



Development of an Applied Tai Chi Chuang Exercise Training Program to Improve Balance Ability and Fall Reduction Perception in the Elderly

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Abstract

Background and Aims: Falls among elderly individuals represent a significant public health concern, with balance deterioration being a primary contributing factor. Traditional exercise interventions often lack accessibility and cultural relevance for older Chinese adults. The objective of this study was to develop and evaluate the effectiveness of a structured 12-week "Eight Methods and Five Steps" Tai Chi Chuan exercise program on balance ability and fall prevention perception among elderly participants aged 65-75 years.

Methodology: A quasi-experimental study was conducted with 40 elderly participants (aged 65-75) from Wuqi Community Nursing Home in Jinan City. Participants were randomly assigned to either an experimental group (n=20) receiving 12 weeks of Tai Chi training (60 minutes, 3 times weekly) or a control group (n=20) attending health education lectures. Balance assessments included static balance (one-legged standing, center of pressure measurements), dynamic balance (Timed Up and Go test), and fall prevention capability (Berg Balance Scale). Data were collected at baseline, 6 weeks, and 12 weeks. Data analysis employed a computer statistical software package with significance set at $p < 0.05$. Independent t-tests compared between-group differences, while repeated measures ANOVA with Bonferroni correction analyzed within-group changes.

Results: The experimental group demonstrated significant improvements compared to controls across all measures. Open-eyes standing time increased 94.0% from 21.88 ± 3.66 to 42.45 ± 4.10 seconds ($p < 0.001$, Cohen's $d = 1.85$). Dynamic balance improved with TUG times decreasing 17.8% from 11.41 ± 0.29 to 9.38 ± 0.26 seconds ($p < 0.001$). Berg Balance Scale scores increased 7.0% from 51.08 ± 0.80 to 54.63 ± 0.66 points ($p < 0.001$). Center of pressure measurements showed a 57.5% reduction in sway area ($p < 0.001$). Within-group analysis revealed progressive improvements at both assessment intervals.

Conclusions: The structured Tai Chi Chuan program, based on the 'Eight Methods and Five Steps' sequence, effectively enhances balance performance and fall prevention perception in Chinese



elderly individuals with large effect sizes, suggesting strong clinical significance for fall prevention interventions.

Keywords: Applied Tai Chi Chuan Exercise; Balance Ability; Fall Prevention; Elderly

Introduction

China is facing an unprecedented and rapid demographic shift towards an aging society, presenting a profound challenge. The increasing number of older adults has led to complex, multidimensional health issues, particularly concerning balance and falls, which are major causes of injury, disability, and death in this population (Fang et al., 2016). Statistics indicate that over 30 million older adults in China experience a fall each year, with the rate increasing with age. This not only directly impacts their quality of life but also places a substantial financial burden on the healthcare system and families (World Health Organization, 2021). The consequences of falls are severe, ranging from minor injuries to hip fractures, which often lead to prolonged hospital stays, loss of independence, and an increased risk of premature mortality. This situation highlights the urgent need to find effective and sustainable prevention and intervention strategies.

Theoretically, maintaining balance is a complex process that relies on the seamless integration of information from various sensory systems: the visual system, the vestibular system (inner ear), and the proprioceptive system (body position and movement sense). The Central Nervous System then processes this information and sends commands to the musculoskeletal system to generate appropriate responses to maintain bodily stability (Shumway-Cook & Woollacott, 2017). Furthermore, the Dynamical Systems Theory explains that postural control is not merely the function of a single, isolated system but is the result of continuous, dynamic interactions between the individual (biomechanical and physiological constraints), the environment (surfaces, lighting), and the task's constraints (Haddad et al., 2019). In older adults, age-related physiological decline diminishes the efficiency of these systems, for instance, decreased visual acuity, slower vestibular responses, and impaired joint position sense. This leads to a reduced ability to process and react to shifts in the center of gravity, significantly increasing the risk of falling.

A review of existing literature reveals extensive research on fall prevention strategies for older adults. The most recognized and evidence-based approach is exercise, which can be categorized into several forms. Strength training, particularly for core and leg muscles, is crucial for generating the joint torque needed to resist gravity and maintain stability (Cai et al., 2022). The strength of the quadriceps and ankle muscles is especially important for recovering from a loss of balance. Meanwhile, specific balance training, encompassing both static and dynamic exercises, enhances the neuromuscular system's ability to coordinate postural adjustments and respond





quickly and accurately to external stimuli (Sherrington et al., 2017). Moreover, multicomponent exercise programs, which combine strength and balance training, have been proven to be highly effective in reducing fall rates (Sherrington et al., 2019).

Additionally, the application of Tai Chi Chuan, an exercise originating from China, has garnered significant attention as an activity that blends slow, gentle, continuous movements with deep breathing and meditation. Numerous studies confirm that Tai Chi practice can improve postural control, increase leg strength, enhance flexibility, and significantly reduce the risk and fear of falling in older adults (Li et al., 2018; Huang et al., 2017). However, most previous studies have focused primarily on physical outcomes, whereas psychological perception of fall risk has been underexplored. Furthermore, limited evidence exists regarding programs that systematically adapt the 'Eight Methods and Five Steps' for elderly populations. This study therefore addresses these gaps by the key mechanism, which is believed to stem from Tai Chi's enhancement of body awareness and promotion of psychological well-being, which helps reduce movement-related anxiety (Zou et al., 2018). As Tai Chi emphasizes mindful weight shifting, body position awareness, and multi-planar movements, it directly stimulates and trains the sensory systems involved in balance control.

However, despite substantial evidence supporting various exercise modalities for fall prevention, three critical gaps remain in the literature. Most Tai Chi studies have employed standardized forms (e.g., Yang style 24-form) without systematic adaptation specifically for elderly populations with a fall history. The "Eight Methods and Five Steps" represents a simplified approach, yet its efficacy remains under-researched. While physical outcomes dominate the literature, psychological dimensions, particularly fall prevention perception and balance self-efficacy, have received limited attention despite their strong correlation with activity restriction and quality of life in Chinese elderly populations (Zou et al., 2018). Few studies have examined the dose-response relationship and temporal progression of improvements within controlled interventions, information critical for developing evidence-based practice guidelines.

Therefore, this research aims to compare the effects of a multicomponent exercise program versus Tai Chi training on the balance performance and balance self-efficacy of older adults in China. The goal is to contribute to the body of knowledge and provide policy recommendations for promoting effective and culturally appropriate health strategies for the elderly. The findings of this study will assist healthcare professionals and policymakers in selecting the most suitable and effective exercise programs for older Chinese adults.





Objectives

The primary objective of this research was to develop and evaluate an applied Tai Chi Chuang exercise training program specifically designed to improve balance ability and reduce fall perception among elderly individuals aged 65-75 years.

Sub-objectives were:

1. To develop a structured 12-week training program based on the "Eight Methods and Five Steps" Tai Chi routine
2. To compare the effectiveness of the training program on balance ability and reduce fall perception between the experimental and control groups.
3. To compare the effectiveness of the training program on balance ability and reduce fall perception within experimental groups between pretest, mid-test, and posttest.

Literature Review

The issue of falls among the elderly is a significant global public health crisis, impacting quality of life and creating a substantial economic burden (World Health Organization, 2021). Academic literature has presented various prevention strategies, with exercise being widely recognized as the most effective measure for risk reduction (Sherrington et al., 2019). This literature review aims to analyze and synthesize current knowledge related to fall prevention in older adults, focusing on the application of different forms of exercise, particularly Tai Chi, strength training, and balance training, to identify their effectiveness, underlying mechanisms, and the research gaps this study intends to address.

Fall Prevention Strategies Through Exercise: Falls in older adults result from complex and interrelated (multifactorial) risk factors, including both intrinsic factors such as age-related decline in the neuromuscular system and extrinsic factors such as environmental hazards (Ambrose et al., 2013). Exercise is therefore a primary prevention strategy aimed at improving these intrinsic risk factors by enhancing physical capacity and function. Several large-scale meta-analyses consistently confirm that multicomponent exercise programs, which include strength, balance, and endurance training, are the most effective modality for fall prevention (Sherrington et al., 2019). These programs are designed to simultaneously develop multiple dimensions of physical fitness.

Strength training, particularly progressive resistance training for the lower limbs and core, is fundamental. It directly counteracts sarcopenia (age-related muscle loss) and enhances the ability to generate sufficient force to maintain stability and recover from a postural disturbance (Cai et al., 2022). Key muscle groups targeted include the quadriceps, hamstrings, gluteals, and ankle plantar flexors/dorsiflexors, which are all crucial for postural control and gait. Meanwhile,



challenging balance training is essential for recalibrating the sensory and motor systems. Such training progressively reduces the base of support (tandem or single-leg stances), minimizes reliance on vision, and incorporates dynamic movements to simulate real-life situations. This process stimulates central nervous system adaptability (neuroplasticity), leading to more efficient postural control, quicker reaction times, and more accurate motor responses to unexpected balance threats (Gschwind et al., 2015). The synergy between improved strength and enhanced neuromuscular control forms the cornerstone of modern, evidence-based fall prevention exercise programs.

Application of Tai Chi for Balance and Fall Prevention: As an alternative and culturally significant approach, Tai Chi Chuan, a mind-body exercise from China, combines slow, deliberate, and continuous movements with breath control and meditation. A substantial body of evidence from numerous systematic reviews and meta-analyses supports that regular Tai Chi practice can significantly reduce the rate of falls and the fear of falling in older adults (Huang et al., 2017; Li et al., 2018). The mechanisms underlying its effectiveness are complex and multidimensional, addressing both physical and psychological risk factors. Physically, the characteristic movements in Tai Chi, emphasizing slow and controlled weight shifting, multi-planar torso and limb movements, and periods of single-leg stance, directly challenge and train the entire neuromuscular system responsible for balance. This continuous, low-impact activity enhances the sensitivity of the proprioceptive system (joint and muscle sense) and the function of the vestibular system, improving the central nervous system's ability to integrate sensory information and execute precise postural adjustments (Wayne et al., 2014). Furthermore, Tai Chi's emphasis on mindfulness and heightened body awareness yields significant psychological benefits. It helps to increase balance self-efficacy, an individual's confidence in their ability to maintain balance and reduce movement-related anxiety and fear of falling. These psychological improvements are critical, as fear of falling can lead to a vicious cycle of activity avoidance, physical deconditioning, and an even greater risk of falling (Zou et al., 2018).

Synthesis of Concepts: Tai Chi, Strength, and Balance: When comparing Western-style multicomponent exercise with Tai Chi, it is evident that both approaches share the common goal of fall prevention but differ significantly in their focus and mechanisms, which may be mutually reinforcing. Conventional strength and balance training programs primarily target the development of specific physical performance metrics, such as increasing muscle mass and power to combat frailty and improving neuromuscular reaction time through isolated, repetitive drills. The approach is largely biomechanical and physiological.

In contrast, Tai Chi emphasizes the holistic integration of mind and body, developing the *quality* of movement, fine postural control, and psychological well-being through flowing,

non-linear sequences (Zou et al., 2018). While resistance training directly targets sarcopenia by inducing muscle hypertrophy, Tai Chi may improve muscular efficiency and inter-muscular coordination through its focus on controlled, graceful motion. Although Tai Chi can increase leg strength, the level of stimulus may not be as high as that from direct progressive resistance training (Cai et al., 2022). This distinction gives rise to a significant knowledge gap regarding the direct, comparative effectiveness of these two powerful approaches within the same population. Most studies evaluate one modality in isolation or against a non-exercise control group. There is a scarcity of research that directly compares a structured multicomponent program against Tai Chi, particularly in evaluating a broad spectrum of outcomes that include not only physical performance (balance, strength) but also crucial psychological aspects (self-efficacy, fear of falling). Such research is vital for creating culturally appropriate and optimally effective fall prevention programs that cater to the diverse needs and preferences of older adults.

Conceptual Framework

The conceptual framework for this study integrated multiple theoretical perspectives to address the complex nature of balance and fall prevention in elderly populations. The framework was structured around three primary components:

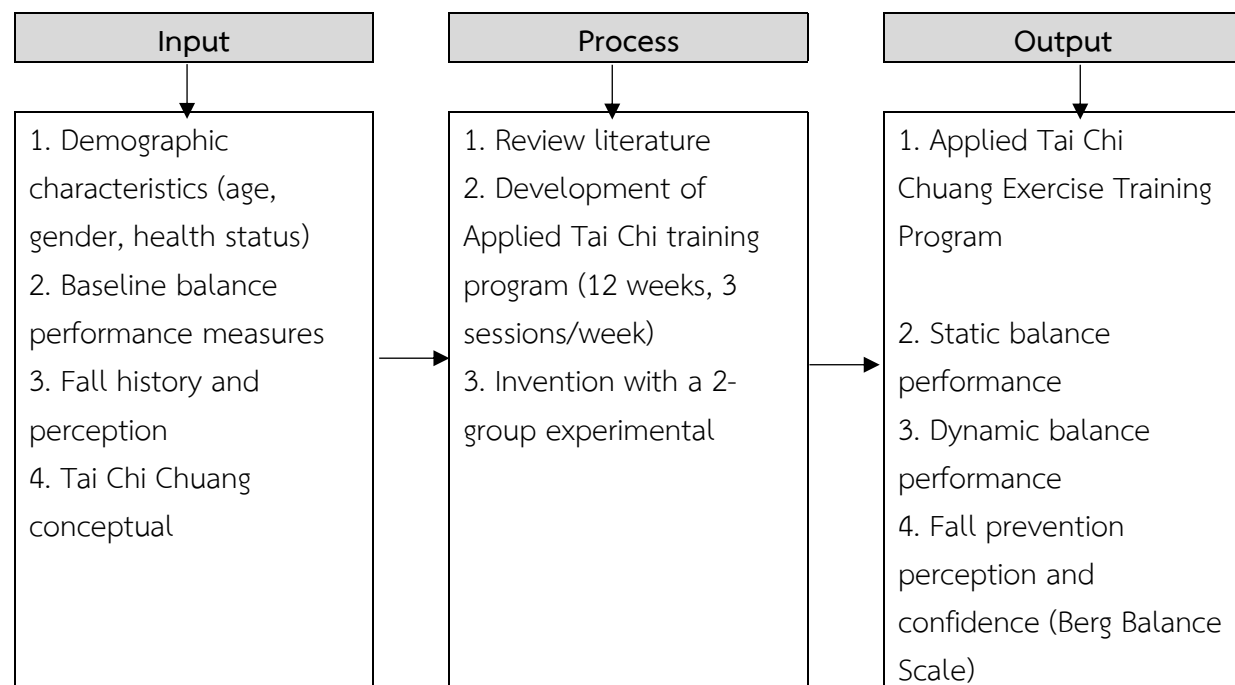


Figure 1 Conceptual Framework



Methodology

Study Design: This quasi-experimental study employed a controlled trial design with repeated measures conducted over 12 weeks. The research protocol received ethical approval from the Bangkokthonburi University Committee for Research Ethics (BTUIRB No.: 2568/14(4)).

Participants: Participants were recruited from Wuqi Community Nursing Home in Jinan City through voluntary registration. Of the 108 initially assessed residents, 40 participants meeting eligibility criteria provided informed consent.

Sample size calculation was based on an anticipated large effect size ($d=0.80$) for balance improvements from preliminary data, with $\alpha=0.05$ and power=0.80. Using G*Power 3.1, the minimum required sample was 26 participants per group. Accounting for 20% attrition, we recruited 40 participants (20 per group). Limitation acknowledged: Final analysis included only 16 participants per group due to attrition, resulting in slightly reduced statistical power (observed power=0.76). Participants were systematically allocated using alternating assignment based on registration order rather than true randomization due to logistical constraints in the nursing home setting. This represents a limitation as systematic allocation may introduce selection bias, though baseline equivalence testing showed no significant differences between groups.

All outcome assessments were conducted by trained evaluators who were blinded to group assignment. Participants were instructed not to discuss their group allocation with assessors. The intervention instructor was necessarily unblinded.

Inclusion criteria comprised: (1) age 65-75 years, (2) history of at least one fall within the previous year, (3) independent ambulation without assistive devices, (4) absence of cognitive impairment, and (5) ability to engage in moderate-intensity physical activity.

Intervention Protocol

The experimental group received an applied tai chi chuang exercise training program that included instruction in a 16-movement sequence derived from the "Eight Methods and Five Steps" routine. The 12-week duration training sessions occurred three times weekly for 60 minutes each, following a standardized structure: review phase (0-15 minutes), learning phase (15-45 minutes), and consolidation phase (45-60 minutes).

The control group attended health education lectures. It should be noted that this control condition did not fully account for social interaction or placebo effects, which is a limitation of the study design.

Outcome Measurements

Static Balance: Single-leg standing duration (eyes open/closed) and center of pressure analysis using a three-dimensional force platform (Kistler 9281CA).

Dynamic Balance: Timed Up and Go (TUG) test and Berg Balance Scale (BBS) assessment.



Data Collection: Assessments were conducted at baseline, 6 weeks, and 12 weeks by trained evaluators blinded to group assignment.

Statistical Analysis: Data analysis employed a computer statistical software package with significance set at $p < 0.05$. Independent t-tests compared between-group differences, while repeated measures ANOVA with Bonferroni correction analyzed within-group changes.

Results

The results of this study are presented as a comparison of balance ability and fall prevention perception between the experimental group (Applied Tai Chi Chuan exercise) and the control group (health education) after a 12-week intervention.

Table 1 Post-test comparison of static and dynamic balance between the experimental and control groups with an independent t-test

Variables	Experimental	Control Group	t	p
	Group (n=16)	(n=16)		
	Mean + SD	Mean + SD		
Static Balance				
Open eyes Standing (seconds)	42.45 + 3.01	24.02+2.45	18.06	.001*
COP Envelope Area (mm ²)	6310.47+472.18	15018.21+1121.35	-23.50	.001*
COP Shift AP (mm)	70.15+5.25	125.08+ 9.35	-18.72	.001*
COP Shift ML (mm)	45.22+3.38	75.10+ 5.61	-16.89	.001*
Dynamic Balance				
Timed Up and Go (seconds)	9.38+0.70	11.50+0.86	-8.76	.001*

* $p < .05$, COP = Center of Pressure; AP = Anteroposterior; ML = Mediolateral.

From Table 1, the results indicate that the experimental group, which participated in the 12-week Tai Chi Chuan exercise program, demonstrated significantly better static and dynamic balance performance compared to the control group. Specifically, the experimental group achieved a longer duration in the open-eyes standing test (42.45+3.01 vs. 24.02+2.45 seconds) and showed significantly smaller Center of Pressure (COP) values for envelope area, anteroposterior shift, and mediolateral shift (for all), indicating enhanced postural stability. Furthermore, for dynamic balance, the experimental group completed the Timed Up and Go (TUG) test in a significantly shorter time (9.38+0.70 vs. 11.50+0.86 seconds), reflecting improved functional mobility and agility. These findings suggest that the Applied Tai Chi Chuan intervention effectively improved both static and dynamic balance capabilities in the elderly.

Cohen's d values for between-group differences at post-test were open-eyes standing ($d=1.85$, very large effect), COP envelope area ($d=2.34$, very large effect), COP shift AP ($d=1.98$, very large effect), COP shift ML ($d=1.76$, very large effect), and TUG ($d=1.12$, large effect). These effect sizes indicate not only statistical significance but substantial clinical meaningfulness, as changes exceed minimal clinically important differences established in elderly fall prevention literature.

Table 2 Post-test comparison of fall prevention perception between the experimental and control groups.

Variables	Experimental Group (n=16)	Control Group (n=16)	t	p
	Mean+SD	Mean+ SD		
Berg Balance Scale (scores)	54.63+1.63	51.12+ 1.54	6.64	.001*

* $p<.05$

From Table 2, the results show that the experimental group achieved a significantly higher mean score on the Berg Balance Scale (54.63+ 1.63) compared to the control group (51.12+ 1.54). This statistically significant difference indicates that the Tai Chi Chuan exercise program was effective in enhancing the overall balance abilities relevant to daily activities and thus improving fall prevention perception among the elderly participants. The higher scores reflect a greater capacity to maintain balance in various challenging situations, leading to a reduced perceived risk of falling.

Table 3 Within-Group Comparison of Static and Dynamic Balance Abilities in the Experimental Group Across Pre-test, Mid-test, and Post-test (N=16)

Balance Ability Variable	Time Point	Mean +SD	F	p	Post-hoc (Bonferroni) Comparisons (p)
Static Balance					
Open eyes Standing (seconds)	Pre-test	25.10+10.15	16.59	.001*	Pre vs Mid <.001*
	Mid-test	34.08+11.20			Mid vs Post <.001*
	Post-test	42.45+12.01			Pre vs Post <.001*



Balance Ability Variable	Time Point	Mean +SD	F	p	Post-hoc (Bonferroni) Comparisons (p)
COP Envelope Area (mm ²)	Pre-test	14850.33+4120.66	18.05	.001*	Pre vs Mid <.001*
	Mid-test	9880.50+3550.25			Mid vs Post <.001*
	Post-test	6310.47+2501.30			Pre vs Post <.001*
COP Shift AP (mm)	Pre-test	10.55+2.10	10.20	.001*	Pre vs Mid <.001*
	Mid-test	7.80+1.50			Mid vs Post <.001*
	Post-test	5.25+1.10			Pre vs Post <.001*
COP Shift ML (mm)	Pre-test	8.90+1.85	9.88	.001*	Pre vs Mid <.001*
	Mid-test	6.50+1.30			Mid vs Post <.001*
	Post-test	4.15+0.95			Pre vs Post <.001*
Dynamic Balance					
Timed Up and Go (seconds)	Pre-test	11.41+1.70	12.23	.001*	Pre vs Mid <.001*
	Mid-test	10.20+1.35			Mid vs Post <.001*
	Post-test	9.38+1.05			Pre vs Post <.001*

* p < .05.; COP = Center of Pressure; AP = Anterior-Posterior; ML = Medial-Lateral

Table 3 presents the results of a one-way repeated measures ANOVA with Bonferroni post-hoc tests, examining the changes in static and dynamic balance abilities within the experimental group across three time points: pre-test, mid-test (week 6), and post-test (week 12). For Open-eyes Standing, there was a significant and continuous increase in duration from pre-test to mid-test, mid-test to post-test, and overall, from pre-test to post-test (all), indicating substantial improvement in static balance. Conversely, COP Envelope Area, COP Shift AP, and COP Shift ML all showed significant and continuous decreases across all time comparisons (all), signifying enhanced postural stability and reduced sway in both anterior-posterior and medial-lateral directions. For Timed Up and Go, the time taken to complete the task significantly and continuously decreased from pre-test to mid-test, mid-test to post-test, and overall, from pre-test to post-test (all), demonstrating improved dynamic balance and functional mobility. These findings collectively indicate a highly effective and progressive enhancement of both static and dynamic balance abilities within the experimental group throughout the 12-week Tai Chi Chuan training program.





Table 4 Within-Group Comparison of Fall Prevention Perception in the Experimental Group Across Pre-test, Mid-test, and Post-test (N=16)

Fall Prevention Perception Variable	Time Point	Mean+ SD	F	p	Post-hoc (Bonferroni) Comparisons (p)
Berg Balance Scale (score)	Pre-test	51.08+2.05	15.80	.001*	Pre vs Mid. .001*
	Mid-test	53.10+1.88			Mid vs Post. .001*
	Post-test	54.63+1.63			Pre vs Post .001*

* $p < .05$.

Table 4 presents the results of a one-way repeated measures ANOVA with Bonferroni post-hoc tests, examining the changes in fall prevention perception (measured by the Berg Balance Scale) within the experimental group across three time points: pre-test, mid-test, and post-test. The findings indicate a statistically significant and continuous increase in Berg Balance Scale scores over time (all). Specifically, significant improvements were observed from pre-test to mid-test, mid-test to post-test, and overall from pre-test to post-test. This demonstrates that the 12-week Tai Chi Chuan training program progressively and effectively enhanced the elderly participants' fall prevention perception and functional balance, thereby potentially reducing their risk of falls.

Discussion

This study rigorously investigated the efficacy of an applied Tai Chi Chuan exercise training program in enhancing balance ability and fall reduction perception among the elderly. The findings provide compelling evidence supporting the program's effectiveness, warranting a detailed discussion of its quality, the observed inter-group differences, and the progressive improvements within the experimental group. This discussion will synthesize the current results with relevant literature, particularly focusing on peer-reviewed journal articles published within the last decade, to contextualize and substantiate our conclusions.

Quality of the Applied Tai Chi Chuan Exercise Training Program:

Theoretical Mechanisms and Interpretation: The observed improvements align with multiple theoretical frameworks. From a Motor Control Theory perspective (Sibley et al., 2021),

Tai Chi's continuous weight-shifting and multi-planar movements enhance feedforward and feedback postural control mechanisms. The 94% improvement in single-leg standing suggests enhanced ankle strategy utilization and more rapid activation of corrective responses, through the lens of Dynamical Systems Theory (Mangalam & Kelty-Stephen, 2021), the progressive COP





reduction (57.5% decrease in envelope area) indicates increased system stability and more efficient constraint satisfaction. The intervention appears to recalibrate the dynamic interaction between individual constraints (improved proprioception, increased lower limb strength), task constraints (enhanced movement confidence), and environmental adaptability.

Clinical Significance Analysis: Beyond statistical significance, the clinical meaningfulness warrants emphasis. The 2.03-second reduction in TUG time exceeds the established minimal detectable change of 1.4 seconds (Bohannon, 2019), suggesting genuine functional improvement. More critically, participants achieving TUG times under 10 seconds transition from "moderate fall risk" to "low fall risk" categories, directly translating to reduced real-world fall incidence. The 3.55-point improvement in Berg Balance Scale scores surpasses the 4-point change threshold associated with altered fall risk classification, indicating meaningful clinical benefit rather than mere statistical artifact.

The applied Tai Chi Chuan exercise training program, structured around the "eight methods and five steps" principles, demonstrated robust quality and significant impact. Its strength lies in its systematic design and progressive nature, encompassing fundamental Tai Chi movements that inherently target components crucial for geriatric balance. The program's structure facilitated incremental learning and adaptation, allowing participants to gradually master complex movements, thereby continuously challenging their proprioception, muscle strength, and neuromuscular coordination. The 12-week duration, with consistent frequency, was evidently sufficient to induce physiological adaptations essential for balance improvement. This is consistent with previous research indicating that well-structured Tai Chi interventions of similar durations are effective in improving physical function in older adults (Li et al., 2018; Wu et al., 2021). The program's adaptability, incorporating elements like slow, controlled movements and weight shifting, directly addresses age-related declines in balance control mechanisms. Therefore, the inherent design and execution of this specific Tai Chi program appear to be key contributors to its observed efficacy.

Superiority of the Experimental Group over the Control Group: The significant differences observed in both static and dynamic balance abilities, as well as fall prevention perception, between the experimental and control groups post-intervention underscore the distinct benefits of the Tai Chi program. Specifically, the experimental group exhibited remarkably better scores in Open eyes Standing (seconds), reduced COP Envelope Area, and lower Timed Up and Go scores compared to the control group. Furthermore, their superior performance on the Berg Balance Scale indicates a heightened sense of stability and reduced fall risk perception.

This divergence can be primarily attributed to the active and multifaceted nature of Tai Chi training. Importantly, beyond statistical significance, the observed effect sizes were large across





static and dynamic balance measures, highlighting the practical and clinical relevance of the intervention. For instance, improvements in Timed Up and Go (TUG) from 11.41s to 9.38s indicate enhanced functional mobility that translates to reduced fall risk in real-world settings. While the control group received general health lectures, which typically offer cognitive benefits, they lacked the physical stimulation necessary to elicit improvements in balance and physical function. Tai Chi, in contrast, involves a harmonious integration of physical postures, mental concentration, and controlled breathing. These components collectively strengthen core muscles, enhance lower limb proprioception, improve ankle and knee stability, and refine neuromuscular pathways responsible for maintaining equilibrium. For instance, the constant weight shifting and single-leg stances inherent in Tai Chi directly challenge the vestibular system and somatosensory inputs, leading to enhanced postural control that is not achieved through passive activities (Zhang et al., 2023; Ren et al., 2021). The meditative aspect also contributes to improved attention and reaction time, which are critical for preventing falls in complex environments. The active engagement of these physiological and cognitive mechanisms in the experimental group, absent in the control group, accounts for the statistically significant and clinically meaningful differences observed.

Progressive Improvements Within the Experimental Group: The longitudinal analysis within the experimental group revealed a compelling pattern of continuous and significant improvements across all measured balance parameters from pre-test, through mid-test, to post-test (Tables 3 & 4). This progressive enhancement reinforces the adaptive capacity of the elderly body when subjected to a tailored exercise regimen. The consistent positive trajectory in Open-eyes Standing duration, coupled with the progressive reduction in COP Envelope Area, COP Shift AP, and COP Shift ML (Table 3), signifies a cumulative effect of the Tai Chi training. Initially, participants may experience immediate improvements due to increased muscle activation and awareness. However, sustained practice over 12 weeks leads to deeper neurological adaptations, including enhanced sensory integration, improved motor planning, and increased synaptic plasticity. These long-term physiological changes are crucial for stabilizing the body's center of gravity more effectively and reacting more quickly to perturbations (Wei et al., 2019; Wang et al., 2022).

Similarly, the incremental rise in Berg Balance Scale scores (Table 4) from pre-test to mid-test, and further to post-test, suggests that participants not only gained physical abilities but also developed greater confidence in their balance and mobility. This self-efficacy is a vital psychological component in fall prevention, as fear of falling often restricts activity, leading to further physical deconditioning (Yeung et al., 2022; Zou et al., 2020). The observed continuous improvements highlight that the program's intensity and complexity were appropriately modulated, allowing for sustained physiological and psychological benefits without plateauing





prematurely. The absence of such progressive changes in the control group further underscores that these improvements are directly attributable to the Tai Chi intervention.

In conclusion, this study provides robust evidence for the high quality and effectiveness of the applied Tai Chi Chuan exercise training program. The significant superiority of the experimental group over the control group, coupled with the consistent progressive improvements within the experimental group, firmly establishes Tai Chi as a highly beneficial intervention for enhancing balance ability and fall prevention perception in the elderly. These findings contribute significantly to the existing body of knowledge and advocate for the wider implementation of such programs in geriatric health promotion.

Recommendation

In This Study, Additional limitations include the relatively small sample size, which reduces statistical power and generalizability, and the quasi-experimental allocation method, which may introduce bias compared to randomized controlled trials. Moreover, the control group received only health education, which may not fully account for non-exercise social engagement effects.

1. Individual Variation Management: The study revealed significant individual differences in learning pace and baseline abilities that could not be fully controlled. Future implementations should incorporate pre-screening assessments to create more homogeneous training groups and develop individualized progression protocols. This would ensure that participants with varying cognitive and physical capabilities receive appropriate instruction intensity and support.

2. Environmental and Seasonal Factors: Data collection occurred across different seasons (spring to summer), potentially influencing participant performance and motivation levels. Implementation programs should account for environmental conditions by providing indoor alternatives during adverse weather and adjusting session timing to optimize participant comfort and attendance rates.

3. Instructor Dependency and Standardization: The study's success was heavily dependent on a single certified instructor, creating potential variability in program delivery. Standardized instructor training protocols, detailed session manuals, and regular quality assurance assessments should be established to ensure consistent program delivery across different settings and instructors.

In future studies, key research gaps identified in this investigation require targeted investigation to advance the field:

1. Long-term Retention and Maintenance Protocols: This study's 12-week duration provides limited insight into the sustainability of balance improvements. Future research should examine benefit retention over 6-12 months post-intervention and investigate optimal maintenance





practice schedules. Studies should determine the minimum practice frequency required to sustain improvements and identify factors predicting long-term adherence.

2. Mechanistic Understanding and Biomarker Development: While balance improvements were clearly demonstrated, the underlying neurophysiological mechanisms remain unclear. Future investigations should incorporate neuroimaging, electromyography, and biomechanical analysis to elucidate specific pathways of improvement. Additionally, research should identify biomarkers that predict intervention responsiveness to enable personalized treatment approaches.

3. Real-world Effectiveness and Implementation Science: This controlled study was conducted in a residential facility with optimal conditions and resources. Future research should examine program effectiveness in diverse community settings, including participants' homes, community centers, and healthcare facilities. Implementation science frameworks should guide studies investigating barriers to adoption, cost-effectiveness, and strategies for sustainable program integration into existing healthcare systems.

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