SIN-CHN SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2025, 22(4), 1574.
https://doi.org/10.62617/mcb1574

Article

Biomechanical analysis of Yi Jin Jing on the effects of muscle strength, gait characteristics and anti-fall risk in elderly males

Sensen Gong[1], Yaoyao Huang[2], Feilong Wu[3,4,*], Juan Jiang[5,*]

[1] Department of Physical Education, Shenzhen Polytechnic University, Shenzhen 518055, China
[2] Physical Education Center, Nanfang College Guangzhou, Guangzhou 510970, China
[3] Department of Medical Psychology, Air Force Medical University, Shaanxi 710032, China
[4] College School of Sports Science, Shenyang Normal University, Shenyang 110034, China
[5] School of Martial Arts and Dance, Shenyang Sport University, Shenyang 110102, China
*** Corresponding authors:** Feilong Wu, 201607025@xaau.edu.cn; Juan Jiang, Jiangjuan@syty.edu.cn

CITATION

Gong S, Huang Y, Wu F, Jiang J. Biomechanical analysis of Yi Jin Jing on the effects of muscle strength, gait characteristics and anti-fall risk in elderly males. Molecular & Cellular Biomechanics. 2025; 22(4): 1574. https://doi.org/10.62617/mcb1574

ARTICLE INFO

Received: 15 February 2025
Accepted: 7 March 2025
Available online: 12 March 2025

Abstract: This study examines the effects and intervention outcomes of Yi Jin Jing and Tai Chi on lower limb muscle strength, gait characteristics, and fall risk among elderly males from a biomechanical perspective. **Methods:** A total of 96 participants were randomly assigned to the Yi Jin Jing Group (YJG) and the Tai Chi Group (TCG), with 48 individuals in each group. The study employed lower limb muscle strength testing, gait analysis, fall index assessment, the Berg Balance Scale (BBS), and the Fugl-Meyer Assessment Scale (FMA) to evaluate the differences in lower limb muscle groups, gait characteristics, fall risk, dynamic balance ability, and sports function between two groups of elderly males. **Results:** The relative peak torque of the three major joint muscle groups in the lower limbs of the YJG and TCG during isokinetic concentric contractions at 60°/s and 120°/s exhibited a significant increase compared to pre-intervention levels, with the most pronounced changes observed in the ankle joint muscle group (60°/s: Cohen's d = 1.68/0.62, 95% CI: [1.16 to 2.20, 0.16 to 1.08]; 120°/s: Cohen's d = 1.22/1.66, 95% CI: [1.16 to 2.20, 0.16 to 1.08]; $P < 0.05$). Notable differences were also identified in the gait and fall index (30.32 ± 9.64 vs. 57.23 ± 6.67; 31.72 ± 7.42 vs. 46.67 ± 5.93; Cohen's d = 1.67, 95% CI: [−2.27 to −1.21]; 51.19 ± 4.72 vs. 36.50 ± 3.94; 50.58 ± 3.12 vs. 43.78 ± 4.41, Cohen's d = −1.74, 95% CI: [−2.27 to −1.21]; $P < 0.05$). Significant differences were also observed in the BBS and FMA scores (BBS: 51.27 ± 3.57 vs. 43.63 ± 4.09, Cohen's d = 1.99, 95% CI: [1.43 to 2.54]; FMA: 65.76 ± 5.37 vs. 62.86 ± 3.27, Cohen's d = 0.65, 95% CI: [1.43 to 2.54]; $P < 0.05$). Furthermore, YJG demonstrated a significant advantage over TCG. These changes in parameters suggest enhanced lower limb strength, improved gait stability, and better dynamic balance in elderly males, effectively reducing the risk of falls. Conclusion: Both the YJG and TCG interventions can significantly improve lower limb muscle strength, dynamic balance, gait ability, and overall motor function in elderly males. However, the efficacy of YJG is notably superior to that of TCG. This finding provides valuable insights and important clinical implications for fall prevention strategies in the elderly population.

Keywords: lower limb muscle strength; gait characteristics; dynamic equilibrium; sports function; anti-fall ability

1. Introduction

With the increasingly severe global aging population, the health issues faced by the elderly have garnered significant international attention [1]. Falls represent a common health threat in the daily lives of older adults, and the incidence and associated risk factors were gradually receiving increased scrutiny [2]. According to statistics from the World Health Organization (WHO), an estimated 684,000 individuals worldwide die from falls each year, with over 80% of these fatalities occurring in low- and middle-income countries [3]. Fall-related injuries not only impair the daily living abilities of elderly individuals but also impose substantial burdens on families and society [4].

Muscle loss refers to a syndrome characterized by a sustained decline in skeletal muscle mass, strength, and function [5], which can pose significant threats to life and health [6]. According to Guangming Net, from ages 40 to 70, the body's muscle mass decreases by 8% every decade, culminating in a total loss of 30% by age 60. After age 70, muscle mass decreases by 15% every ten years [7]. Moreover, the decline in muscle strength and abnormal gait among the elderly are key factors contributing to an increased risk of falls [8]. This is primarily due to aging and a lack of exercise, which lead to muscle atrophy [9]. Consequently, there is a reduction in muscle volume, the number of muscle fibers, and muscle strength, accompanied by a weakening of neural regulatory functions. Ultimately, this results in a decline in proprioceptive function and a decrease in body balance ability, thereby increasing the fall risk index [10,11]. Furthermore, factors such as gait stability, stride length, and step frequency directly affect the walking ability of the elderly. Impaired walking ability further jeopardizes the safety of the elderly [12]. Additionally, these factors exhibit a positive correlation with falls among this demographic [13]. Research indicates that unstable gait is one of the primary causes of falls in the elderly [14]. Therefore, it is particularly important to pursue effective interventions aimed at enhancing muscle strength and improving gait stability in older adults.

Exercise intervention, as a non-pharmacological approach, is one of the most widely utilized methods for promoting health among the elderly population [15]. Such as Tai Chi, Baduanjin, Yoga, and resistance training have been shown to positively impact muscle strength and gait stability in older adults [16,17]. Studies have demonstrated that appropriate exercise can effectively delay muscle atrophy, enhance muscle strength, and improve gait stability, thereby further enhancing balance in the elderly population and reducing the risk of falls [18]. Furthermore, exercise promotes the functions of the vestibular, visual, and proprioceptive systems, which contributes to improved posture control and balance maintenance [19,20]. Additionally, exercise fosters neuronal connections, enhances memory and concentration, and aids the brain in better processing and integrating information [21]. This, in turn, strengthens the nervous system's ability to control limbs, resulting in more precise orientation and balance control, ultimately reducing the risk of falls [22]. The Yi Jin Jing, a traditional fitness method, aims to enhance the body's flexibility, coordination, core muscle strength, and stability through its unique movements and breathing techniques. In particular, the positional adjustments and movement exercises inherent to Yi Jin Jing are effective in improving muscle strength, joint flexibility, and balance ability [23]. Although existing studies have explored the potential benefits of Yi Jin Jing and Tai Chi in reducing the risk of falls among the elderly, most of these studies are limited to the assessment of single indicators and lack comprehensive analysis. For instance, some research has shown through gait analysis that Tai Chi practice can significantly improve gait symmetry and stability in older adults; however, there is less emphasis on evaluating muscle strength and fall risk indices [24]. Additionally, some studies have focused on the effects of Yi Jin Jing in enhancing muscle strength among the elderly, but there is a notable absence of specific analyses regarding gait characteristics and fall risk [25]. Therefore, current research has not yet comprehensively elucidated the specific effects of Yi Jin Jing and Tai Chi on muscle strength, gait characteristics, and fall risk in older adults. In particular, there is a significant lack of comparative studies on the intervention effects of Yi Jin Jing and Tai Chi, which necessitates further in-depth exploration to address this gap.

This study aims to investigate the effects of Yi Jin Jing and Tai Chi on lower limb muscle strength, gait characteristics, and fall risk indices in elderly men through biomechanical analysis. Specifically, based on primary outcome measures (muscle strength testing, gait analysis, and fall risk assessment) and secondary outcome measures (the Berg Balance Scale and the Fugl-Meyer Assessment Scale), this study will systematically explore the effects of Yi Jin Jing and Tai Chi practice on lower limb muscle strength, gait parameters, and fall risk in elderly men, thereby addressing gaps in previous research. Through this research, we aim to provide a scientific basis for elderly healthcare, promote the development of personalized exercise programs, and effectively prevent the risk of falls among elderly men, which holds significant clinical reference value.

2. Materials and methods

2.1. Baseline information

From 11 to 18 November 2024, a total of 114 retired men aged 60 to 70 were recruited from two elderly care centers in Shenyang, China. Based on the established inclusion and exclusion criteria, as well as the specific content and requirements of the experiment, 96 elderly men ultimately participated in this study. The participants were randomly assigned to the Yi Jin Jing Group (YJG) or the Tai Chi Group (TCG), with 48 individuals in each group. The experiment was conducted from 25 November 2024 to 19 January 2025, spanning a duration of eight weeks, with five sessions each week, each lasting 50 min. Prior to the formal intervention, both groups underwent five days of intensive training to familiarize the participants with the fundamental movements of Yi Jin Jing and the eight-form Tai Chi techniques. Following the training, all participants rested for two days before commencing the formal intervention. The specific intervention movements for the two groups were as follows:

1) Yi Jin Jing: The YJG implemented the Yi Jin Jing program, a national fitness initiative promoted by the General Administration of Sport of China. The specific movements included are the First Posture of Weituo Presenting the Pestle, the Second Posture of Weituo Presenting the Pestle, the Third Posture of Weituo Presenting the Pestle, the Posture of Picking Stars and Changing the Dipper, the Posture of Pulling Nine Oxen by Their Tails Backwards, the Posture of Extending Claws and Displaying Wings, the Posture of Nine Ghosts Pulling the Sabre, the Posture of Three Plates Falling to the Ground, the Posture of the Green Dragon Stretching Its Claw, the Posture of the Crouching Tiger Pouncing on Its Prey, the Posture of Bowing, and the Posture of Swinging the Tail. Six physical education

teachers, each with a minimum of ten years of experience in teaching Yi Jin Jing, supervised and guided the participants. During the practice, the teachers instructed the participants to focus on the standardization of movements, the coordination of breathing, and the method of exerting force. For instance, when performing the 'Dao Zhua Jiu Niu Wei Shi,' it is crucial to emphasize the continuity and softness of the movements, the shifting of the center of gravity, the coordination of exhalation, toe gripping, the twisting of the upper limbs and waist, and the maintenance of body stability and responsiveness.

2) Tai Chi: The TCG participated in an intervention involving the 8-form Tai Chi, which comprises specific movements including the Commencing Form, Parting the Wild Horse's Mane on Both Sides, White Crane Spreads Its Wings, Brushing Knee and Twisting Step on Both Sides, Playing the Lute, Repulse Monkey on Both Sides, Grasping the Bird's Tail on the Left Side, Cross Hands, and Closing Form. This practice was supervised by six physical education teachers, each possessing a minimum of 10 years of experience in Tai Chi instruction. The teachers emphasized the importance of movement continuity and fluidity, as well as the shifting of the center of gravity. For example, during the "Parting the Wild Horse's Mane on Both Sides" movement, participants were guided to rotate their limbs slowly around the waist as the axis, ensuring a smooth transition of the body's center of gravity.
3) Inclusion criteria: (1) The study focuses on male retirees aged 60 and above who meet specific criteria for participation. (2) Participants must be assessed for fall risk using clinical methods and must fulfill the comprehensive assessment criteria for fall risk in the elderly as defined by T/CGSS 014-2020 [26]. (3) Participants should exhibit clear mental faculties, with no identified cognitive dysfunction, allowing them to comprehend the research content and engage fully in the study. (4) Participation in this survey is voluntary, with all participants having signed an informed consent form, and they must be willing to consistently cooperate with researchers throughout the trial intervention. (5) Participants should have no history of practicing Yi Jin Jing or any other regular exercise routines.
4) Exclusion criteria: (1) long-term bed rest or significant lack of mobility; (2) audiovisual dysfunction that impairs the ability to comprehend researchers' instructions; (3) individuals with trauma that restricts participation in physical activities or those with severe osteoporosis; (4) participants who voluntarily withdraw from the study for any reason during the research process.
5) Termination criteria include the following: (1) occurrence of serious adverse reactions during the experiment; (2) poor compliance, characterized by a lack of adherence to the exercise regimen outlined in the experimental plan; (3) individuals deemed unsuitable for other reasons to continue their participation in the experiment.

In accordance with the Declaration of Helsinki, 96 informed consent statements from the participants and their families were signed and subsequently approved by the Academic Ethics Committee of the Sports Department at Shenzhen Vocational and Technical University (Approval No.: SZTY202401021).

2.2. Measurement indicators

2.2.1. Main outcome measures

(1) Lower limb muscle strength test: The lower limb muscle strength test utilized the CON-TREX isokinetic feedback biomechanical testing and training system developed by German PHSIOMED GmbH. This system was employed to assess the dynamic contraction muscle strength of the hip, knee, and ankle joints through both slow and fast contractions at speeds of 60°/s and 120°/s, respectively. The test indicators included the maximum relative peak torque of centripetal and centrifugal contractions of the lower limb joints at these two speeds. It is crucial to adhere strictly to the guidelines of the CON-TREX force measurement and rehabilitation system throughout the testing process, and participants should refrain from engaging in intense exercise prior to the test [27–29].

(2) Gait test: The gait test was conducted using the Vicon operating system produced by Vicon Motion Systems Ltd in the UK, utilizing the MX13 camera with a sampling frequency of 120 Hz. Gait assessments were performed separately for the two groups of subjects. A total of 49 marker balls were employed in accordance with the calibration requirements of the equipment. All subjects wore experimental clothing and comfortable shoes, and the tests were conducted under the guidance of the experimenter. The kinematic indicators of gait selected for this study included step size, pace speed, the percentage of time spent in the standing and swinging phases, the torsion angles of the shoulder and hip axes, trunk left and right shaking amplitude, and trunk forward angle, among others [30,31].

(3) Fall index test: The fall index test utilizes the Tetrax balance function diagnosis and training system, developed by Sunlight Medical in Israel, to assess foot pressure distribution (vertical pressure in both the anterior and posterior directions) while standing. The system processes the incoming data using automated computer analysis software. Ultimately, the subject's fall index is calculated, with a range of 0 to 100. This index categorizes fall risk as follows: low (0–36), medium (37–58), and high (59–100). A lower index value indicates a reduced probability of falling [32,33].

2.2.2. Secondary outcome measures

(1) The Berg Balance Scale (BBS): The BBS was utilized in this study to assess the balance abilities of elderly males engaged in Yijin Jing and 8-style Tai Chi exercises. All participants completed 14 tasks, which included sitting to standing, standing independently, and standing with eyes closed. These tasks encompassed movements such as transitioning between sitting and standing, maintaining posture, engaging in physical activities, and walking. Each task was scored according to a specific 0–4 scoring criterion, and the scores from all 14 tasks were summed, yielding a total score ranging from 0 to 56 points. A higher score indicates better balance ability and a lower risk of falling. Generally, a score below 40 points suggests an increased risk of falling [34,35].

(2) The Fugl-Meyer Assessment Scale (FMA): FMA was employed to evaluate the effects of Yijin Jing and 8-style Tai Chi on the sports function of elderly males, utilizing the Chinese simplified version of the FMA. This scale encompasses upper limb sports functions, which include five dimensions: shoulder movement, elbow movement, forearm movement, wrist movement, and hand movement, as well as lower

limb sports function, comprising four dimensions: hip movement, knee movement, ankle movement, and toe movement. Each specific item within these dimensions was scored on a scale of 0 to 2, depending on the completion of the movement. The scores for upper and lower limb movements are then summed to obtain a total score, which ranges from 0 to 100 points. The scoring segments were categorized as follows: low segment (0–33 points), middle segment (34–66 points), and high segment (67–100 points). A higher total score indicates better sports function in the patient [36].

2.3. Data statistical analysis

Data analysis was conducted using SPSS version 25.0 software. For normally distributed measurement data, the mean ± standard deviation (M ± SD) was used for representation, while enumeration data were expressed as percentages. In terms of statistical testing methods, independent sample *t*-tests were employed to assess the differences between the YJG and the TCG, while paired *t*-tests were utilized to evaluate the differences and changes within two groups. Through between-group and within-group assessments, we can effectively clarify the changes in lower limb muscle strength, gait characteristics, and fall risk resistance in elderly males, as indicated by the primary outcome measures (muscle strength testing, gait analysis, and fall risk assessment) and secondary outcome measures (Berg Balance Scale and Fugl-Meyer Assessment Scale). By calculating Cohen's *d* value, we evaluated the effect sizes of the primary and secondary outcome measure parameters post-intervention in both groups (Cohen's *d* value ranges from −1 to 1; values greater than 1 indicate a positive and significant effect). Statistical significance was defined as $P < 0.05$.

3. Results

3.1. Baseline data analysis

Table 1. General data comparison of baseline characteristics between two groups (*M* ± SD).

General Information		YJG (n = 48)	TCG (n = 48)	P
Age		66.7 ± 4.22	64.1 ± 3.61	0.36
Height (cm)		171.92 ± 6.73	172.12 ± 7.12	0.88
Weight (kg)		68.43 ± 7.81	69.56 ± 6.34	0.68
Number of falls (within six months)		8.47 ± 3.23	7.63 ± 3.36	0.76
Do you have a history of surgery (%)	Yes	17 (35.41)	14 (29.17)	0.43
	No	31 (64.59)	34 (70.83)	

The study evaluated the general characteristics of two groups, including age, height, weight, the number of falls over a six-month period, and surgical history. Based on the baseline data, the following results were observed: age (YJG: 66.7 ± 4.22 years; TCG: 64.1 ± 3.61 years; P = 0.36); height (YJG: 171.92 ± 6.73 cm; TCG: 172.12 ± 7.12 cm; P = 0.57); weight (YJG: 68.43 ± 7.81/kg; TCG: 69.56 ± 6.34/kg; P = 0.68); number of falls in six months (YJG: 8.47 ± 3.23/times; TCG: 7.63 ± 3.36/times; P = 0.76); and surgical history (YJG: 35.41%; TCG: 29.17%). The comparison of baseline characteristics indicated no statistically significant differences between the two groups across various indicators ($P > 0.05$), suggesting that the two groups are comparable in their baseline characteristics (**Table 1**).

3.2. Lower limb muscle strength assessment

The results in **Table 2** indicate that at both 60°/s and 120°/s, the YJG exhibited superior muscle strength across multiple joints compared to the TCG, particularly in the extensors and flexors of the hip and ankle joints. In the 60°/s test, the YJG (HE: 281.68 ± 43.52 vs. 350.18 ± 41.42; HF: 187.39 ± 24.21 vs. 211.35 ± 31.41; $P < 0.05$) and the TCG (HE: 283.72 ± 39.26 vs. 318.51 ± 3 6.83; HF: 186.50 ± 23.44 vs. 191.12 ± 28.32; $P < 0.05$) demonstrated significant differences within their respective groups regarding the hip joint muscle groups. Post-test comparisons between the groups further revealed that the YJG exhibited a more pronounced improvement effect on the hip joint muscle groups than the TCG (Cohen's d = 0.81/0.68, 95.0% [13.73 to 49.61, 6.56 to 33.90], $P < 0.05$), indicating a moderate effect size. Regarding the knee joint muscle groups, both the YJG (KE: 232.41 ± 20.31 vs. 298.61 ± 22.76; KF: 122.34 ± 14.16 vs. 148.58 ± 16.43; $P < 0.05$) and the TCG (KE: 234.25 ± 19.27 vs. 297.27 ± 20.43; KF: 122.36 ± 14.28 vs. 146.52 ± 16.36; $P < 0.05$) showed significant differences within their groups, but no significant difference was observed between the two groups (Cohen's d = 0.06/0.13, 95.0% [−8.55 to 11.23, −5.43 to 9.55], $P >$ 0.05), indicating a very small effect size, which suggests that the two interventions have relatively similar effects on the knee joint muscle groups. In terms of ankle joint muscle groups, both the YJG (AE: 39.28 ± 6.70 vs. 52.75 ± 6.21; AF: 133.37 ± 12.64 vs. 148.23 ± 15.12; $P < 0.05$) and the TCG (AE: 38.62 ± 7.13 vs. 43.19 ± 5.14; AF: 132.26 ± 11.15 vs. 139.37 ± 13.27; $P < 0.05$) exhibited significant within-groups differences, demonstrating a larger effect in flexors and a moderate effect in extensors (Cohen's d = 1.68/0.62, 95.0% [1.16 to 2.20, 0.16 to 1.08], $P < 0.05$). Furthermore, the company was committed to continuously enhancing the quality of its products and services to meet the diverse needs of its customers. In terms of ankle joint muscle groups, significant differences were observed both within and between the YJG (AE: 39.28 ± 6.70 vs. 52.75 ± 6.21; AF: 133.37 ± 12.64 vs. 148.23 ± 15.12; $P < 0.05$) and the TCG (AE: 38.62 ± 7.13 vs. 43.19 ± 5.14; AF: 132.26 ± 11.15 vs. 139.37 ± 13.27; $P < 0.05$). Notably, a larger effect size was noted in the flexor muscles, while a moderate effect size was observed in the extensor muscles (Cohen's d = 1.68 / 0.62, 95.0% [1.16 to 2.20, 0.16 to 1.08], $P < 0.05$). In the 120°/s test, both the YJG (HE: 235.12 ± 19.67 vs. 291.53 ± 17.47; HF: 121.43 ± 26.68 vs. 152.38 ± 27.28; $P < 0.05$) and the TCG (HE: 234.45 ± 20.14 vs. 267.09 ± 19.82; HF: 120.84 ± 23.12 vs. 136.18 ± 22.42; $P < 0.05$) demonstrated significant improvements in hip muscle groups. Post-test comparisons further revealed that the YJG had a significantly greater effect on the enhancement of hip muscle groups compared to the TCG (Cohen's d = 1.31/0.65, 95.0% [0.19 to 1.11, 0.19 to 1.11], $P < 0.05$), with a larger effect observed on extensors and a moderate effect on flexors. Regarding knee muscle groups, both the YJG (KE: 129.63 ± 15.75 vs. 146.69 ± 17.43; KF: 92.19 ± 14.14 vs. 107.36 ± 14.76; $P < 0.05$) and the TCG (KE: 130.23 ± 16.58 vs. 144.15 ± 16.27; KF: 92.17 ± 15.73 vs. 106.23 ± 13.82; $P < 0.05$) exhibited significant within-group changes; however, there was no significant difference between the groups (Cohen's *d* = 0.15/0.08, 95.0% [−0.30 to 0.60, −0.37 to 0.53], $P > 0.05$), indicating a very small effect size. This suggests that the impact of both interventions on knee muscle groups is relatively comparable. In terms of the muscle groups surrounding the ankle joint, both the YJG (AE: 22.16 ± 4.01 vs. 32.91 ± 5.12; AF: 62.34 ± 6.18 vs. 82.89 ± 9.73; $P < 0.05$) and the TCG (AE: 22.23 ± 4.09 vs. 25.94 ± 6.26; AF: 61.63 ± 9.78 vs. 70.26 ± 10.33; $P < 0.05$) exhibited significant differences both within and between groups (Cohen's *d* = 1.68/0.62, 95.0% [1.16 to 2.20, 0.16 to 1.08], $P < 0.05$), indicating a large effect size. This suggests that the Yi Jin Jing intervention was significantly more effective than Tai Chi in enhancing muscle strength around the ankle joint. At angular velocities of 60°/s and 120°/s, with the exception of the knee joint muscle groups, the analysis results were largely consistent with previous studies [37], indicating that Yi Jin Jing was significantly more effective than Tai Chi in improving lower limb muscle strength, particularly in the hip and ankle joint muscle strength. (**Figures 1** and **2**).

Table 2. Changes in lower limb muscle groups at 60°/s and 120°/s were constant-centered at 60°/s and 120°/s (*M* ± SD).

Indicator	**Joint**	**Muscle group**	**YJG (*n* = 48）**		**TCG (*n* = 48)**		**Cohen's *d***	**95.0% CI**
			Pre	**Post**	**Pre**	**Post**		
60°/s	Hip	Extensor (HE)	281.68 ± 43.52	350.18 ± 41.42#	283.72 ± 39.26	318.51 ± 36.83#*	0.81	13.73 to 49.61
		Flexor (HF)	187.39 ± 24.21	211.35 ± 31.41#	186.50 ± 23.44	191.12 ± 28.32#*	0.68	6.56 to 33.90
	Knee	Extensor (KE)	232.41 ± 20.31	298.61 ± 22.76#	234.25 ± 19.27	297.27 ± 20.43#	0.06	−8.55 to 11.23
		Flexor (KF)	122.34 ± 14.16	148.58 ± 16.43#	122.36 ± 14.28	146.52 ± 16.36#	0.13	−5.43 to 9.55
	Ankle	Extensor (AE)	39.28 ± 6.70	52.75 ± 6.21#	38.62 ± 7.13	43.19 ± 5.14#*	1.68	1.16 to 2.20
		Flexor (AF)	133.37 ± 12.64	148.23 ± 15.12#	132.26 ± 11.15	139.37 ± 13.27#*	0.62	0.16 to 1.08
120°/s	Hip	Extensor (HE)	235.12 ± 19.67	291.53 ± 17.47#	234.45 ± 20.14	267.09 ± 19.82#*	1.31	0.81 to 1.81
		Flexor (HF)	121.43 ± 26.68	152.38 ± 27.28#	120.84 ± 23.12	136.18 ± 22.42#*	0.65	0.19 to 1.11
	Knee	Extensor (KE)	129.63 ± 15.75	146.69 ± 17.43#	130.23 ± 16.58	144.15 ± 16.27#	0.15	−0.30 to 0.60
		Flexor (KF)	92.19 ± 14.14	107.36 ± 14.76#	92.17 ± 15.73	106.23 ± 13.82#	0.08	−0.37 to 0.53
	Ankle	Extensor (AE)	22.16 ± 4.01	32.91 ± 5.12#	22.23 ± 4.09	25.94 ± 6.26#*	1.22	0.73 to 1.71
		Flexor (AF)	62.34 ± 6.18	82.89 ± 9.73#	61.63 ± 9.78	70 26 ± 10.33#*	1.26	0.77 to 1.75

Note: *$P < 0.05$ between groups; #$P < 0.05$ within groups.

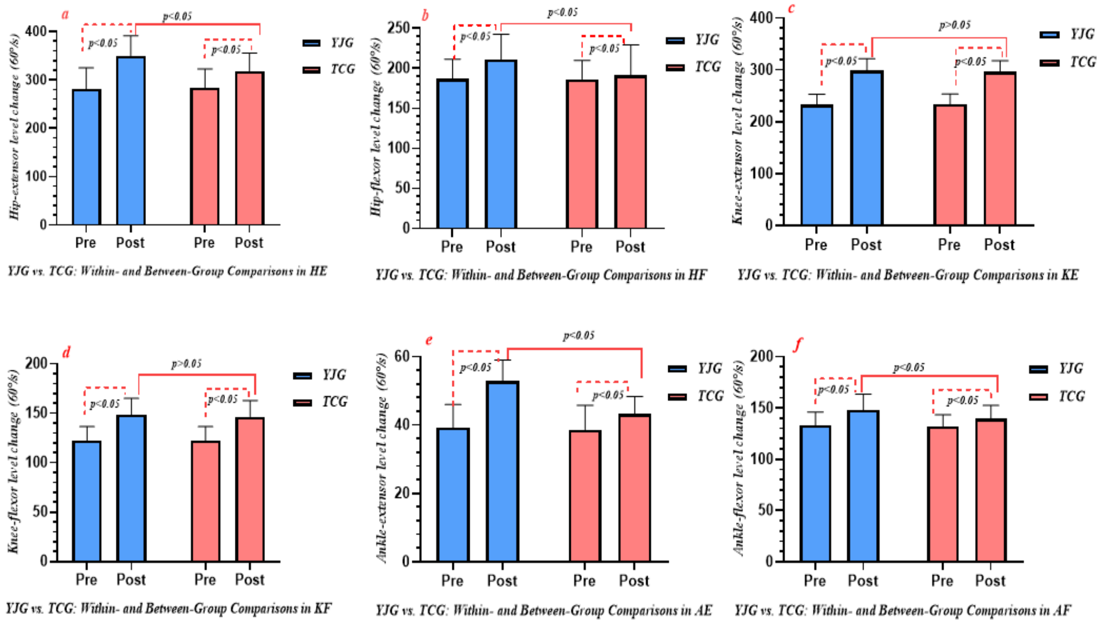

Figure 1. YJG vs. TCG: Changes in extensor and flexor muscle of hip, knee, and ankle at 60°/s in two groups.

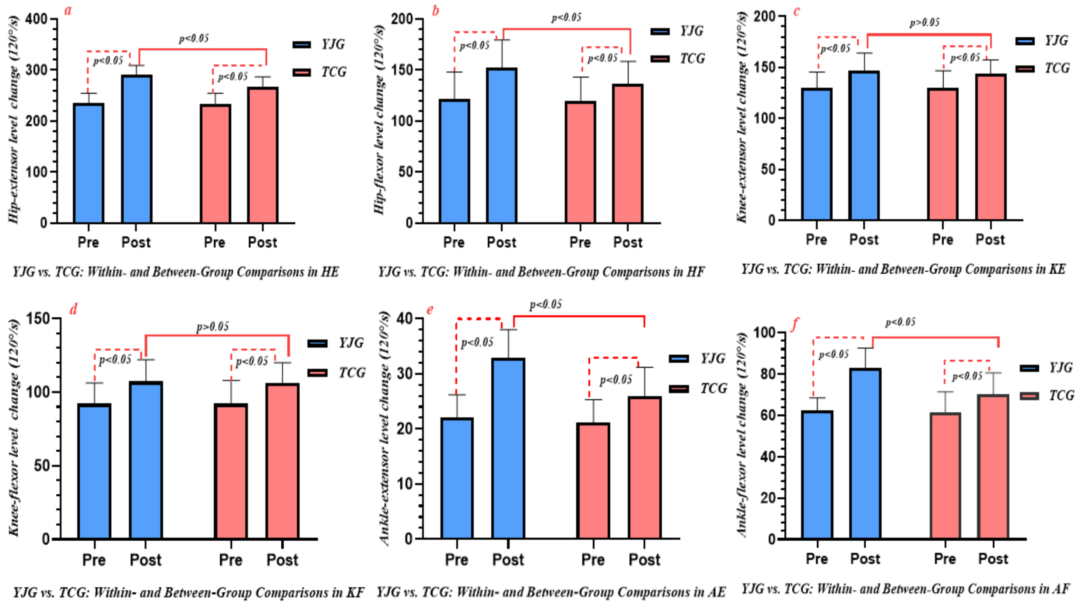

Figure 2. YJG vs. TCG: Changes in extensor and flexor muscle of hip, knee, and ankle at 120°/s in two groups.

3.3. Gait and fall index assessment

The data presented in **Table 3** indicate that there were significant differences in step length (cm) between the YJG and the TCG in both the anterior and posterior measurements (30.32 ± 9.64/31.72 ± 7.42 < 57.23 ± 6.67 > 46.67 ± 5.93, Cohen's d = 1.67, 95.0% [1.15 to 2.19], $P < 0.05$). Additionally, walking speeds (1.10 ± 0.33/1.09 ± 0.34 < 1.22 ± 0.42 > 1.12 ± 0.37, Cohen's d = 0.25, 95.0% [−0.20 to 0.70], $P < 0.05$), standing phase (66.28 ± 11.67 / 65.46 ± 9.48 > 57.35 ± 7.62 < 60.91 ± 10.51, Cohen's d = −0.39, 95.0% [−0.86 to 0.07], $P < 0.05$), and moving phase (32.82 ± 7.56/31.14 ± 6.22 < 43.31 ± 6.38 > 37.25 ± 7.16, Cohen's d = 0.89, 95.0% [0.42 to 1.36], $P < 0.05$).

Furthermore, the fall index showed significant differences (51.19 ± 4.72 / 50.58 ± 3.12 > 36.50 ± 3.94 < 43.78 ± 4.41, Cohen's d = −1.74, 95.0% [−2.27 to −1.21], P < 0.05). The shoulder and hip torsion angle (°) also exhibited significant differences (9.26 ± 0.53/9.13 ± 0.32 < 13.33 ± 0.67 > 9.13 ± 0.32, Cohen's d = 2.96, 95.0% [2.31 to 3.61], P < 0.05), the left and right swaying of the torso (8.17 ± 0.25/8.84 ± 0.18 > 5.39 ± 0.22 < 6.74 ± 0.23, Cohen's d = −6.28, 95.0% [−7.38 to −5.18], P < 0.05), and the torso forward tilt angle (7.26 ± 3.51 / 7.93 ± 2.17 > 5.67 ± 2.76 < 6.19 ± 3.31, Cohen's d = −0.17, 95.0% [−0.62 to 0.28], P < 0.05). The data analysis revealed significant differences both within and between groups, with the exception of the WS and TFTA groups, consistent with previous research findings [38]. This further indicates that Yi Jin Jing training was more effective than Tai Chi training in enhancing various gait and fall-related indicators (**Figures 3** and **4**).

Table 3. Changes in gait and fall index of the pre and post of the two groups (M ± SD).

Indicator	YJG (n = 48)		TCG (n = 48)		Cohen's d	95.0% CI
	Pre	Post	Pre	Post		
Step length (SL, cm)	30.32 ± 9.64	57.23 ± 6.67$^{\#}$	31.72 ± 7.42	46.67 ± 5.93$^{\#*}$	1.67	1.15 to 2.19
Walking speeds (WS, m/s)	1.10 ± 0. 33	1.22 ± 0.42$^{\#}$	1.09 ± 0.34	1.12 ± 0.37*	0.25	−0.20 to 0.70
Standing phase (SP, %)	66.28 ± 11.67	57.35 ± 7.62$^{\#}$	65.46 ± 9.48	60.91 ± 10.51$^{\#*}$	−0.39	−0.86 to 0.07
Moving phase (MS, %)	32.82 ± 7.56	43.31 ± 6.38$^{\#}$	31.14 ± 6.22	37.25 ± 7.16$^{\#*}$	0.89	0.42 to 1.36
Fall index (FI)	51.19 ± 4.72	36.50 ± 3.94$^{\#}$	50.58 ± 3.12	43.78 ± 4.41$^{\#*}$	−1.74	−2.27 to −1.21
Shoulder and hip torsion angle (SHTA, °)	9.26 ± 0.53	13.33 ± 0.67$^{\#}$	9.13 ± 0.32	11.67 ± 0.41$^{\#*}$	2.96	2.31 to 3.61
Left and right swaying of torso (LRST, cm)	8.17 ± 0.25	5.39 ± 0.22$^{\#}$	8.84 ± 0.18	6.74 ± 0.23$^{\#*}$	−6.28	−7.38 to−5.18
Torso forward tilt angle (TFTA, °)	7.26 ± 3.51	5.67 ± 2.76$^{\#}$	7.93 ± 2.17	6.19 ± 3.31*	−0.17	−0.62 to 0.28

Note: *P < 0.05 between groups; $^{\#}P$ < 0.05 within groups.

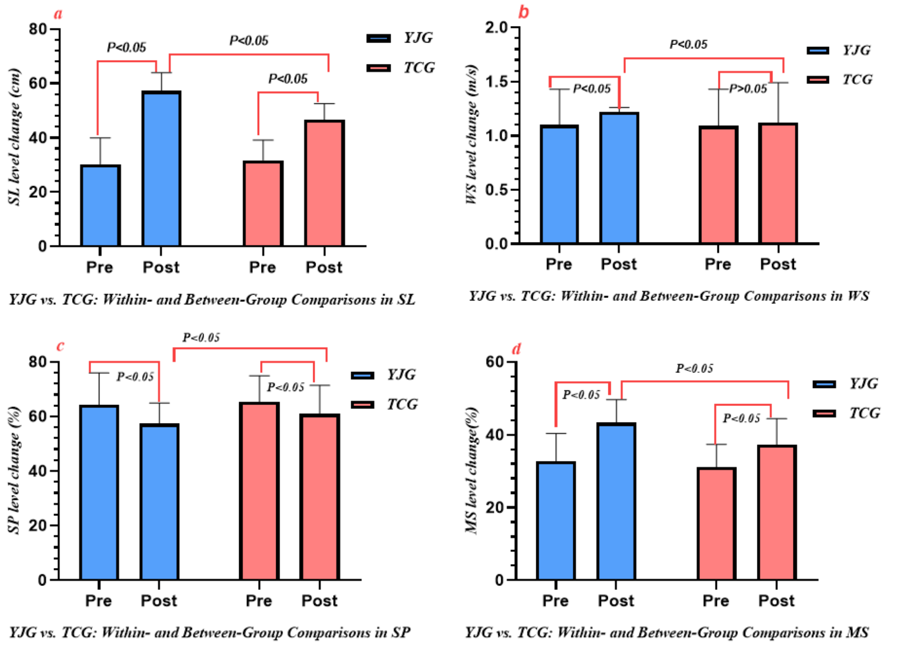

Figure 3. YJG vs. TCG: Changes in SL, WS, SP, and MS between two groups

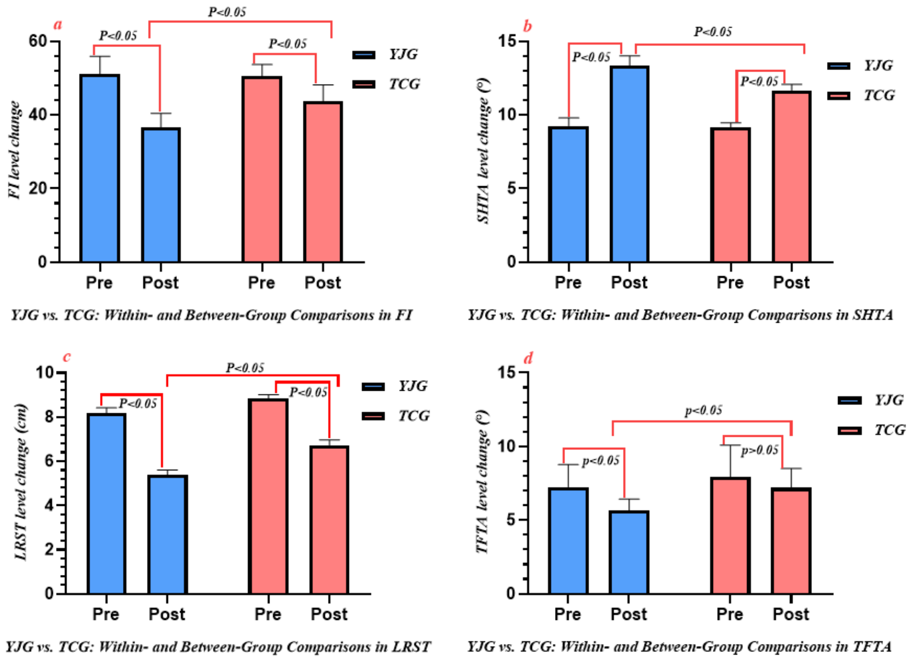

Figure 4. YJG vs. TCG: Changes in FI, SHTA, LRST, and TFTA between two groups.

3.4. BBS and FMA evaluation

The analysis of the participants' conditions revealed that the BBS score for the TCG significantly increased from 36.42 ± 4.58 to 51.27 ± 3.57, while the FMA score also showed substantial improvement, rising from 32.16 ± 3.99 to 65.76 ± 5.37. These results clearly demonstrate that participants achieved significant enhancements in balance ability and motor function (P < 0.05). In the TCG, the BBS score increased from 35.29 ± 5.23 to 43.63 ± 4.09, and the FMA score rose from 31.56 ± 4.41 to 62.86 ± 3.27, reflecting significant within-group differences (P < 0.05). From an inter-group perspective, the YJG exhibited significantly higher scores in both BBS and FMA compared to the TCG (BBS: 51.27 ± 3.57 > 43.63 ± 4.09; FMA: 65.76 ± 5.37 > 62.86 ± 3.27; Cohen's d = 1.99/0.65, 95.0% [1.43 to 2.54, 0.19 to 1.12], P < 0.05), with BBS demonstrating a large effect size and FMA showing a medium effect size. Both groups revealed significant differences in the posterior aspect of BBS (P < 0.05); however, between-groups differences in the posterior aspect of FMA were not significant (P > 0.05). The findings of this study clearly indicate that Yi Jin Jing training was superior to Tai Chi in improving balance ability and motor function in elderly men, which was consistent with previous research [39]. This superiority may be attributed to the unique movements and breathing techniques of Yi Jin Jing, which were more effective in enhancing core stability and body coordination, thereby resulting in more pronounced improvements in balance and motor function (**Table 4**, **Figure 5**).

Table 4. Changes in pre and post of the BBS and FMA indicators in the two groups (M ± SD).

Indicator	YJG (n = 48)		TCG (n = 48)		Cohen's d	95.0% CI
	Pre	Post	Pre	Post		
BBS	36.42 ± 4.58	51.27 ± 3.57[#]	35.29 ± 5.23	43.63 ± 4.09[#*]	1.99	1.43 to 2.54
FMA	32.16 ± 3.99	65.76 ± 5.37[#]	31.56 ± 4.41	62.86 ± 3.27[#]	0.65	0.19 to1.12

Note: *$P < 0.05$ between groups; #$P < 0.05$ within groups.

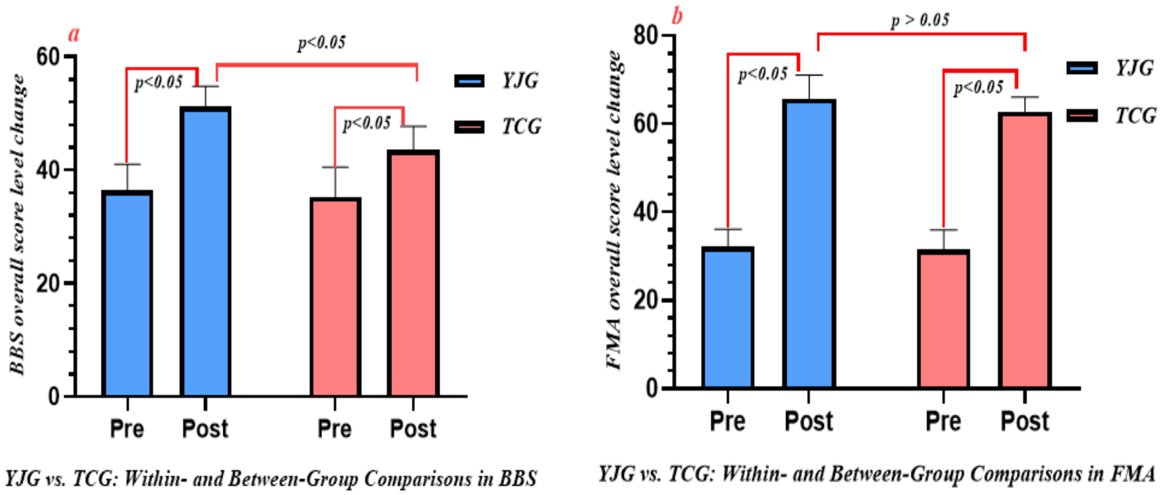

Figure 5. YJG vs. TCG: Changes in BSS and FMA between two groups.

4. Discussions

This study evaluated the effects of the YJG and TCG on lower limb muscle strength, gait characteristics, and fall risk in elderly men from a biomechanical perspective, combined with related measurement indicators such as lower limb muscle strength testing, gait analysis, fall index, BBS, and FMA. Research has shown that both groups exhibit significant advantages, but YJG was significantly better than TCG in reducing the risk of falls in elderly men, enhancing the strength and endurance of lower limb muscle groups, and improving gait, balance, and sports function. These findings not only provide strong evidence support for relevant theories, further filling the gap in previous research in this field, but also provide new ideas and exercise programs for preventing falls in the elderly.

As they age, the muscle strength of elderly people continues to decline, which has led to a series of hospitalizations and even fatal cases due to falls [40]. This not only causes more pain for elderly patients themselves but also imposes a heavy economic and caregiving burden on their families [41]. Studies have demonstrated that after the age of 65, the lower limb muscle strength of elderly individuals declines at a rate of 1% to 2% per year [42]. This decline in muscle strength is a crucial factor contributing to instability in the body's center of gravity during standing and walking, thereby complicating the maintenance of postural stability. Consequently, this deterioration adversely impacts the daily functional activities of the elderly, further increasing the risk of falls and posing a significant threat to their safety [43]. To change this situation, research has confirmed that the plasticity of skeletal muscles primarily arises from their sensitivity to external stimuli induced by resistance training, highlighting the positive impact of exercise on mitigating muscle loss in the elderly population [44].

Firstly, the results of this study confirm that the relative peak torque of lower limb muscle groups during isokinetic centripetal contraction at velocities of 60°/s and 120°/s is consistent with findings from previous research [45,46]. Previous studies have demonstrated that elderly individuals who practice Tai Chi exhibit significantly greater relative peak torque in isokinetic concentric contractions of the lower limb joint flexion and extension muscles compared to those who engage in prolonged walking. Strengthening and enhancing the endurance of lower limb muscle groups can substantially improve balance and proprioceptive function [47]. While both Yijin Jing and Tai Chi demonstrate considerable benefits, the effectiveness of Yijin Jing was notably superior to that of Tai Chi. This difference may be attributed to Yijin Jing's greater emphasis on enhancing muscle strength in targeted areas, coupled with a relatively higher exercise intensity. Consequently, this practice primarily contributes to improvements in muscle strength, endurance, and body flexibility [48]. In contrast, the Yi Jin Jing movement was strong and powerful, emphasizing more on muscle contraction, extension, stretching, and twisting, which requires the active and antagonistic muscles to constantly switch between contractions during exercise. Throughout the entire process of practice of Yi Jin Jing, the center of gravity of the human body remains at a medium or low level and moves back, forth, left, and right (such as the postures such as the lying tiger pouncing on food and the pulling the nine ox tail posture), which effectively promotes the ability of the hip, knee, ankle, and other lower limb joint extensor and flexor muscles to withstand maximum loads, as well as the grasping ability of the toes (such as the Qinglong claw probing posture and tail dropping posture), further enhancing body stability [49]. Furthermore, the enhancement of neural regulation functions by the Yi Jin Jing promotes improved coordination and conversion among the active, coordinating, and antagonistic muscles during exercise. This, in turn, significantly enhances the strength and endurance of the lower limb muscle groups in elderly individuals [50]. An interesting finding from this research is the significant individual variability among the elderly. During the intervention process, it is essential to continuously adjust the exercise intensity based on the actual circumstances of the elderly to address their personalized exercise needs, which aligns with previous research findings. Studies indicate that distinct exercise programs tailored to the individual differences among the elderly should be developed; for instance, for elderly individuals with diminished muscle strength, an increased emphasis on resistance training is warranted, whereas for those with compromised balance, balance training should be prioritized [51]. Moreover, throughout the exercise regimen, it is crucial to closely monitor the physical reactions of elderly participants and timely adjust the exercise plan according to their physical conditions [52]. Additionally, for elderly individuals at risk of falling, it is important to complement Yi Jin Jing exercises with measures aimed at improving their living environment, such as installing handrails in bathrooms and removing obstacles at home, to mitigate the risk of falls [53].

Secondly, with advancing age, the twisting ability of the trunk and pelvis of elderly people decreases, the angle of movement of lower limb joints decreases, the support time increases, and due to muscle weakness, the stability of hip, knee, and ankle joints significantly decreases, the walking speed slows down, the step length decreases (such as the common "dragging" phenomenon) [54], and the decline in reaction and balance abilities will further exacerbate the risk of falls [55]. While Tai Chi can enhance balance and improve muscle strength [56], the biggest difference from Tai Chi was that the benefit and the key distinction of the Yi Jin Jing intervention was its ability to not only improve the trunk balance regulation reflex function in elderly individuals but also to enhance overall body stability, as well as both dynamic and static balance capabilities and normal walking ability. Notably, Yi Jin Jing focuses more on improving physical support and movement ability, which has a more direct improvement effect on gait problems caused by insufficient muscle strength or decreased joint function.

In addition, the factors contributing to falls in elderly individuals are complex and closely linked to diminished physical function. While the decline in muscle strength and proprioceptive ability was one of the contributors to falls [57], the deterioration of balance response capability in the elderly may result in an increased incidence of falls. Consequently, enhancing the balance ability of older adults is crucial for fall prevention [58]. Previous studies have demonstrated that Tai Chi can significantly enhance balance and posture control in elderly individuals, thereby reducing the risk of falls [59,60]. This finding aligns with the results of the current study. However, the results of this study suggest that the Yi Jin Jing intervention can further strengthen the control, coordination, and toe grasping abilities of the pelvis, trunk, and various joints. This intervention enhances proprioception, not only improving the dynamic balance abilities of the elderly but also further enhancing their overall exercise function, thereby reducing the risk of falls.

Finally, the training of Yi Jin Jing emphasizes that body coordination, balance, flexibility, core stability, and the torsional nature of the body are intricately linked to neural muscle control, cerebral cortex activity, and nerve conduction velocity. This aligns with prior research in related sports [61,62]. Studies indicate that physical exercise enhances neural muscle connections and improves the activation of motor neurons, thereby increasing muscle strength and motor function performance while maintaining body balance [63]. Additionally, sports may enhance motor control by promoting cerebral cortex activity, which further improves balance and coordination in the human body. Research has shown that among elderly individuals engaged in sports, significant changes in cerebral cortex activity and enhanced nerve conduction velocity can facilitate the formation of new synaptic connections between neurons or strengthen existing ones. This process subsequently improves balance function, reaction speed, and motor coordination, thereby reducing the risk of falls among the elderly [64].

Although this study has compared the effects of Yijin Jing and Taiji Quan on the changes in lower limb muscle groups, gait characteristics, and fall risk in elderly men, demonstrating significant intervention effects, it still has certain limitations. First, the participant demographic is relatively homogeneous, consisting solely of elderly men, which limits the generalizability of the findings to different genders. Second, the research period is short, lacking long-term follow-up investigations and an assessment of the impact of exercise intensity. Additionally, although randomization was employed for grouping during the research process, the grouping method is simplistic, and the blinding procedure is inadequate. Furthermore, factors such as participants' diet and circadian rhythms have not been adjusted, and there are relatively few related index parameters. Lastly, the internal mechanisms, such as the central nervous system and the gratitude system, and their interactions with the skeletal muscle system have not been explored. Therefore, future research should incorporate neuroimaging techniques (such as fMRI or EEG) or other neurophysiological methods to further elucidate how Yijin Jing and Tai Chi enhance the balance and motor function of the elderly through neuromodulation. Additionally, it is essential to increase the sample size and broaden the age range to explore the intervention effects across different populations (such as elderly women) and assess the sustainability of the intervention. Moreover, other parameters (such as step width, double support time, and exercise intensity) should be fully considered, along with personalized exercise intervention plans and prevention strategies to enrich future research. Finally, comparisons with other sports program interventions should be made, and an influence factor model should be constructed to clarify the optimization of intervention effects and promote the physical health of the elderly.

5. Conclusions

This research investigates the effects of Yi Jin Jing and Tai Chi on the lower limb joint muscle groups, gait characteristics, and fall risk among elderly men from a biomechanical perspective. The results indicate that while both Yi Jin Jing and Tai Chi interventions yield significant benefits, the effects of Yi Jin Jing are superior to those of Tai Chi. Specifically, Yi Jin Jing significantly enhances the strength and endurance of the hip, knee, and ankle muscle groups in elderly men, along with improvements in control ability, coordination, flexibility, toe grip, and overall motor function. These enhancements lead to significant improvements in walking and dynamic balance, thereby reducing fall risk. This finding holds substantial clinical implications within the domains of sports science and healthcare. On one hand, leveraging the unique advantages of Yi Jin Jing allows for the formulation of personalized exercise plans tailored to the elderly. For individuals with varying physical conditions and exercise goals, progressive Yi Jin Jing training courses can be designed to facilitate scientific exercise. On the other hand, Yi Jin Jing can serve as a pivotal method for disease prevention and health management. Medical institutions should advocate for the practice of Yi Jin Jing among the elderly and incorporate it into health record management. Additionally, for elderly individuals with chronic diseases or physical dysfunction, Yi Jin Jing can be utilized as an adjunct in rehabilitation treatment. This approach not only enhances rehabilitation outcomes but also considers physical functions and psychological factors, such as stress management and chronic disease monitoring, thereby fully reflecting the positive impact of Yi Jin Jing on the physical and mental health of the elderly and enabling a broader demographic to benefit.

Author contributions: Conceptualization, SG, YH, JJ and FW; data curation, YH, FW and JJ; formal analysis, JJ and FW; investigation, SG, YH, JJ and FW;

methodology, SG, YH, JJ and FW; project administration, FW; resources, SG, YH, JJ and FW; software, SG, YH, JJ and FW; supervision, JJ and FW; validation, SG, YH, JJ and FW; visualization, SG and YH; writing—original draft, SG and YH; writing—review and editing, FW and JJ. All authors have read and agreed to the published version of the manuscript.

Ethical approval: The study was conducted in accordance with the Declaration of Helsinki, 96 informed statements were signed by the participants themselves and their families, and were approved by the Academic Ethics Committee of the Department of Physical Education of Shenzhen Polytechnic University (Approval No.: SZTY202401021).

Availability of data and materials: We need to seek approval from the project approval unit. If the unit agrees, the author can provide data and materials.

Conflict of interest: The authors declare no conflict of interest.

References

1. Bai X, Soh KG, Omar Dev RD, et al. Effect of Brisk Walking on Health-Related Physical Fitness Balance and Life Satisfaction Among the Elderly: A Systematic Review. Frontiers in Public Health. 2022; 9. doi: 10.3389/fpubh.2021.829367
2. World Health Organization. Ageing and Health Report. Available online: https://www.who.int/news-room/fact-sheets/detail/ageing-and-health (accessed on 20 November 2024).
3. World Health Organization. Falls. Available online: https://www.who.int/zh/news-room/fact-sheets/detail/falls (accessed on 20 November 2024).
4. Ghahramani M, Stirling D, Naghdy F. The sit to stand to sit postural transition variability in the five time sit to stand test in older people with different fall histories. Gait & Posture. 2020; 81: 191-196. doi: 10.1016/j.gaitpost.2020.07.073
5. Yuan S, Larsson SC. Epidemiology of sarcopenia: Prevalence, risk factors, and consequences. Metabolism. 2023; 144: 155533. doi: 10.1016/j.metabol.2023.155533
6. Ruiz JR, Sui X, Lobelo F, et al. Association between muscular strength and mortality in men: prospective cohort study. BMJ; 2008. doi: 10.1136/bmj.a439
7. Kwangmyong. Is it hard to buy a lot of money to lose weight in old age? Saving money is worse than saving muscle. Available online: https://baijiahao.baidu.com/s?id=1768365386019019113&wfr=spider&for=pc (accessed on accessed on 20 November 2024).
8. Ramdharry GM, Reilly-O'Donnell L, Grant R, et al. Frequency and circumstances of falls for people with Charcot–Marie–Tooth disease: A cross sectional survey. Physiotherapy Research International. 2017; 23(2). doi: 10.1002/pri.1702
9. Volpi E, Nazemi R, Fujita S. Muscle tissue changes with aging. Current Opinion in Clinical Nutrition and Metabolic Care. 2004; 7(4): 405-410. doi: 10.1097/01.mco.0000134362.76653.b2
10. Henry M, Baudry S. Age-related changes in leg proprioception: implications for postural control. Journal of Neurophysiology. 2019; 122(2): 525-538. doi: 10.1152/jn.00067.2019
11. Cadore EL, Rodríguez-Mañas L, Sinclair A, et al. Effects of Different Exercise Interventions on Risk of Falls, Gait Ability, and Balance in Physically Frail Older Adults: A Systematic Review. Rejuvenation Research. 2013; 16(2): 105-114. doi: 10.1089/rej.2012.1397
12. Lam FMH, Lau RWK, Chung RCK, et al. The effect of whole body vibration on balance, mobility and falls in older adults: A systematic review and meta-analysis. Maturitas. 2012; 72(3): 206-213. doi: 10.1016/j.maturitas.2012.04.009
13. Donatoni da Silva L, Shiel A, McIntosh C. Effects of Pilates on the risk of falls, gait, balance and functional mobility in healthy older adults: A randomised controlled trial. Journal of Bodywork and Movement Therapies. 2022; 30: 30-41. doi: 10.1016/j.jbmt.2022.02.020
14. Marini K, Mahlknecht P, Schorr O, et al. Associations of Gait Disorders and Recurrent Falls in Older People: A Prospective Population-Based Study. Gerontology. 2021; 68(10): 1139-1144. doi: 10.1159/000520959
15. Navarrete-Villanueva D, Gómez-Cabello A, Marín-Puyalto J, et al. Frailty and Physical Fitness in Elderly People: A

Systematic Review and Meta-analysis. Sports Medicine. 2020; 51(1): 143-160. doi: 10.1007/s40279-020-01361-1
16. Feng Y. Biomechanical Analysis of Tai Chi (Eight Methods and Five Steps) for Athletes' Body Balance Control. Molecular & Cellular Biomechanics. 2023; 20(2): 97-108. doi: 10.32604/mcb.2023.045804
17. Cheng Y, Song Y, Wu F. Biomechanical analysis of balance control in the elderly By Ba Duan Jin. Molecular & Cellular Biomechanics. 2024; 21(3): 541. doi: 10.62617/mcb541
18. Yang Y, Wang K, Liu H, et al. The impact of Otago exercise programme on the prevention of falls in older adult: A systematic review. Frontiers in Public Health. 2022; 10. doi: 10.3389/fpubh.2022.953593
19. Shayman CS, Peterka RJ, Gallun FJ, et al. Frequency-dependent integration of auditory and vestibular cues for self-motion perception. Journal of Neurophysiology. 2020; 123(3): 936-944. doi: 10.1152/jn.00307.2019
20. Han J, Anson J, Waddington G, et al. The Role of Ankle Proprioception for Balance Control in relation to Sports Performance and Injury. BioMed Research International. 2015; 2015: 1-8. doi: 10.1155/2015/842804
21. Gabriel DA, Kamen G, Frost G. Neural Adaptations to Resistive Exercise. Sports Medicine. 2006; 36(2): 133-149. doi: 10.2165/00007256-200636020-00004
22. Mahalakshmi B, Maurya N, Lee SD, et al. Possible Neuroprotective Mechanisms of Physical Exercise in Neurodegeneration. International journal of molecular sciences. 2020; 21(16), 5895. https://doi.org/10.3390/ijms21165895
23. Liu YC, Yan JT, Wang ZY, et al. Influence of Yi Jin Jing on Skeletal Muscle Contractile Function in Gerontism with Sarcopenia. Journal of Shanghai University of Traditional Chinese Medicine. 2016; 30(05): 42-45. doi: 10.16306/j.1008-861x.2016.05.011
24. Yang SB, Qin X, Chen XY, et al. Effect of Yi Jin Jing Exercise on Human Balance Function. Guiding Journal of Traditional Chinese Medicine and Pharmacology. 2022. doi: 10.13862/j.cn43-1446/r.2022.04.015
25. Jing LX, Huang LY, Wang YW, & Gao M. Effects of Yi Jin Jing training on lower limb kinetics and muscle contribution in older adults. Journal of Shandong Sport University. 2019. doi: 10.14104/j.cnki.1006-2076.2019.02.012
26. Chinese Geriatrics and Gerontology Society. Specification for comprehensive assessment of fall risk among the elderly. Available online: http://cagg.org.cn/ (accessed on 20 November 2024).
27. Ahn JH, Bae TS, Kang KS, et al. Longitudinal Tear of the Medial Meniscus Posterior Horn in the Anterior Cruciate Ligament–Deficient Knee Significantly Influences Anterior Stability. The American Journal of Sports Medicine. 2011; 39(10): 2187-2193. doi: 10.1177/0363546511416597
28. Mouhli D, Cojean T, Lustig S, et al. Influence of hamstring stiffness on anterior tibial translation after anterior cruciate ligament rupture. The Knee. 2024; 47: 121-128. doi: 10.1016/j.knee.2024.02.002
29. Maffiuletti NA, Bizzini M, Desbrosses K, et al. Reliability of knee extension and flexion measurements using the Con-Trex isokinetic dynamometer. Clinical Physiology and Functional Imaging. 2007; 27(6): 346-353. doi: 10.1111/j.1475-097x.2007.00758.x
30. Zhang S, Wang L, Liu X, et al. Effects of Kinesio taping on lower limb biomechanical characteristics during the cutting maneuver in athletes after anterior cruciate ligament reconstruction. PLOS ONE. 2024; 19(3): e0299216. doi: 10.1371/journal.pone.0299216
31. Goldfarb N, Lewis A, Tacescu A, et al. Open source Vicon Toolkit for motion capture and Gait Analysis. Computer Methods and Programs in Biomedicine. 2021; 212: 106414. doi: 10.1016/j.cmpb.2021.106414
32. Tekkarismaz N, Doruk Analan P, Ozelsancak R, et al. Effect of Kidney Transplant on Balance and Fall Risk. Experimental and Clinical Transplantation. 2020; 18(Suppl 1): 73-77. doi: 10.6002/ect.tond-tdtd2019.p19
33. Kaya DO, Ergun N, Hayran M. Effects of different segmental spinal stabilization exercise protocols on postural stability in asymptomatic subjects: Randomized controlled trial. Journal of Back and Musculoskeletal Rehabilitation. 2012; 25(2): 109-116. doi: 10.3233/bmr-2012-0318
34. Berg K. Measuring balance in the elderly: preliminary development of an instrument. Physiotherapy Canada. 1989; 41(6): 304-311. doi: 10.3138/ptc.41.6.304
35. Maki BE, Holliday PJ, & Topper AK. A rehabilitation-specific measure of balance. Physical Therapy. 2000; 80(9): 889-898. doi: 10.1093/ptj/80.9.889
36. Chen RQ, Wu JX, & Shen XS. Study on the minimal clinically important change of the Chinese version of Fugl—Meyer sports function Assessment Scale. Acta Universitatis Medicinalis Anhui. 2015; 50(4): 519-522. doi: 10.19405/j.cnki.issn1000-1492.2015.04.025
37. Gschwind YJ, Kressig RW, Lacroix A, et al. A best practice fall prevention exercise program to improve balance,

strength/power, and psychosocial health in older adults: study protocol for a randomized controlled trial. BMC Geriatrics. 2013; 13(1). doi: 10.1186/1471-2318-13-105

38. Lacroix A, Hortobágyi T, Beurskens R, et al. Effects of Supervised vs. Unsupervised Training Programs on Balance and Muscle Strength in Older Adults: A Systematic Review and Meta-Analysis. Sports Medicine. 2017; 47(11): 2341-2361. doi: 10.1007/s40279-017-0747-6
39. Wiedenmann T, Held S, Rappelt L, et al. Exercise based reduction of falls in communitydwelling older adults: a network meta-analysis. European Review of Aging and Physical Activity. 2023; 20(1). doi: 10.1186/s11556-023-00311-w
40. Moreland B, Kakara R, Henry A. Trends in Nonfatal Falls and Fall-Related Injuries Among Adults Aged ≥65 Years — United States, 2012–2018. MMWR Morbidity and Mortality Weekly Report. 2020; 69(27): 875-881. doi: 10.15585/mmwr.mm6927a5
41. Lin X, Meng R, Peng D, et al. Cross-sectional study on prevalence and risk factors for falls among the elderly in communities of Guangdong province, China. BMJ Open. 2022; 12(11): e062257. doi: 10.1136/bmjopen-2022-062257
42. Skelton DA, Greig CA, Davies JM, et al. Strength, Power and Related Functional Ability of Healthy People Aged 65–89 Years. Age and Ageing. 1994; 23(5): 371-377. doi: 10.1093/ageing/23.5.371
43. Zhou M, Peng N, Li CH, et al. Trend analysis of the influence of Tai Chi training on lower limb skeletal muscle strength in the elderly. Chinese Journal of Rehabilitation Medicine. 2014.
44. Qaisar R, Bhaskaran S, Van Remmen H. Muscle fiber type diversification during exercise and regeneration. Free Radical Biology and Medicine. 2016; 98: 56-67. doi: 10.1016/j.freeradbiomed.2016.03.025
45. Tang YC, & Wu S. A review of muscle strength evaluation indicators for the elderly abroad. Chinese Journal of Sports Medicine. 2012; 31(05): 456-461. doi: 10.16038/j.1000-6710.2012.05.015
46. Yao Y, & Yang SD. Research on the influence of Tai Chi exercise on lower limb muscle strength in the elderly. Chinese Journal of Sports Medicine. 2003; (01): 75-77. doi: 10.16038/j.1000-6710.2003.01.016
47. Zhu YQ, Peng N, & Zhou M. Influence of Tai Chi on lower limb muscle strength and function in the elderly. Chinese Journal of Integrated Traditional and Western Medicine. 2016.
48. Yang C, Wu AL, Xie J, et al. Comparative analysis of proprioceptive neuromuscular facilitation stretching and Yijinjing exercise. Massage and Rehabilitation Medicine. 2018; 9(19): 3-5. doi: 10.19787/j.issn.1008-1879.2018.19.002
49. Fang L, Li ZR, Tao XC, & Luo J. Clinical study on the influence of Yijinjing on the fall risk of elderly patients with sarcopenia and balance disorders. Chinese Journal of Rehabilitation Medicine. 2020.
50. Zhang S, Guo G, Li X, et al. The Effectiveness of Traditional Chinese Yijinjing Qigong Exercise for the Patients with Knee Osteoarthritis on the Pain, Dysfunction, and Mood Disorder: A Pilot Randomized Controlled Trial. Frontiers in Medicine. 2022; 8. doi: 10.3389/fmed.2021.792436
51. Sherrington C, Michaleff ZA, Fairhall N, et al. Exercise to prevent falls in older adults: an updated systematic review and meta-analysis. British Journal of Sports Medicine. 2016; 51(24): 1750-1758. doi: 10.1136/bjsports-2016-096547
52. Thomas E, Battaglia G, Patti A, et al. Physical activity programs for balance and fall prevention in elderly. Medicine. 2019; 98(27): e16218. doi: 10.1097/md.0000000000016218
53. Heng H, Jazayeri D, Shaw L, et al. Hospital falls prevention with patient education: a scoping review. BMC Geriatrics. 2020; 20(1). doi: 10.1186/s12877-020-01515-w
54. Nikolić M, Malnar-Dragojević D, Bobinac D, et al. Age-related skeletal muscle atrophy in humans: an immunohistochemical and morphometric study. Collegium antropologicum; 2001.
55. Dhillon RJS, Hasni S. Pathogenesis and Management of Sarcopenia. Clinics in Geriatric Medicine. 2017; 33(1): 17-26. doi: 10.1016/j.cger.2016.08.002
56. Wayne PM, Gow BJ, Hou F, et al. Tai Chi training's effect on lower extremity muscle co-contraction during single- and dual-task gait: Cross-sectional and randomized trial studies. PLOS ONE. 2021; 16(1): e0242963. doi: 10.1371/journal.pone.0242963
57. Pšeničnik Sluga S, Kozinc Z. Sensorimotor and proprioceptive exercise programs to improve balance in older adults: a systematic review with meta-analysis. European Journal of Translational Myology. 2024. doi: 10.4081/ejtm.2024.12010
58. Binda SM, Culham EG, Brouwer B. Balance, Muscle Strength, and Fear of Falling in Older Adults. Experimental Aging Research. 2003; 29(2): 205-219. doi: 10.1080/03610730303711
59. Jacobson BH, Ho-Cheng C, Cashel C, et al. The Effect of T'AI Chi Chuan Training on Balance, Kinesthetic Sense, and Strength. Perceptual and Motor Skills. 1997; 84(1): 27-33. doi: 10.2466/pms.1997.84.1.27

60. Huang D, Ke X, Jiang C, et al. Effects of 12 weeks of Tai Chi on neuromuscular responses and postural control in elderly patients with sarcopenia: a randomized controlled trial. Frontiers in Neurology. 2023; 14. doi: 10.3389/fneur.2023.1167957
61. Proske U, Gandevia SC. The Proprioceptive Senses: Their Roles in Signaling Body Shape, Body Position and Movement, and Muscle Force. Physiological Reviews. 2012; 92(4): 1651-1697. doi: 10.1152/physrev.00048.2011
62. Di Lorito C, Long A, Byrne A, et al. Exercise interventions for older adults: A systematic review of meta-analyses. Journal of Sport and Health Science. 2021; 10(1): 29-47. doi: 10.1016/j.jshs.2020.06.003
63. Rosado H, Pereira C, Bravo J, et al. Benefits of Two 24-Week Interactive Cognitive–Motor Programs on Body Composition, Lower-Body Strength, and Processing Speed in Community Dwellings at Risk of Falling: A Randomized Controlled Trial. International Journal of Environmental Research and Public Health. 2022; 19(12): 7117. doi: 10.3390/ijerph19127117
64. Wang Y, Chen X, Wang M, et al. Repetitive Transcranial Magnetic Stimulation Coupled with Visual-Feedback Cycling Exercise Improves Walking Ability and Walking Stability After Stroke: A Randomized Pilot Study. Zhao Z, ed. Neural Plasticity. 2024; 2024(1). doi: 10.1155/np/8737366