

A Study on Differences in Static Balance Ability Among Older Women Engaged in Different Types of Exercise

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Abstract: Older women face significantly increased fall risk due to muscle atrophy and vestibular decline. Balance is a critical factor in fall prevention, yet the effects of different exercise modalities on static balance remain unclear. This study aimed to compare the effects of Taiji, square dancing, brisk walking, and no exercise on static balance in older women, providing evidence for developing community-based fall prevention exercise strategies. The study recruited 172 women aged 60 years and older, who were classified into Taiji, square dancing, brisk walking, or no exercise groups based on their exercise habits. The Israeli Tetrax balance tester was used to assess overall stability (ST), weight distribution index (WDI), and fall risk index (FI) across eight postures. The effects of different exercise modalities were explored using analysis of variance and linear regression models. Results: Significant differences in ST were observed across multiple postures (NC, PC, HR, HL, HB) among all four groups ($P < 0.05$). The Taiji group showed the best stability in most postures, followed by square dance;

brisk walking showed only limited improvement. WDI indicated a more even weight distribution in the Taiji group during head rotation conditions. Regression analysis showed that Taiji, square dancing, and brisk walking all significantly reduced fall risk ($P < 0.001$), with Taiji showing the greatest effect. Conclusions: Regular exercise significantly improves static balance and reduces fall risk in older women. Taiji excels under multisensory deprived conditions by enhancing the integration of the visual, proprioceptive, and vestibular systems, warranting prioritized implementation in community settings.

Keywords: Different Exercise Modalities, Older Women, Static Balance Ability, Taiji, Tetrax Balance

Introduction

Falls and related injuries are major public-health problems in older people [1]. Roughly 50 % of community-dwelling adults aged ≥ 65 report at least one fall each year [2], and the incidence continues to

climb as the population ages. Women experience higher rates of falls, injuries and fall-related mortality than men, a disparity linked to more pronounced muscle wasting and accelerated bone loss after menopause [3][4]. Fall risk in women rises markedly from the fifth decade onward. Beyond immediate trauma such as fractures or head injury, falls can trigger “fall phobia”, leading to social withdrawal and reduced quality of life [5]. Annual global health-care expenditure attributable to falls has been estimated at approximately US 50 billion [5], underscoring the urgent need for effective prevention strategies. The risk of falling is closely related to balance ability. Balance control is central to fall prevention.

Dynamic balance governs locomotor tasks such as walking and turning, whereas static balance—the ability to maintain a stable stance—provides the foundation for dynamic control. Older adults experience progressive deterioration in balance control due to factors like diminished neuromuscular coordination, reduced joint mobility, and slowed central processing speed. Postural stability depends on the seamless integration of visual, proprioceptive and vestibular inputs; any degradation within this sensorimotor network elevates fall likelihood [6]. Consequently, improving static balance is a logical target for community interventions aimed at preserving independence and reducing falls.

Among community programmes promoted to older women, Taiji, square dancing and brisk walking are the most common. Taiji, a traditional Chinese mind–body exercise, emphasises slow weight-shifting, axial rotation and controlled lower-limb loading.

These demands elicit eccentric activation of hip-abductor and ankle-dorsiflexor muscles and have been shown to improve joint proprioception and reduce postural sway [7]. After 24 weeks of practice, single-leg-stance time increased by 43 % and COP sway area decreased by 29 % in older adults [8]. Square dancing combines music with multidirectional steps, providing low-level vestibular stimulation and rhythmic lower-limb coordination [9]. Brisk walking improves cardiorespiratory fitness, but its sagittal-plane movement pattern offers limited challenge to frontal or transverse balance control; its effect on multidimensional stability remains contentious [10].

Studies examining the effects of different exercise modalities on static balance in older women remain limited, with inconsistent findings across research. Post-menopausal women lose muscle mass more rapidly than men because of abrupt oestrogen withdrawal, resulting in a steeper trajectory of balance decline [11].

Identifying the most effective exercise for this population is therefore imperative. The present cross-sectional study compared static balance among community-dwelling women who regularly practised Taiji, square dancing or brisk walking, and a non-exercising control group. By relating exercise mode to objective balance outcomes, we aimed to provide an evidence base for designing targeted, feasible and scalable fall-prevention programmes that enhance independence and quality of life in later years.

Methods

Study Population

We conducted a cross-sectional survey at the East Campus of Wuhan University of Technology between October and November 2023. Inclusion criteria: (1) aged ≥ 60 years, (2) free of falls in the preceding 12 months, (3) without documented damage to neurosensory receptors, and (4) free of surgery-related disease within the past year. All participants provided written informed consent and were able to complete the required tests. Exclusion criteria: (1) lower-limb orthopaedic disease, (2) neurological disease, (3) documented impairment of proprioception, vision or vestibular function, and (4) Flat feet or high arches. Of 185 women initially screened, 172 met the criteria and were allocated to one of four groups according to their primary exercise habit during the previous year: Taiji ($n = 46$), square dance ($n = 42$), brisk walking ($n = 44$) or no regular exercise ($n = 40$). Prior to formal testing, all participants were informed of the study's purpose, procedures, and potential risks, and signed informed consent forms. All assessments were performed in the university gymnasium under standardised environmental conditions.

Research Tools

General Information Questionnaire

Self-developed, including age, body mass index (BMI), history of chronic diseases, history of falls, etc.

Tetrax Balance Tester

The Israeli Sunlight Tetrax Balance Diagnostic and Training Device was used

to assess postural stability in various positions. Testing occurred indoors under constant lighting conditions on a level wooden floor (Figure 1). The Tetrax Balance Tester evaluates postural stability by detecting pressure changes across four gravitational points—the forefeet and heels on both sides—while the subject stands on the platform [12]. The operator instructed subjects to stand barefoot on the platform and perform eight maneuvers: NO: Normal position with eyes open; NC: Normal position with eyes closed; PO: Eyes open on pillows; PC: Eyes closed on pillows; HR: Head turned right and eyes closed; HL: Head turned left and eyes closed; HB: Eyes closed head positioned backward 30° ; HF: Eyes closed head positioned forward 30° . Each position must be maintained for 32 seconds [13]. Different postures reveal distinct issues: NO, NC, PO, and PC assess forward-facing postural stability. Poor performance indicates significant visual, proprioceptive, and/or vestibular dysfunction. HR, HL, HB, and HF assess postural issues during head rotation. Poor results suggest potential problems with the neck, vestibular function, and/or the spine and limbs [14]



Figure 1. Static balance testing equipment used in this study

The Tetrax Balance System yields three core metrics—Fall Risk Index (FI), Overall Stability (ST) and Weight Distribution Index (WDI)—that are evaluated against normative data [15]. The Fall-Risk Index, one of the parameters provided by the Tetrax® Balance Function Diagnostic and Training System, quantitatively reflects an individual's balance capacity and offers an intuitive estimate of fall risk. The participant's fall probability ranges from 0 to 100, where 0 indicates no fall risk and 100 indicates a high probability of falling [16].

The Tetrax Stability Index (ST) quantifies overall postural stability; mathematically, it represents the magnitude of postural sway and thus reflects the individual's capacity to compensate for and control postural perturbations [17]. A higher Stability Index indicates poorer stability in the subject; a smaller Stability Index indicates better stability.

A negative value relative to the standard predicts good stability, superior to typical postural stability [18]. The Weight-Distribution Index (WDI) quantifies how body weight is distributed across the system's four force plates; normal values range from 4 to 6. Ideally, 25% of the participant's body weight is borne by each plate. Elevated WDI scores are associated with orthopaedic or neurological pathologies, whereas values approaching zero suggest excessive postural rigidity [19].

Statistical analysis

Statistical analyses were conducted using SPSS 26.0. The continuous variables were expressed as mean $\pm$ standard deviation (Mean $\pm$ SD), while categorical data are

presented as counts (N). Outcome observation indicators were analyzed using one-way analysis of variance (ANOVA). Intergroup comparisons employed the LSD method, and when statistically significant differences were detected, multiple comparisons were conducted using the Dunn-Bonferroni method. Linear regression models were employed to examine associations between different exercise modalities and fall risk. Model 1 served as an unadjusted model, including only the dependent variable (fall risk ratio) and independent variables (exercise modalities). Model 2 adjusted the unadjusted model for age, BMI, chronic disease history, and prior fall history. Statistical significance was determined using a threshold of $p < 0.05$.

Results

The demographic characteristics of the four groups are summarized (Table 1). No statistically significant differences were observed in age, height, weight, or BMI among the groups ($P > 0.05$).

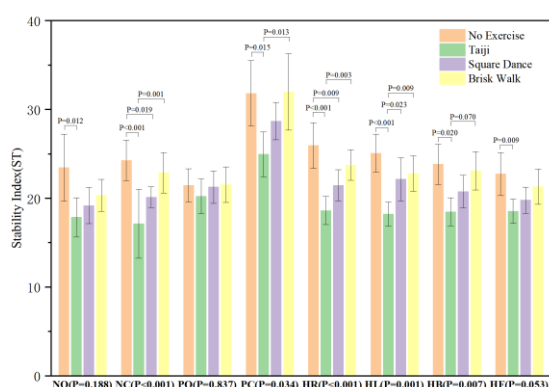
Comparison of Overall Stability (ST) Among Elderly Women in Different Exercise Modes

Significant between-group differences in ST were observed under NC, PC, HR, HL, and HB conditions, prompting post-hoc multiple comparisons (Figure 2). Under PO, no significant group differences were detected ($P > 0.05$). Under NO, the Taiji group showed superior stability compared with the control ($P = 0.012$). Under NC, the control exhibited lower stability than Taiji ($P < 0.001$) and square dancing ($P = 0.019$), and Taiji outperformed brisk walking ($P = 0.001$). Under PC, both the control and

Table1. Baseline Characteristics of Participants

	No Exercise (n = 40)	Taiji (n = 46)	Square Dance (n = 42)	Brisk Walking (n = 44)	F	P
Age (years)	67.897±8.989	69.406±8.12	67.033±6.851	70.828±7.778	11.852	0.188
Height (cm)	156.39±5.567	158.025±5.938	157.61±5.263	155.648±6.889	1.304	0.277
Weight (kg)	57.117±7.1	59.019±7.828	57.767±6.681	58.138±8.02	1.023	0.385
BMI (kg/m ²)	23.49±2.977	23.628±2.986	23.34±2.796	23.917±3.365	0.349	0.790
Data are presented as Mean + SD, One-way ANOVA used across four groups, No significant differences were observed (all p > 0.05)						

brisk walking groups showed lower stability than Taiji ($P = 0.015$ and $P = 0.013$, respectively). Under HR, the control showed lower stability than Taiji ($P < 0.001$) and square dancing ($P = 0.009$), and brisk walking was lower than Taiji ($P = 0.003$). Under HL, Taiji exceeded the control ($P < 0.001$), square dancing ($P = 0.023$), and brisk walking ($P = 0.009$). Under HB, the control and brisk walking groups showed lower stability than Taiji ($P = 0.020$ and $P = 0.070$, respectively); the latter did not reach statistical significance. Under HF, brisk walking was lower than Taiji ($P = 0.009$).

**Figure 2.** Overall Stability Index(ST) Across Postural Conditions, Elderly Women by Exercise Modality

Comparison of Weight Distribution Index (WDI) Among Elderly Women Engaging in Different Exercise Modalities

Comparing the WDI among older women across different exercise modalities revealed that under HR, the WDI in the Taiji group was significantly higher than that in the no-exercise group and the brisk walking group ($p < 0.05$). No statistically significant differences in WDI were observed between groups for other postures (e.g., PO, HF)(Figure 3).

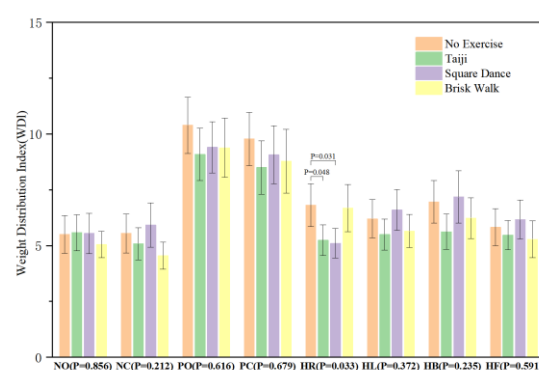
**Figure 3.** Weight Distribution Index(WDI) Across Postural Conditions, Elderly Women by Exercise Modality

Table 2. Linear Regression Analysis of Different Exercise Modalities and Fall Risk in Older Women

Variables	Model1		Model2	
	β (95%CI)	<i>P</i>	β (95%CI)	<i>P</i>
Exercise Routine				
No exercise	0.00 (Reference)		0.00 (Reference)	
Taiji	-27.62 (-30.45 ~ -24.79)**	< .001	-28.39 (-31.11 ~ -25.68)**	< .001
Square dancing	-21.04 (-23.92 ~ -18.16)**	< .001	-20.02 (-22.72 ~ -17.32)**	< .001
Brisk walking	-14.83 (-17.73 ~ -11.93)*	0.003	-16.74 (-19.55 ~ -13.93)**	< .001
CI: Confidence Interval				
Model1: Crude				
Model2: Adjust: age, body mass index (BMI), history of chronic diseases, history of falls				

Comparison of Fall Injury Risk Factors (FI) Among Elderly Women Engaged in Different Exercise Modalities

Given that demographic characteristics may confound fall risk, this study further employed linear regression models to estimate the independent effects of exercise modalities on fall risk. Model 1 included exercise modality alone; Model 2 added age, BMI, chronic disease history and prior falls (Table 2). In Model 1, all three exercise modes were significantly associated with reduced fall risk coefficients: compared with the non-exercising group, the Taiji group had a coefficient 27.62 lower (95% CI: 24.79 ~ 30.45), the square dance group had a 21.04% lower risk (95% CI: 18.16 ~ 23.92), and the brisk walking group had a 14.83% lower risk (95% CI: 11.93 ~ 17.73) ($p < 0.001$). After adjusting for age, BMI, history of falls, and chronic diseases in Model 2, the effects of each exercise

modality remained stable and significant: Taiji group $\beta = -28.39$ (95% CI: -31.11 ~ -25.68), square dance group $\beta = -20.02$ (95% CI: -22.72 ~ -17.32), brisk walking group $\beta = -16.74$ (95% CI: -19.55 ~ -13.93) (all $p < 0.001$), with Taiji showed the largest risk reduction in both models.

Discussion

Overall Stability (ST) Analysis

The Overall Stability coefficient (ST) quantifies postural sway by integrating sway area, amplitude, velocity, and center-of-gravity excursions measured across four force plates, yielding a composite measure of postural steadiness. ST values differed significantly among exercise groups under NC, PC, HR, HL, and HB, However, no significant differences were observed among groups under the PO condition. When visual input was available (PO), participants relied predominantly on vision,

thereby masking modality-specific exercise effects; however, once visual input was removed or head position altered, group differences related to exercise intervention became apparent.

Taiji practitioners demonstrated significantly lower ST values (indicating reduced postural sway) compared with both non-exercising controls and other exercise groups under the NC, PC, HR, HL, and HB conditions. This aligns with findings from multiple studies [20], indicating that Taiji provides broad protective effects for maintaining static postural stability.

The characteristic slow, continuous weight shifts and axial rotations inherent to Taiji require ongoing gaze stabilization and spatial orientation, thereby enhancing visuomotor integration and the efficiency of visual information processing [21]. Long-term practice promotes a shift in sensory weighting toward vestibular and proprioceptive inputs, enabling the maintenance of postural stability in the absence of vision [22].

Moreover, systematic weight transfer, controlled stepping, and variations in joint angles augment proprioceptive feedback from the ankles and knees, improving joint position sense and lower-limb sensorimotor sensitivity. These adaptations contribute to improved balance control under conditions of visual deprivation or on unstable surfaces [23]. Additionally, repeated head turning, tilting, and flexion movements provide cyclical vestibular stimulation, facilitating faster restoration of center-of-gravity alignment during head perturbations.

Research by Wang Rui et al. (2016) similarly indicated that 16 weeks of regular Taiji practice enhances vestibular-trunk coordination and fall prevention capabilities [24].

The square-dance group also exhibited significantly lower ST values than the control group under the NC and HR conditions. In the NC posture, visual input is eliminated, requiring individuals to rely primarily on the vestibular and proprioceptive systems to maintain balance. The rhythmic, multidirectional stepping patterns performed to music necessitate continuous adjustments of the trunk and limbs, which are postulated to sharpen proprioceptive acuity and fine-tune the vestibulospinal reflex[25].

During the HR condition, rightward head rotation stimulates the semicircular canals; the frequent head turns and spins practiced in square dancing provide repeated vestibular stimulation, thereby improving compensatory responses to changes in head position.

Under the HR condition, square dancers exhibited greater postural steadiness than non-exercisers, suggesting enhanced lower-limb coordination and integrated vestibular–trunk–leg motor control.

In contrast, brisk walking was associated with significantly higher ST values than Taiji under the PC, HR, HL, HB, and eyes-open foam surface (HF) conditions. The predominantly sagittal-plane movement pattern of walking provides minimal challenge to cervical and vestibular systems; consequently, when rapid or off-axis head movements are required, brisk walkers may demonstrate diminished head–

trunk stabilization, resulting in increased postural sway and elevated fall risk[26].

Weight Distribution Index (WDI) Analysis

Further analysis revealed that, under the eyes-closed right-head-rotation (HR) condition, both the non-exercise and brisk-walking cohorts exhibited abnormally elevated weight-distribution indices (WDI > 6), significantly exceeding the Taiji cohort whose WDI converged on the optimal range (4–6). When visual input was withdrawn and vestibular perturbation was induced by head rotation, the former groups were unable to stabilise the centre of mass via effective multidirectional weight transfer; instead, they displayed anomalous load concentration on one or two force plates. This pattern accords with prior evidence that “high WDI reflects orthopaedic or neurological compensatory control deficits.” In contrast, the Taiji cohort, after prolonged whole-body integration training emphasising “explicit distinction between insubstantial and substantial, spiral and torsional forces,” achieved balanced weight distribution across four vectors through a kinematic chain linking ankle–knee–hip–trunk–neck. This strategy precluded both the compensatory load concentration indexed by supra-normal WDI and the postural rigidity indexed by near-zero WDI. Taiji-induced modulation of heart-rate variability and autonomic tone may further attenuate cardio-autonomic fluctuation during eyes-closed head rotation [27], indirectly enhancing postural stability. Li et al.'s research additionally demonstrated that different Taiji stances exert distinct effects on cortical electrical activity: “intention-

driven” movements selectively augment low-frequency EEG power, while action–cognition coupling may potentiate central regulation of asymmetrical stance[28]. These data furnish a plausible neural substrate for the optimal weight distribution observed in the Taiji group under proprioceptive–vestibular challenge. The findings converge with previous reports indicating that Taiji not only ameliorates balance in older adults but also reduces fall risk through multi-system coordination [29][30]. Sagittal-plane straight-line walking is insufficient to enhance coronal- and transverse-plane dynamic control, whereas physical inactivity further aggravates weight-distribution imbalance. Multi-planar, multi-articular, rhythmic weight-shifting inherent in Taiji constitutes the critical determinant for improving dynamic weight distribution and reducing fall risk in older women exposed to complex perturbations.

Fall Risk Index (FI) Analysis

The Fall Risk Index (FI), derived from the eight-standard-posture Tetrax Balance Function Diagnostic and Training System, quantifies fall risk; higher values denote poorer balance. The no exercise cohort exhibited the highest FI, indicating that physical inactivity markedly compromises postural control and lower-limb stability. In contrast, Taiji, square-dance, and brisk-walking groups all displayed significantly lower FI, reaffirming the central role of systematic exercise in mitigating fall risk. These results accord with a recent systematic review and meta-analysis of Taiji-based fall-prevention programmes [31].

Although brisk walking surpassed inactivity, its FI exceeded that of Taiji. This discrepancy likely reflects the predominance of sagittal-plane motion in brisk walking, which preferentially trains anteroposterior centre-of-mass control but provides limited challenge to coronal- and transverse-plane dynamic balance [32]; consequently, the multidimensional sensory re-weighting required for complex equilibrium is insufficiently engaged. Square dance, incorporating frequent horizontal-plane rotations, lateral weight shifts, and cross-steps, together with rapid rhythmic transitions, accelerates neuromuscular adaptation to multidirectional perturbations, thereby lowering FI.

Taiji's slow, continuous alternation between “empty” and “full” stances—e.g., “Hug Knee and Twist Step” to “Play Pipa”—demands sustained eccentric activation of lower-limb stabilisers, augmenting joint proprioceptive inflow. Multi-planar rotational sequences such as “Cloud Hands” concurrently train vestibulo-spatial orientation [33].

This integrated neuromuscular conditioning enhances static postural control, enabling rapid compensatory recruitment during sudden destabilization and markedly reducing fall probability. Gu Jie et al. (2025) further demonstrated that Taiji establishes an unbroken kinetic chain through synergistic lower-extremity support and upper-extremity traction, strengthening global neural integration of balance and improving both perturbation resistance and recovery capacity[34].

Thus, for older women, exercise modalities incorporating multi-directional, multi-planar demands (e.g., Taiji or square dance) appear superior to unidirectional activities such as brisk walking for fall-risk reduction.

The study systematically compared Taiji, square dance, brisk walking, and no exercise across eight Tetrax postures. Taiji and square dance outperformed brisk walking and the sedentary condition on FI, overall stability index, and weight-distribution coefficient. Strengths include a large sample, absence of baseline inter-group differences, and rigorous control of confounders. By combining multiple stances with sensory-deprivation challenges, the protocol comprehensively evaluated the contributions of visual, vestibular, and proprioceptive systems, overcoming the limitations of earlier single-metric assessments.

Cross-sectional design, however, precludes causal inference. Participants were recruited exclusively from one Wuhan university community, yielding a socio-culturally homogeneous cohort that limits external validity. Group assignment relied solely on self-reported “most frequent activity during the past year”, without objective documentation of intensity, frequency, or duration; total daily physical activity was likewise unquantified, obscuring dose–response relationships. While the findings inform community-based fall-prevention programmes for older women, randomised controlled trials with long-term follow-up and multi-centre replication are required to validate and refine intervention strategies.

Conclusion

This cross-sectional study systematically examined the associations between habitual Taiji, square-dancing, brisk-walking, or no exercise and static balance performance in community-dwelling older women. Regular exercise significantly improved static balance and reduced fall risk; Taiji, in particular, optimised performance under multisensory-deprivation conditions by enhancing visual, proprioceptive, and vestibular integration. It is therefore recommended as the preferred modality for community-based fall-prevention programmes.

Conflict of Interest

The authors declare that there is no duality of interest associated with this paper.

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Ethical Compliance

This study involves human participants and ethical approval was provided by the Ethics Committee of Wuhan Institute of Physical Education (No.:2025119_). Participants gave informed consent to participate in the study before taking part.

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