms	1562.79 (545.44)	1588.80 (826.07)	1613.05 (628.03)

Results

A total of 142 participants were enrolled in the study (Figure 1). Following the baseline assessment, seven individuals were excluded due to physical discomfort ($n = 2$), malignant neoplasm ($n = 1$), or refusal to participate in the intervention ($n = 4$). The remaining 135 eligible participants were randomly allocated to one of three groups: TC+RB-D ($n = 45$), TC ($n = 45$), and 24-TC ($n = 45$). Baseline characteristics of the 135 participants are summarized in Table 1. Overall, 67.41% were female. The mean ages were 66.98 years in the TC+RB-D group, 66.87 years in the TC group, and 67.98 years in the 24-TC group. No significant differences in baseline characteristics were observed among the groups. During the 12-week intervention period, one participant was lost to follow-up, three withdrew due to physical discomfort, and two withdrew due to scheduling conflicts. As a result, a total of 129 participants completed the intervention. Attendance rates were 84.94% in the TC+RB-D group, 82.25% in the TC group, and 82.04% in the 24-TC group. However, all participants ($n = 135$) responded to the outcome assessments.

Although the final sample analyzed was slightly smaller than planned, we performed a sensitivity analysis in G*Power. With $\alpha = 0.05$, power = 0.80, three groups, and testing the group \times time interaction, the observed sample size ($n = 135$) could detect a minimum effect size of 0.274, approximately a medium effect. Thus, the study retained adequate power to identify medium and larger effects, although its ability to detect smaller effect was correspondingly reduced.

Balance and Mobility Function Outcome

When assessing the simple effect of time, the majority of outcome measures demonstrated significant changes from baseline across all groups (Figure 4 and Appendix 5), with the exception of the 5-repetition sit-to-stand test, which did not change significantly in the TC+RB-D and TC groups ($P = 0.367$ and $P = 0.153$, respectively). The results of the linear

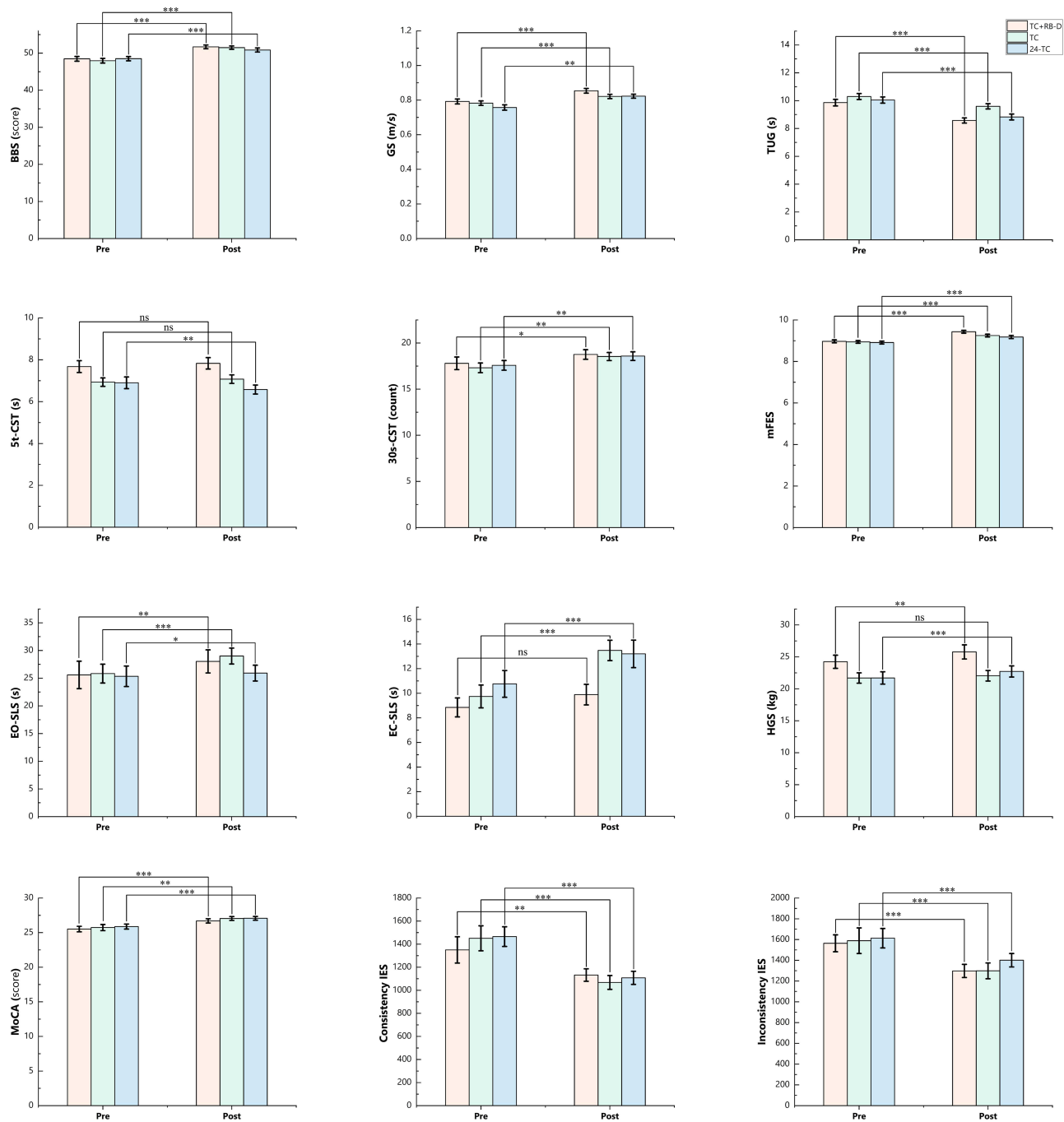


Figure 4 Time Effects of Interventions on Outcome Measures. *:p<0.05. **:p<0.01. ***:p<0.001. **Abbreviation:** ns, not significant.

mixed model (LMM) analysis are presented in Table 2. No significant group-by-time interaction effects were observed for BBS ($P = 0.141$), EO-SLS ($P = 0.329$), or 30s-CST ($P = 0.825$), indicating that the magnitude of improvement did not differ significantly among the three groups after the intervention. Compared with the TC+RB-D ($\beta = -1.281$, 95% CI: $-1.564 \sim -0.998$, $p < 0.001$), the 24-TC group ($\beta = 0.065$, 95% CI: $-0.335 \sim 0.465$, $p = 0.748$) showed no significant difference in improvement of TUG, although a non-significant trend toward slower TUG performance was still observed relative to the combined group, whereas the TC group exhibited significantly less improvement ($\beta = 0.576$, 95% CI: $0.176 \sim 0.975$, $p = 0.005$), corresponding to a 0.576-unit smaller gain compared with the reference group. A similar pattern

Table 2 Mixed Linear Model Results

Outcome	Group	Group-by-Time Interaction Effect	Group Effect	Time Effect		Post		
						ΔMean[95% CI]	P-value	Cohen's d
TUG	TC+RB-D	0.009	0.031	<0.001	Intercept-TC+RB-D	-1.281[-1.564,-0.998]	<0.001	1.315
	TC				TC+RB-D vs TC	0.576[0.176,0.975]	0.005	0.523
	24-TC				TC+RB-D vs 24-TC	0.065[-0.335,0.465]	0.748	1.214
GS	TC+RB-D	0.029	0.19	<0.001	Intercept-TC+RB-D	0.062[0.048,0.075]	<0.001	1.291
	TC				TC+RB-D vs TC	-0.023[-0.042,-0.004]	0.033	0.455
	24-TC				TC+RB-D vs 24-TC	0.004[-0.044,-0.002]	0.74	0.72
BBS	TC+RB-D	0.141	0.836	<0.001	Intercept-TC+RB-D	3.222[2.349,4.095]	<0.001	0.809
	TC				TC+RB-D vs TC	0.311[-0.924,1.546]	0.619	0.96
	24-TC				TC+RB-D vs 24-TC	-0.889[-2.124,0.346]	0.157	0.62
EO-SLS	TC+RB-D	0.329	0.768	0.005	Intercept-TC+RB-D	2.442[-0.045,4.93]	0.054	0.159
	TC				TC+RB-D vs TC	0.726[-2.792,4.244]	0.684	0.68
	24-TC				TC+RB-D vs 24-TC	-1.855[-5.373,1.663]	0.299	0.053
EC-SLS	TC+RB-D	0.009	0.09	<0.001	Intercept-TC+RB-D	1.044[-0.17,2.257]	0.091	0.239
	TC				TC+RB-D vs TC	2.705[0.989,4.421]	0.002	1.167
	24-TC				TC+RB-D vs 24-TC	1.392[-0.324,3.108]	0.111	0.329
5t-CST	TC+RB-D	0.01	0.009	0.91	Intercept-TC+RB-D	0.156[-0.091,0.402]	0.215	0.136
	TC				TC+RB-D vs TC	-0.014[-0.363,0.335]	0.936	0.217
	24-TC				TC+RB-D vs 24-TC	-0.477[-0.826,-0.128]	0.008	0.531
30s-CST	TC+RB-D	0.825	0.884	<0.001	Intercept-TC+RB-D	0.956[0.313,1.599]	0.004	0.382
	TC				TC+RB-D vs TC	0.267[-0.643,1.176]	0.58	0.549
	24-TC				TC+RB-D vs 24-TC	0.044[-0.865,0.954]	0.923	0.3
mFES	TC+RB-D	0.012	0.226	<0.001	Intercept-TC+RB-D	0.463[0.366,0.561]	<0.001	1.581
	TC				TC+RB-D vs TC	-0.159[-0.296,-0.021]	0.024	0.819
	24-TC				TC+RB-D vs 24-TC	-0.198[-0.336,-0.061]	0.005	0.83
MoCA	TC+RB-D	0.941	0.69	<0.001	Intercept-TC+RB-D	1.178[0.604,1.751]	0.604	0.496
	TC				TC+RB-D vs TC	0.133[-0.678,0.944]	0.746	0.528
	24-TC				TC+RB-D vs 24-TC	0.022[-0.789,0.833]	0.957	0.563
HGS	TC+RB-D	0.073	0.033	<0.001	Intercept-TC+RB-D	1.536[0.821,2.25]	<0.001	0.467
	TC				TC+RB-D vs TC	-1.178[-2.188,-0.167]	0.023	0.065
	24-TC				TC+RB-D vs 24-TC	-0.513[-1.524,0.497]	0.317	0.657
Consistency-IES	TC+RB-D	0.232	0.912	<0.001	Intercept-TC+RB-D	-217.828[-362.394,-73.263]	0.003	0.365
	TC				TC+RB-D vs TC	-165.042[-369.489,39.406]	0.113	0.646
	24-TC				TC+RB-D vs 24-TC	-139.742[-344.19,64.705]	0.179	0.736
Inconsistency-IES	TC+RB-D	0.601	0.778	<0.001	Intercept-TC+RB-D	-266.206[-376.986,-155.427]	<0.001	0.877
	TC				TC+RB-D vs TC	-24.163[-180.828,132.503]	0.761	0.423
	24-TC				TC+RB-D vs 24-TC	53.989[-102.676,210.655]	0.497	0.393

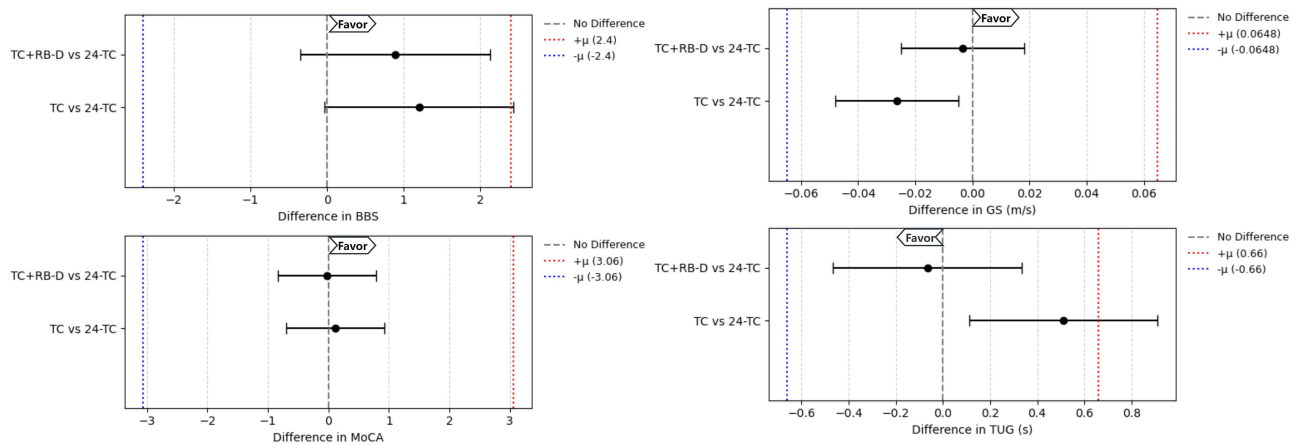


Figure 5 Non-Inferiority Test Results.

was observed for GS, with no significant difference between the TC+RB-D($\beta=0.062$, 95% CI: 0.048~0.075, $p<0.001$) and 24-TC groups ($\beta=0.004$, 95% CI: -0.044~0.002, $p=0.74$), but significantly lower improvement in the TC group ($\beta=-0.023$, 95% CI: -0.042~-0.004, $p=0.033$), corresponding to a 0.023-unit decrease compared with the reference group. Additionally, TC demonstrated a unique advantage in EC-SLS ($\beta=2.705$, 95% CI: 0.989~4.421, $p=0.002$), while TC+RB-D showed significantly greater improvement in mFES compared to the other groups ($\beta=0.463$, 95% CI: 0.366~0.561, $p<0.001$), which corresponds to an increased confidence in performing daily activities without falling. The 24-TC group showed significant within-group improvement in 5T-CST ($P = 0.001$), and the magnitude of improvement was significantly greater than that in both the TC+RB-D and TC groups.

Cognitive Function Outcome

Significant differences from baseline were observed in all three groups for MoCA, a measure directly related to cognitive function, as well as for the inverse efficiency scores (IES) of both the congruent and incongruent tasks of the Stroop Color and Word Test (Figure 4). In contrast, for HGS, an indicator indirectly associated with cognitive function in older adults, no significant difference from baseline was observed in the TC group ($p = 0.326$). After the 12-week intervention, all three groups showed significant improvements in MoCA scores, with no significant differences in the magnitude of improvement among them. Compared with the TC+RB-D group, there were no significant differences in the improvements of both Consistency-IES and Inconsistency-IES in the TC and 24-TC groups. Overall, the indicators directly related to cognitive function demonstrated significant enhancement following the intervention, with comparable degrees of improvement across the three groups.

Non-Inferiority Analysis

To evaluate the second hypothesis, a non-inferiority analysis was conducted. Figure 5 illustrates these results. For GS, BBS, and MoCA, the lower bounds of their 95% confidence intervals were all above the prespecified non-inferiority margin ($-\mu$), indicating that both the TC+RB-D and TC groups met the non-inferiority criteria. Because the non-inferiority direction for TUG is reversed, we instead examined the upper bounds for the TC+RB-D and TC groups; the TC group’s upper bound exceeded $+\mu$, thereby failing the non-inferiority test.

Adverse Events

Notably, over the course of the 12-week intervention, 3 potential exercise-related adverse events were identified, leading the research team to recommend withdrawal from the study. Among these, participants in both the TC + RB-D and TC groups reported knee pain despite denying any prior history of related injury. Additionally, one individual in the TC group, who had a self-reported history of anterior cruciate ligament injury, experienced an exacerbation of pain at week 6 and subsequently withdrew from the trial.

Discussion

Our study findings indicated that a 12-week physical activity intervention combining Tai Chi and Roliball Demonstration effectively enhances both balance, mobility and cognitive function in community-dwelling older adults, with the potential to reduce fall risk. Moreover, the combined intervention conferred superior benefits across most outcome measures compared with either modality administered in basic Tai Chi and 24-form simplified Tai Chi. Overall, significant improvements in GS, TUG, BBS, and MoCA were observed in both the TC and TC+RB-D groups, supporting Hypothesis 1. Our results also showed that the Tai Chi+Roliball Demonstration was non-inferior to the traditional 24-form simplified Tai Chi in functional fall-risk tests and cognitive function; however, the structured Taiji group's improvement in TUG was inferior to that of the 24-TC group, thus only partially supporting Hypothesis 2.

This study is the first to investigate a combined intervention of Taichi Chuan and Roliball Demonstration two culturally homologous physical activity modalities. TCC has been supported by a substantial body of evidence, across multiple levels of research, for its effectiveness in improving balance function and fall-related outcomes in community-dwelling older adults.^{58–60} TCC is also recommended by various physical activity guidelines as an exercise with high-quality evidence for the prevention of falls in older adults.^{12,16,38} Especially for functional measures such as the TUG, GS and the BBS, recommended for predicting fall risk in older adults, the effects of TCC exercise have been supported by numerous prospective studies.^{26,61,62} Consistent with our findings, trials using TCC alone, whether through structured basic routines or the traditional 24 form simplified Tai Chi, have reported comparable improvements. By integrating Roliball, a culturally analogous weapon-based activity, into a combined exercise regimen with TCC, this study introduces a novel approach that significantly enhances balance, mobility and cognitive function in older adults. This confirms the protective effects of multi modal exercise interventions on physical function in the elderly.⁶³

Distinct from prior studies, the present intervention was tailored to the unique characteristics of each exercise modality. TCC training followed a progressive structure encompassing posture and breathing regulation, gait training, technical skill development, and fundamental form practice. The Roliball protocol was similarly sequenced, beginning with ball-sense training, advancing through stationary and locomotive technical drills, and culminating in fundamental form practice. This stepwise progression from simple to complex tasks reduced the burden of motor learning for participants and achieved outcomes comparable to traditional approaches. Although TCC and Roliball Demonstration share cultural homology, they differ significantly in movement characteristics. TCC is slower and emphasizes proprioception, whereas Roliball Demonstration features a faster tempo and intensity, focusing more on the coordination among the body, racket, and ball. The beneficial effects of TCC on mobility and balance in older adults can be attributed to its unique lower-limb movement patterns. A study by Mao et al demonstrated that lower-limb training using only TCC techniques may yield greater improvements in functional activity than the standard 8-form Tai Chi, owing to continuous concentric and eccentric contractions during practice, which enhance overall lower-limb strength—particularly in the knee flexor muscle group.^{26,64,65} Furthermore, a review by Zou et al highlighted the crucial role of TCC in improving proprioception related to ankle plantarflexion, dorsiflexion, and knee flexion-extension.³¹ Our intervention emphasized these features by enhancing the content related to various TCC stepping patterns and incorporating specific proprioception training for the lower limbs. These elements are of critical importance in improving functional mobility and balance.

In contrast to traditional TCC, Roliball Demonstration integrates gait training elements resembling calisthenics and throwing–catching tasks performed under posturally demanding conditions. Accumulating evidence suggests that ball throwing and catching can effectively enhance postural control in older adults. Notably, even a single bout of such training has been shown to significantly improve stability in non-trained balance tasks,⁶⁶ potentially through the facilitation of anticipatory postural adjustments, with observable transfer effects across various motor activities.⁶⁷ However, falls typically occur during multi-task scenarios where different tasks compete for limited attentional resources, creating potential interference between concurrent activities.⁶⁸ Older individuals require greater attentional allocation for postural control during perturbation recovery compared to younger populations,⁶⁹ and therefore selecting interventions that improve adaptation to increased attentional loads are important for fall prevention.⁷⁰ During motor skill acquisition, directing exercisers' attention to movement outcomes (external focus of attention) appears more beneficial than focusing on body movements (internal focus of attention). Preliminary evidence indicates that an internal focus may constrain the

motor system by interfering with natural control processes, whereas an external focus facilitates automatic movement regulation.^{71,72} Balance training using external-focus strategies has been shown to enhance postural stability in older adults, potentially contributing to reduced fall risk.⁷³ These interventions employ anticipatory postural adjustments to mitigate the effects of predictable perturbations, with proactive postural strategies being further potentiated when introducing secondary tasks.⁷⁴ According to research, performing ball throwing and catching under challenging postural conditions is considered a motor dual-task paradigm, which functions as a hybrid perturbation model.^{75,76} This integration likely enhances both anticipatory and compensatory postural adjustments, thereby promoting the transfer of stability gains to everyday multi-task situations.

Interestingly, the basic TC group showed comparatively poorer performance on the TUG than the other two groups. A plausible explanation is that, although TC emphasizes lower-limb strength and proprioception, it involves relatively limited direct and repetitive gait-specific training. By contrast, Roliball demonstration incorporates locomotor tasks such as throwing and catching performed under dynamic postural conditions, thereby providing greater gait-related stimulation. The combined intervention (TC+RB-D) further magnified these effects by integrating both lower-limb strengthening and complex gait challenges, a trend that was similarly observed for the BBS.

Moreover, TCC has been shown to exert a significant positive effect on global cognitive function among older adults.⁷⁷ Qi et al demonstrated that, compared with simpler and more repetitive activities such as brisk walking, Tai Chi training elicited significantly greater bilateral prefrontal cortex activation and enhanced performance on the SCWT.⁷⁸ These findings may be attributable to the higher cognitive demands inherent in TCC practice. Supporting this, Forte et al reported that multicomponent exercise interventions appear to exert a direct impact on executive functions, particularly inhibitory control, whereas isolated progressive resistance training influences inhibition only indirectly via gains in muscular strength.⁷⁹ This finding aligns with our results, wherein participants in the TC+RB-D group exhibited significantly greater improvements when performing cognitively demanding tasks. The enhancement in inhibitory control among older adults in this group may have yielded a greater effect compared to the TC and 24-TC groups (Cohen's *d*: 0.877). Overall, in which the Tai Chi component was intended to target lower-limb strength and proprioception in older adults, while the Roliball Demonstration component focused on enhancing postural control. Notably, the combined intervention involves a higher level of task complexity compared to any single-modality exercise.

This study also offered a novel approach to community-based exercise for older adults. The intervention was designed to reduce the cognitive and physical demands of learning by adopting a progressive structure, integrating TCC and RB training from fundamental movements to technical skills and finally to structured protocols. While achieving effects comparable to traditional repetitive TCC routines, the program maintained high adherence and provided participants with foundational motor skills for long-term engagement in either TCC or RB practice. Moreover, even basic-level TCC training alone was sufficient to confer protective benefits to physical function in older adults.

Limitation and Future Directions

We acknowledge several limitations of this study. First, the relatively short intervention period precluded evaluation of long-term effects, as no follow-up or fall incidence data were collected. This limits conclusions regarding the durability and broader clinical relevance of the findings. Second, the mean age of participants was below 70 years, which may restrict the generalizability of the results to more advanced age groups; caution is therefore warranted when extrapolating these outcomes to older populations. Third, while the interventions were well received, group differences in exercise engagement appeared to be influenced by participants' perceptions of technical complexity and cultural familiarity, which may have introduced bias and limited the comparability of adherence across groups.

Despite these limitations, the study offers several strengths, including the structured design of the interventions and their emphasis on practical applicability, which may promote sustained engagement beyond the trial period. Future research should address the current gaps by conducting long-term follow-up studies that incorporate fall incidence as a primary outcome, enrolling more diverse and older populations, and comparing the effects of culturally tailored versus standardized exercise protocols. In addition, integrating qualitative evaluations from participants, instructors, and community stakeholders will help refine these programs and enhance their feasibility. Finally, large-scale, multi-center trials are warranted to validate the effectiveness of combined TCC and RB-D interventions in broader older adult populations.

Conclusion

In this study, we developed a structured physical activity program rooted in Tai Chi culture, comprising foundational Tai Chi practice and equipment-based ball exercises. The intervention included core Tai Chi techniques and stepping patterns, alongside multidirectional throwing and catching tasks designed to enhance motor coordination. Findings from the study suggested that this multimodal exercise approach may confer significant benefits in preserving balance, mobility, and cognitive function among older adults.

However, caution is warranted before scaling this intervention to larger populations or drawing conclusions about its long-term effects.

Abbreviations

TCC, Taichi Chuan; RB-D, Roliball demonstration; RB, Roliball; TC, Basic Taichi Chuan; 24-TC, 24-From Simplified Taichi; BBS, Berg Balance Scale; GS, 4-Meter Gait Speed; TUG, Timed Up and Go Test; EO-SLS, Eyes-Open Single Leg Stance; EC-SLS, Eyes-Closed Single Leg Stance; 5t-CST, Five-Times Sit-to-Stand Test; 30s-CST, 30-Second Chair Stand Test; mFES, Modified Falls Efficacy Scale; MoCA, Montreal Cognitive Assessment; SCWT, Stroop Color and Word Test; HGS, Hand Grip Strength Tests; IES, Inverse Efficiency Score; PAG-A, Physical Activity Guidelines for Americans 2nd Edition; PAG-E, UK Physical Activity Guidelines: Older Adults in Transition; WG-FPM, World Guidelines for Falls Prevention and Management for Older Adults: A Global Initiative; LMM, Linear Mixed Model.

Data Sharing Statement

The authors can offer complete individual participant data without identifying information if available. Please send your request for original data to the e-mail address of Enjing Li, Ph.D. at leeej@ccnu.edu.cn.

Ethics Approval and Informed Consent

This study was reviewed and approved by the Institutional Review Board of the Ethics Committee of Central China Normal University (CCNU-IRB-202502010b) and was conducted in accordance with the principles of the Declaration of Helsinki. All participants received a full explanation of the study's purpose, procedures, potential benefits and risks, and their rights as participants. They provided written informed consent prior to enrollment. Participation was voluntary, and participants were informed that they could withdraw at any time without penalty, and all data would be anonymized and reported in aggregate only.

Consent for Publication

All authors consent to the publication of this manuscript.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors declare that they have no competing interests in this work.

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