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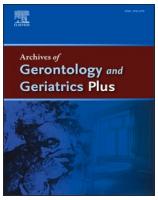

Evaluating the effectiveness of Tai Chi in short-term, medium-term, and long-term on balance and strength among the elderly: A systematic review and meta-analysis

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ABSTRACT

Objective: To evaluate Tai Chi's effectiveness on balance and strength in the elderly across different intervention durations.
Methods: We conducted a comprehensive meta-analysis of 37 randomised controlled trials (RCTs) on balance and 22 RCTs on strength. The databases were searched in February 2023: AMED, CINAHL Plus, Medline, Web of Science, and Embase.
Results: Tai Chi significantly improved balance (SMD = 0.40; 95 % CI: 0.05 to 0.75; $P = 0.03$) and strength (SMD = 0.43; 95 % CI: 0.01 to 0.84; $P = 0.04$) in the elderly, especially in medium-term interventions (8–16 weeks). Long-term effects were not statistically significant, indicating variability in the sustained impact of Tai Chi.
Conclusions: Tai Chi is effective in improving balance and strength among the elderly, particularly with medium-term interventions. The variability in results across different study durations suggests a need for further research to optimise Tai Chi protocols and maximise its benefits in elderly care.

1. Background

1.1. Importance of balance and muscle strength in ageing population

Balance and muscle strength are fundamental to maintaining mobility and independence in older adults (Frank & Patla, 2003). Balance is the cornerstone of an individual's ability to maintain an erect posture and facilitate locomotion, crucial for performing daily activities safely (Melzer, 2004). However, as people age, their balance often deteriorates due to factors such as sensory decline, slowed reflexes, and weakening muscles, which collectively impair postural control and leads to a higher risk of falling (Konrad et al., 1999; Paraskevoudi et al., 2018; Thomas et al., 2019). Likewise, muscle strength is essential for maintaining functional mobility and preventing falls, and ageing is often accompanied by sarcopenia, or the progressive loss of muscle mass and strength (Lynch et al., 1999). Sarcopenia and accompanying reduced bone mineral density have severe health implications, such as increased risk of disability, falls, and hip fractures, all of which contribute to a loss of independence and require long-term care (Martin, 2017). Declines in both balance and muscle strength not only increase the risk of falls and related injuries, but also contribute to a cycle of physical decline (e.g., decreased levels of physical activity (PA), which further weakens muscles and balance) that can severely affect the quality of life in older adults (Gardner et al., 2000; Sims et al., 2010).

The consequences of impaired balance and muscle strength extend beyond individual health, imposing a significant burden on healthcare systems worldwide (Montero-Odasso et al., 2021). Falls are a leading cause of injury among older adults, often resulting in fractures, particularly hip fractures, which are associated with high morbidity and mortality rates (Stevens & Olson, 2000). The direct medical costs associated with fall-related injuries are substantial, including expenses for hospital admissions, surgeries, and rehabilitation services (Su et al., 2021). Additionally, falls often lead to long-term disability, loss of independence, and the need for long-term care, further increasing healthcare costs (Kaye et al., 2010). Therefore, addressing the issues of balance and muscle strength in the elderly is not only crucial for individual health and well-being but also essential for reducing the overall burden on healthcare systems.

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1.2. Challenges of physical inactivity among older people

PA plays a pivotal role in elderly health outcomes and ageing overall (Andrieieva et al., 2019; Miranda, Soares & Silva, 2016). Engaging in higher levels of PA is associated with a decrease in both morbidity and mortality rates, along with a reduction in fall risk by 30 % to 50 % among the elderly (Bembom et al., 2009). Specifically, exercises focusing on leg strength and balance have been recognised as effective strategies for minimising fall risks and enhancing the health status of older adults (Thomas et al., 2019).

The World Health Organization (WHO) considers a lack of PA to be a key risk factor for ill-health and one of the major causes of mortality (Fiona et al., 2020). The WHO's PA guidelines recommends that older adults (aged 65 and over) participate in aerobic exercise, muscle strengthening, and balance activities (WHO, 2020). Despite these recommendations, surveys conducted in America and UK revealed that most older people do not meet the PA recommendations (Tappen et al., 2021; Salman & Sellami, 2019). Moreover, in England (UK), only 17 % of older adults met the muscle strength guideline and 19 % met the guideline pertaining to balance (NatCen Social Research, 2024). Therefore, it has become an international priority for health promotion to encourage older people to become physically active, specifically focussing on policies that enhance the awareness and adoption of these overlooked guidelines related to muscle strengthening, balance, and coordination within older age groups (WHO, 2020; Strain et al., 2016).

1.3. The role of Tai Chi in enhancing physical function in elderly

Tai Chi is a traditional Chinese martial art and mind-body exercise that has evolved into various styles, in which Chen, Yang, Sun, Wu and Hao are the most famous and widely practised styles today (Xutian et al., 2011; Lan et al., 2013). Each style is unique, but all share essential elements: mind concentration, breath control and continuous circular movements to maintain balance while shifting one's body weight (McCarthy & Langweiler, 2015; Miller & Taylor-Piliae, 2014). Due to its safe and gentle approach, Tai Chi has long been favoured by older adults since it offers a low to moderate level of intensity that is well-suited to those with physical limitations or various chronic conditions, making it easily adaptable to all fitness levels unlike more vigorous forms of exercise like running (Tong et al., 2018; Lan *et al.*, 2013; Xianjian & Datao, 2021). The combination of physical and mental exercises inherent in the practice of Tai Chi improves muscle coordination and overall physical stability, making it an effective intervention for mitigating balance and strength decline (Chen et al., 2023). Indeed, regular Tai Chi practice has been found to significantly increase lower body strength, which is essential for maintaining balance and preventing falls, and reduce the risk of injury; furthermore, it has been shown to enhance wellbeing in older populations (Wang et al., 2020; Taylor-Piliae & Finley, 2020).

1.4. Aim and objectives

While existing research has shown positive impacts of Tai Chi on balance and strength in the elderly, the high heterogeneity of intervention duration and participant demographics present in these studies necessitates a more detailed exploration Tai Chi's efficacy across varying time frames. This objectives of this systematic review and meta-analysis are:

1. Consolidate existing knowledge on the effectiveness of Tai Chi in enhancing balance and strength, which are critical for reducing the risk of falls and addressing the overlooked guidelines related to strength and balance in the elderly population.
2. Identify consistencies and discrepancies in the literature regarding the timing and magnitude of Tai Chi's health benefits, with a focus on short-term (up to 8 weeks), mid-term (8 to 16 weeks), and long-term (beyond 16 weeks) intervention periods.
3. Provide evidence-based recommendations on the optimal duration of Tai Chi practice to maximize its effectiveness in improving balance and strength, preventing falls, and reducing the associated healthcare burden.

Understanding the impact of different intervention durations—whether short-term (up to 8 weeks), mid-term (8 to 16 weeks), or long-term (beyond 16 weeks)—is crucial (Zacharia et al., 2015). The timeframe within which Tai Chi is practised may significantly influence its effectiveness in enhancing balance and muscle strength. By using meta-analysis, this study aims to determine the optimal duration of Tai Chi interventions to provide evidence-based recommendations that can be implemented in geriatric care, ultimately helping to reduce the incidence of falls and alleviate the strain on healthcare systems.

2. Methods

2.1. Protocol and registration

This systematic review adheres to the Preferred Reporting Items for Systematic Review and Meta-analyses (PRISMA) guidelines and recommendations of the Cochrane collaboration. This review was registered with PROSPERO on April 2023 (ID:CRD42023415155), prior to the commencement of screening and analysis.

2.2. Selection criteria

Randomised controlled trials (RCTs) are regarded as the gold standard to evaluate the efficacy of interventions (Sullivan, 2011). To provide more reliable evidence of Tai Chi's effectiveness, this systematic review analysed the results of RCTs only. Details about the inclusion and exclusion criteria for studies are presented in Table 1.

2.3. Search strategy

The following databases were searched in February 2023: AMED, CINAHL Plus, Medline, Web of Science, and Embase. Keywords related to Tai Chi (intervention), and older adults (population) were used as part

Table 1
Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Participants: 1) Participants are aged 60 or older 2) Participants are not recruited on the basis of a specific disease or condition	1) Participants are aged below 60 2) Participants are recruited specifically if they had a particular disease or clinical condition
Intervention: 1) Studies report on Tai Chi exercise interventions regardless of the style of Tai Chi, frequency, and duration of intervention	1) Studies in which the intervention condition could not be exclusively categorised as Tai chi 2) Studies that used Tai Chi as a control condition or combined Tai Chi with other sports or forms of exercise 3) Tai Chi training combined with other forms of therapy or other rehabilitation programs
Comparative: 1) Studies that compared Tai chi exercise with usual care, waitlist control, no intervention, health education, routine activity, or other physical activity	1) Studies that used Tai Chi as a control condition No adequate control condition or control group
Outcomes: 1) Studies explored balance and/or strength 2) Studies used one or more validated clinical tests to measure strength and balance	1) Studies with outcomes not related to balance and/or strength
Study: RCTs Published in English	Non-RCT studies Published in any language other than English

of the search strategy. The Boolean operator "AND" was used to combine keywords and index terms relating to two different concepts, such as "Tai Chi" and "aged," whereas the Boolean operator "OR" was used to combine keywords and index terms of a concept (for example, the terms "aged" and "elderly" were used to represent "older adults"). Detailed information about the search terms used is presented in Appendix 1.

Screening was carried out in three stages using Covidence online software. Preliminary title and abstract screening were conducted by one researcher (LN) to eliminate duplicates and irrelevant studies. A subset of the papers was cross-checked by three other researchers (DG, DS, SD). The titles and abstracts of all studies were double screened by four researchers (LN, DG, DS, SD) with studies categorised as "Yes" (satisfied eligibility criteria), "No" (did not satisfy eligibility criteria) and "Maybe" (Uncertain). The final step was to review the full texts of studies in the "Yes" and "Maybe" categories in further detail by all researchers (LN, DG, DS, SD). The full text for each record was reviewed by two researchers and discrepancies were resolved through discussion among all authors.

2.4. Data extraction

The following data was extracted using a standardised form: study population, characteristics, intervention and outcome measures, significance of outcomes on balance and strength (Table 2). The standardised extraction form was used to categorise the Tai Chi intervention types in each trial to aid accurate data analysis. For each included trial, one researcher (LN) extracted the mean and standard deviation of score changes for all relevant outcomes. When more than one publication was apparent for the same trial, data were collated. All data were double-checked by other researchers (DG, DS, SD). To enhance the reliability of our meta-analysis, we attempted to contact the authors of the included studies when raw data cannot be retrieved. We reached out via email, detailing our request for additional data that was either missing or unclear in the published articles. If raw data could not be retrieved, the trial was not included in the meta-analysis.

2.5. Quality assessment

The Cochrane "Risk of Bias" (ROB) assessment tool as denoted in the Cochrane Handbook of Systematic Reviews of Interventions was used to assess bias (Higgins et al., 2019). The following domains were assessed by one researcher (LN): random sequence generation (selection bias), allocation concealment (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias), and selective reporting (reporting bias). Each study was methodically judged in all domains and placed into one of the following categories: low, high, or unclear risk of bias.

2.6. Meta-Analysis

RevMan 5.4 software, provided by the Cochrane Collaboration, was used for meta-analysis. In the analysis of studies by duration, outcome data were organised into short-term ($\leq$8 weeks), medium-term and long term ($\geq$16 weeks) categories. The time cutoffs for short, medium and long-term interventions were selected based on a combination of factors, including physiological adaptation periods reported in prior studies and practical considerations for intervention implementation in clinical settings (Zacharia, 2015). For balance, only assessments such as single leg balance, Time up and go, Berg's balance test, the Tinetti Balance and Gait Assessment (TBGA), short physical performance battery were included in the meta-analysis. Other measurements, such as Center of Pressure (COP) and dynamic balance were not included due to the lack of the composite index and difficulties in interpreting the data. Since units of measurements of different studies could not be converted, standard mean difference (SMD) was used instead of mean difference. Hedges' g statistic was used to compute effect sizes, and Forest plots were created with 95 % confidence intervals (CI). Effect sizes were categorised as follows: $d < 0.2$ was designated as indicating a very small effect size, $0.2 \leq d < 0.5$ denoted a small effect size, $0.5 \leq d < 0.8$ represented a moderate effect size and $d \geq 0.8$ indicated a large effect size. The I^2 statistic was used to assess the extent of heterogeneity (I^2 =0–30 %, low; I^2 =30–60 %, moderate; I^2=50–90 %, substantial, I^2=75–100 %, considerable). If heterogeneity was not significant (P-value >0.10 and I^2 <30 %), the fixed-effects model was adopted. However, if statistical heterogeneity was noted (I^2 >40 %), meta-analysis was performed using a random-effects model.

2.7. Subgroup analysis

We conducted a sub-analysis focusing specifically on the Time Up and Go (TUG) test, the One Leg Stand (OLS) test, the grip strength test, the combined Chair rise test and Sit to Stand test to evaluate Tai Chi's impact on balance and muscle strength in elderly participants. Both datasets underwent a meta-analysis to calculate standardised mean differences (SMD) and 95 % confidence intervals (CI). This targeted approach allowed us to analyse the influence of Tai Chi across different assessments, addressing the hypothesis that diverse measurement tools might introduce high heterogeneity into our findings. This sub-analysis aims to provide a clear understanding of distinct benefits of Tai Chi on essential balance abilities crucial for fall prevention in the elderly.

3. Results

The initial data search yielded 2973 records studies. After the removal of duplicates, 1819 articles were identified and a total of 1635 articles were excluded after screening their titles and abstracts. Out of the 184 remaining papers, 8 records could not be retrieved. Accordingly, 176 records full text studies were assessed to determine if they met the eligibility criteria; 115 papers were excluded for the following reasons: inappropriate participants not aged above 60, participants with specific diseases, non-RCTs, outcomes irrelevant, Tai Chi as condition, language not English, non-peer reviewed paper. In the end, 61 studies involving 6147 participants were included in the final analysis (Fig. 1).

3.1. Study characteristics

Two studies were excluded due to the unavailability of raw data, despite efforts to contact the authors. The remaining 59 studies were summarised in Table 2. All studies adopted RCTs design to examine the effectiveness of Tai Chi: 45 studies used a two-arm RCT intervention designs, while 14 papers employed three-arm RCT methodology. Studies were carried out in 11 countries: mainland of China (18 papers); Hong Kong (4 papers); US (21 papers); Iran and Korea (3 papers); Netherland, Australia and Turkey (2 papers); Finland, Germany, New Zealand and Canada (1 paper).

3.2. Participant characteristics

In total, 6137 participants participated in the studies, with sample sizes ranging from 19 to 684. The mean age of the participants ranged from 60.63 $\pm$ 2.65 years old to 86.0 $\pm$ 5.0 in the Tai Chi intervention group and 60.8 $\pm$ 2.91 to 85.0 $\pm$ 6.0 in the control group. One study did not report the mean age of participants per group. Of the 59 studies included in the final analysis, 53 of them recruited participants from the community, three studies recruited from nursing homes, and the remaining three studies recruited solely from either hospital, supportive living, or long-term care facilities. There were more than 70 % female participants in 26 studies. Three studies did not report the proportion of sexes in different groups.

Table 2
Participant, intervention, and study characteristics.

Studies	Participants (number, mean age)	Intervention groups	Control groups	Outcomes	Effect
Audette JF (2006), US a	$N = 19$ Mean age: Tai chi group=71.4 (4.5); Control group = 67.91 (4.42)	Yang style of Tai Chi; Three sessions per week, 40–45 min per session, 12 weeks period	Brisk walking training, Sedentary comparison group	Strength (handgrip muscle strength), balance (single-leg stance time)	Significant gains were seen in the non-dominant knee extensor strength and sing-leg stance time ($P < 0.05$)
Aviles (2019), US	$N = 35$ Mean age: Tai chi group=82.6 (4.5); Control group = 80.9 (6.2)	Yang style of Tai Chi, three times per week, 30 min per session (group practice), 4 weeks period	Treadmill-based reactive balance training (RBT)	Balance (A battery of balance tests which includes 6 standard clinical tests of balance and mobility and a test of reactive balance)	RBT participants exhibited significantly better reactive balance compared with Tai Chi participants. Clinical tests showed minimal differences between groups.
BİRİMOĞLU OKUYAN1 (2017), Turkey	N=44 Mean age: Tai chi group=82.6 (4.5); Control group = 80.9 (6.2)	Yang style of Tai Chi, three times per week, 30 min per session (group practice), 4 weeks period	No intervention	Balance: the Tinetti Balance and Gait Assessment (TBGA)	The balance and of individuals in the Tai Chi Chuan group significantly improved compared with that in the control group ($p < 0.001$).
Faber (2006), Netherland	$N = 278$ Mean age: Intervention group: 84.4 (6.4), Control group:84.9.6 (5.9)	Sun style of Tai Chi, twice per week, 40 min per session, 20 weeks program	No intervention	Balance: time up and go	Participants in both exercise groups showed a small, but significant improvement in their POMA and physical performance scores.
Frye, (2007), US	$N = 84$ Mean age:69.2(9.26)	Sun style of Tai Chi, twice per week, 60 min per session, 12 weeks program	Low-impact exercise (LIE), control group	Balance:8-foot up-and-go test Strength: The chair stand test, grip strength test	The LIE and TC groups both significantly improved their balance ($p < 0.01$). Upper body strength, as measured by grip strength, significantly increased for both exercise groups with a 7.1 % increase in the TC group ($p < 0.05$).
Gatts, (2007), US	$N = 22$ Mean age:77.55	Tai Chi, 5 times per week, 1.5 h per session, 3 weeks program	Axial mobility exercises, balance/awareness education and stress reduction	Balance: Time up-and-go, single stance time, Tandem stance time, Functional Reach	Tai Chi training significantly enhanced balance responses by more efficacious use of mechanisms controlling stepping strategies of the swing leg
Ge, (2022), China	$N = 65$ Mean age: Intervention group: 70.16 (5.4) Control group: 72.91 (6.61)	Tai Chi, 3 times per week, 1 h per session, 8 weeks program	Usual care	Strength: The 4.5 m walking test (WS), The 30 s chair rise test (CRT)	Between-group comparison at the 4th week showed significantly better outcomes in CRT ($P < 0.001$) and WS ($P = 0.001$) in the TCG than those in the CG, the intervention effect of 8 weeks was better than at 4 weeks.
Guo, (2022), China	$N = 40$ Mean age: Intervention group: 68.12 (2.41) Control group: 68.34 (2.52)	24-forms of Tai Chi, 3 times per week, 45 min per session, 8 weeks program	General physical activities	Strength: Sitting-standing test Balance: Berg balance evaluation	The observation group was significantly ($P < 0.05$) superior to the control group concerning sitting-standing test and the Breg balance function scores, showing statistically significant differences ($P < 0.05$).
Holmes, (2016), US	$N = 62$ Mean age: Intervention group: 86.0(5.0) Control group:85.0(6.0)	Yang style of Tai Chi exercise, once per week, 60 min per session, 12 weeks program	Education-control group	Postural control: Area and Velocity	No significant changes were observed in balance measures after 12-week training. Area and Velocity increased when closing the eyes for both groups ($p < 0.01$), yet neither was influenced by the Tai Chi intervention.
Hosseini, (2018), Iran	$N = 60$ Mean Age: Intervention group: 60–70 (53.3 %), 70–80 (56.7 %) Control group: 60–70 (26.7 %), 70–80 (73.3 %)	Tai Chi, twice a week, 55 min per session, 8 weeks	Usual activity	Balance: the Tinetti test	There was a statistical difference in the balance between the Tai Chi group and the control group ($P < 0.001$).
Hu, (2021), China	$N = 31$ Mean age: Intervention group: 66.4(1.7) Control group:66.7(1.8)	Tai Chi, four times per week, 60 min per session, 16 weeks program	No intervention	Balance: COP Variable Test	The COP variables were significantly improved after the 16-weeks Tai Chi practice
Hwang, (2016), China	N=456 Mean age: Intervention group: 72.0(32.9) Control group:77.0(33.8)	Home-based Tai Chi, once per week, 60 min per session, 24 weeks program	Lower extremity training (LET)	Balance: The Tinetti balance Strength: Grip strength	Handgrip strength, Tinetti balance scores improved significantly during the 6-month intervention, and improvements in handgrip strength, remained significant during the entire 18-month study period.
Kim (2020), Korea	$N = 46$ Mean age: Intervention group: 71.4(3.3) Control group:70.9(4.3)	Tai Chi, twice a week, 60 min per session, 12 weeks	Taekkyon	Balance: one-leg standing test (OLS), Timed Up and Go test (TUG Strength: Five Times Sit-to-Stand test (5 × STS) and 30-	Both groups similarly showed statistically significant improvements in balance (TUG, FR, and OLS), and lower extremity strength. Tai chi group showed

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Table 2 (*continued*)

Studies	Participants (number, mean age)	Intervention groups	Control groups	Outcomes	Effect
				second sit-to-stand test (30 s STS),	greater improvement in the OLS test than the Taekkyon group ($P < 0.05$).
Kim HD (2009), Korea	$N = 46$ Mean age: Intervention group: 74.3(6.1) Control group:73.7(5.5)	Tai Chi, three times per week, 60 min per session, 12 weeks	Wellness education (WE) group	Balance: center of pressure (COP)	Subjects in the TC group showed a significant increase in the displacement of COP in the anteroposterior (A-P) and mediolateral (M-L) directions as well as average velocity of the COP displacement after Tai Chi training ($p < 0.01$)
Lee, (2015), Hong Kong	$N = 59$ Mean age: Intervention group: 83.5(8.9) Control group:84.8(8.1)	Tai Chi, three times per week, 60 min per session, 3 months	Mobilizing exercise	Balance: Sequential weight shifting test (SWS), center of pressure (COP)	3-months of sitting Tai Chi training can improve sitting balance.
Lelard, (2010), Finland	$N = 28$ Mean age: Intervention group: 76.8(5.1) Control group:77.0(4.5)	Tai Chi, twice per week, 30 min per session, 3 months	Balance training group	Balance: center of pressure (COP) sway under eyes open (EO) and eyes closed (EC) conditions	After the 12-week training period, there were no significant differences in walking speed or postural parameters in either the EO or EC conditions for the TC and balance training groups.
Li F, (2004), US	$N = 28$ Mean age: 77.48(4.95)	Yang style of Tai Chi, once per week, 60 min per session, 26 weeks	Stretching control	Balance: Berg balance scale (BBS); dynamic gait index (DGI); functional reach (FR)	Tai Chi participants who showed improvements in measures of functional balance at the intervention endpoint significantly reduced their risk of falls during the 6-month postintervention period, compared with those in the control condition
Li F, (2005), US	$N = 56$ Mean age: Intervention group: 76.84(4.69) Control group:77.99 (5.14)	Tai Chi, three times per week, 30 min per session, 6 months	Stretching control group	Balance: Berg Balance Scale, Dynamic Gait Index, Functional Reach, and single-leg standing	Compared with the stretching control participants, the Tai Chi participants showed significant improvements ($p < 0.001$) in all measures of functional balance
Li FZ, (2018), US	$N = 670$ Mean age: Intervention group: 77.5(5.6) Multimodal Exercise group:77.8(5.3); Stretching group: 77.8 (5.9)	Tai Chi, twice per week, 60 min per session, 24 weeks	Multimodal Exercise Intervention, stretching exercise	Balance: functional reach;the Instrumented Timed Up & Go; the Short Physical Performance Battery	The participants in both the Tai Chi and multimodal exercise groups performed significantly better than those in the stretching exercise group on balance, And there were no differences between Tai Chi and multimodal exercise on balance outcomes.
Li FZ, (2004), US	$N = 27$ Aged 60 or older	Tai Chi, twice per week, 60 min per session, 24 weeks	Low-impact exercise	Balance: single leg stand, timed chair rise, 50-foot speed walk	Tai chi participants also showed better scores in balance outcome measures than low-impact exercise participants ($P < 0.001$).
Li FZ, (2002), US	$N = 28$ Mean age: Intervention group: 76.8(5.1) Control group:77.0(4.5)	Tai Chi, twice per week, 60 min per session, 24 weeks	Low-impact exercise	Balance: single leg stand, timed chair rise, 50-foot speed walk	Tai chi participants also showed better scores in balance outcome measures than low-impact exercise participants ($P < 0.001$).
Li JX, (2008), Hong Kong	$N = 50$ Mean age: Intervention group: 75.2(2.9) Control group:64.5(2.2)	24-forms of Tai Chi, four sessions per week, 60 min per session, 16 weeks	No intervention	Balance: single-leg stance with the eyes open (SLO), single-leg stance with the eyes closed (SLC), and tandem stance with the eyes closed (TSC)	Tai Chi intervention improved the kinesthesia of knee flexion and extension and single-leg stance with eyes open.
Lipsitz, (2019), US	$N = 180$ Mean age: Intervention group: 75.9(9.1) Control group:74.6(8.6)	Tai Chi, twice per week, 30 min per session, 1 year	Health Education	Balance: Short Physical Performance Battery (SPPB); standing balance, timed-up-and go (TUG) test Grip strength	6 and 12 months of twice-weekly TC classes were not associated with improvements in functional health.
Liu, (2012), China	$N = 60$ Mean age: Intervention group: 70.5(2.1) Control group:72.8(2.3); control group:68.6 (1.6)	Tai Chi, twice per week, 45 min per session, 16 weeks	Proprioception Exercise Program (PE), control group	Muscle strength of ankle: Biodex System 3 dynamometer	Subjects in the TC and PE groups did not have a larger amount of peak torque and peak torque/weight in both ankles than the control group, and there were no significant differences between groups.
LoggheIHJ, (2009), Netherlands	$N = 269$ Mean age: Intervention group: 77.5(4.7) Control group:76.8(4.6)	Yang style of Tai Chi, twice per week, 60 min per session, 13 weeks	No intervention	Balance: Berg Balance Scale	There were no significant differences between groups in mean scores on balance.
Lou, (2017) China	$N = 80$ Mean age: Intervention group: 62.2(3.43) Control group:62.6(3.54)	Tai Chi softball (TCSB), four sessions per week, 90 min per session, 7 weeks	normal lifestyles d	Strength: 30 s Chair Stand Test; handgrip Strength Test Balance: Time Up and Go Test	A short-term and intensive TCSB training program does not only improve low limb-related physical function such as dynamic balance

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Table 2 (*continued*)

Studies	Participants (number, mean age)	Intervention groups	Control groups	Outcomes	Effect
					and leg strength, but also strengthen upper limb-related physical function.
Lu, (2013), Hong Kong	$N = 31$ Mean age: Intervention group: 73.9(6.6) Control group:68.9(5.8)	12-forms of Yang-style Tai Chi, three sessions per week, 60 min per session, 16 weeks	Education program	Knee joint muscle strength	The subjects in the Tai Chi group showed significant improvements in arterial compliance and eccentric knee extensor strength.
Lu, (2016), Hong Kong	$N = 31$ Mean age: Intervention group: 72.8(6.7) Control group:67.3(6.6)	Yang style of Tai chi, three sessions per week, 60 min per session, 16 weeks	General interest classes	Balance (postural control): center of pressure (COP), single leg stance	Tai Chi significantly improved postural control performance of older woman when dual tasking ($P < 0.05$).
Meng, (2022), China	$N = 150$ Mean age: Intervention group: 75.6(1.92); TCSE group:76.31(2.07); SE group:76.59(2.58)	8-forms of Tai Chi, three sessions per week, 60 min per session, 24 weeks	8-form Tai Chi, strength, and endurance training group (TCSE); Strength and endurance training group (SE)	Grip strength (GS) Balance: timed up and go test (TUGT), six-minute walk test (6 min WT)	Subjects in the TCSE group showed the greatest significant improvements in the six-minute walk test ($p < 0.05$) compared to the TC group and SE group. The improvement in grip strength in the TCSE group (4.29 kg) was slightly less than that in the SE group (5.16 kg). There was neither a significant main effect nor a significant interaction effect for TUGT in subjects.
Mortazavi, (2018), Iran	$N = 53$ Tai chi group:67.20 (5.416) Control group:68.07 (5.232)	Yang style of Tai Chi, 3 sessions per week, 10 weeks	Daily activity	Balance: Berg's Balance Scale	The score of Berg's at the end of 4th, 8th weeks and at the end of exercise period was significantly different between the two groups ($P < 0.05$). Tai Chi exercise can play a significant role in improving balance.
Nam-KukSon, (2016), Korea	$N = 45$ Tai chi group:72.8(4.7) Control group:71.5 (3.6)	Tai Chi, 2 sessions per week, 60 min per sessions,12 weeks	Otago	Balance: The Timed Up and Go (TUG) test, functional reach (FR) test, one-leg standing (OLS) test Strength: 5 times sit-to-stand test (5 × STS), 30-second sit-to-stand (30 s STS) test	Both groups showed statistically significant improvements in balance (TUG and OLS tests), lower extremity strength (5 × STS and 30 s STS tests)
Ni, (2014), US	$N = 39$ Tai chi group:70.27 (5.69) SBEP group:77.80 (7.78); Yoga group: 73.23(5.09)	Tai Chi, 2 sessions per week, 60 min per session, 12 weeks	Standard balance training program (SBEP); Yoga program	Balance:8-foot up-and-go test, 1-leg stance, functional reach, and usual and maximal walking speed.	Training produced significant improvements in all field tests ($P < 0.005$), but group difference and time × group interaction were not detected
RieglevanWest, (2019), Australia	$N = 79$ Mean age: Tai chi group=69.; Control group = 67.6	Tai Chi; Two sessions per week, 60 min per session, 4 weeks period	Poi	Balance: Functional Reach Test; Grip strength: pinch and hand grip Lower body strength: 30-Second Chair Stand Test	Both groups improved postural stability, upper limb strength.
Sadeghian, (2023), Iran	$N = 36$ Mean age: Tai chi group=71.4 (4.5); Control group = 67.91 (4.42)	Tai Chi; once per week, 60–80 min per session, 8 weeks period	SSE (Square-Stepping Exercise)	Balance: Single Leg-Stance-Eyes Open/Closed, Timed Up and Go, Functional Reach Test, Chair Stand	The results indicated that both exercise types improved outcome measures, although the TCC group made greater improvement ($p < 0.05$).
Snapp,(2009), US	$N = 19$ Mean age 65+	Tai Chi, twice per week 60 min per session, 8 weeks	Non Tai chi ecercise	The balance scale	A moderate improvement in balance for Non Tai Chi exercise group and Tai Chi group
Solianik, (2022), Finland	$N = 30$ Mean age: Tai chi group=71.5 (1.9); Control group = 73.9 (3.8)	8-forms of Yang-style Tai Chi; two sessions per week, 60 min per session, 10 weeks period	Usual activities	Balance: Center of pressure velocity (VCoP)	10 weeks of tai chi practice induced improvements in balance ($p < 0.05$)
Song Q, (2014), China	$N = 105$ Mean age: Tai chi group=62.14 (5.52); Dance group = 61.83 (4.37); Walking Group=62.85 (5.29)	Tai Chi; once per week, 40 min per session, 12 months period	Dance Group; Walking Group	Strength: lower limb muscle strength Balance: Dynamic balance test system	Tai Chi group show no significant ($P > 0.05$) after 4 months exercise. However,12 months later, the effect of Tai Chi is improved significantly from day to day when comparing to those in the control group I and group II ($P < 0.05$ or $P < 0.01$).
Sun J, (2015), China	$N = 150$ Mean age: Tai chi group=68.3 (5.9); Control group = 70.1 (5.7)	Yang style of Tai Chi; twice per week, 60 min per session, 6 months period	Non-athletic activities.	Balance: eyes open/leg standing time Left grip strength, and right grip strength	There were no differences between the groups in the one-leg standing time with eyes open, and left grip strength after 3 and 6 months of intervention.
Sun, (2019), China	$N = 48$ Mean age: Tai chi group=71.2 (4.8); Control group = 62.21 (4.72)	Tai Chi; 5 sessions per week, 60 min per session, 16 weeks period	Brisk Walking Exercise	Balance: single-leg standing balance	12 ($p < 0.01$)and 16 weeks ($P < 0.05$) of TCC and BW, respectively were essential to improve balance with eyes closed among the women aged 60–70 years

(*continued on next page*)

Table 2 (*continued*)

Studies	Participants (number, mean age)	Intervention groups	Control groups	Outcomes	Effect
Taylor, (2012), New Zealand	$N = 684$ Mean age: Tai chi (once per week) group=75.3 (7.0); Tai Chi (twice per week) = 74.4(6.2) Control group=73.7(6.2)	Tai Chi; once per week/twice a week, 60 min per session, 20 weeks period	Low-level exercise	Balance: step test Strength: low limb strength, chair stand test	Strength and balance improved similarly in all groups over time.
Taylor-Piliae, (2010), US	$N = 132$ Mean age: Tai chi group=70.6 (5.9); Western exercise=68.5 (5.0) Control group = 68.2 (6.2)	Tai Chi; two sessions per week, 60 min per session, 6 months period	Western exercise, Control group	Balance: single-leg-stance and functional-reach tests. Upper and lower body muscle Strength:0-s timed arm-curl and chair-stand tests,	Tai Chi participants had significantly more improvement in balance than controls (mean difference = 5.5 s, $p < 0.05$).
Tousignant, (2013), Canada	$N = 233$ Mean age: Tai chi group=71.5 (10.3); Control group = 68.2 (10.3)	Tai Chi; two sessions per week, 60 min per session, 15 weeks period	Conventional physical therapy	Balance: Berg's balance test	Tai Chi exercises as part of a rehabilitation program seem to be a practical alternative to the usual balance exercises.
Tousignant, (2012), Canada	$N = 152$ Mean age: Tai chi group=79.1 (6.4); Control group = 80.7 (6.0)	Yang style of Tai Chi; two sessions per week, 60 min per session, 15 weeks period	Physiotherapy program	Balance: Berg's balance test, single-leg standing	Both interventions were associated with improved balance but only the Tai Chi intervention group decreased the incidence of falls.
Voukelatos, (2007), Australia	$N = 702$ Mean age: 69.0(6.5)	Tai Chi; one session per week, 60 min per session, 16 weeks period	No intervention	Balance: six balance tests	There were statistically significant differences in changes in balance favoring the tai chi group on five of six balance tests
Wallsten, (2006), US	$N = 77$ Mean age: 81.2	Tai Chi; two sessions per week, 60 min per session, 20 weeks period	No intervention	Balance: Timed Up and Go Test (TUG) Strength	The results suggest that a relatively short intervention program of 20 weeks can improve older adults' balance and strength.
Wang, (2016), China	$N = 90$ Mean age: Tai chi group=65.3 (7.4); TCRT=65.3(4.3) Control group = 63.3 (8.1)	Yang style of Tai Chi; four sessions per week, 60 min per session, 6 months period	A simplified Tai Chi exercise (TCRT), or a control group (routine activity).	Balance: Functional Movement Screening (FMS)	The TCRT is more effective in improving the physical function in older adults when compared to the traditional Tai Chi modality, particularly for improving balance.
Wayne, (2014), US	$N = 60$ Mean age: Tai chi group=63.84 (8.02); Control group = 64.45 (7.42)	Yang style of Tai Chi; two sessions per week, 60 min per session, 6 months period	Usual care	Balance: Single-legged standing time and Timed-Up–and-Go tests	Both single leg stance time (SLST) and Timed Up and Go (TUG) performance were better in the Tai Chi expert group as compared to the Tai Chi naive group ($P < 0.001$)
Wayne, (2021), US	$N = 38$ Mean age: Tai chi group=64.26 (7.77); Control group = 64.92 (7.55)	Yang style of Tai Chi; two sessions per week, 30 min per session, 6 months period	Usual care	Muscle co-contraction	Subjects randomized to Tai Chi plus usual care and to usual care alone both showed a reduction in co-contraction.
WeiSun, (2018), China	$N = 48$ Mean age: Tai chi group=64.12 (3.21); Brisk walking=63.26 (2.20) Control group = 65.36 (4.31)	Tai Chi; five sessions per week, 60 min per session, 16 weeks period	Brisk walking (BW), and control(C) groups	Balance: single-leg stance time (SLS), center of pressure (COP)	The 24-form TC and BW significantly improved balance with SLS after the 16-week training in older women.
Wolf, (1997), US	$N = 72$ Mean age: Tai chi group=77.7 (5.6); Computerized balance group=77.7(6.5) Education group = 75.2 (4.9)	Tai Chi; two sessions per week, 60 min per session, 15 weeks period	Computerized balance training group; educational group	Balance: The Chattecx Balance system	Unlike computerized balance training, tai chi does not improve measures of postural stability.
Wolf, (1996), US	$N = 200$ Mean age: Tai chi group=76.9 (4.8); Computerized balance group=76.3(5.1) Education group = 75.4 (4.1)	Tai Chi; 15 min per session, twice per day;15 weeks period	Computerized balance training group; educational group	Strength: Grip strength	Grip strength declined in all groups, and lower extremity range of motion showed limited but statistically significant changes ($P < 0.05$)
Wolf, (2006), US	$N = 311$ Mean age: Tai chi group=81.0 (6.4); Control group = 80.8 (5.9)	24-forms of Tai Chi; two sessions per week, 30 min per session, 12 months period	Wellness education	Leg strength: chair-stands	Tai Chi significantly improved chair-rise
Woo, (2007), Hong Kong	$N = 38$ Mean age: Tai chi	24-forms of Tai Chi; three sessions per	Resistance exercise	Muscle strength: handgrip dynamometer Grip D;	TC did not result in any significant improvement in muscle strength,

(*continued on next page*)

Table 2 (*continued*)

Studies	Participants (number, mean age)	Intervention groups	Control groups	Outcomes	Effect
	group=68.26 (2.4); Resistance training=68.67(3.0) Control group = 60.07 (2.7)	week, 30 min per session, 12 months period		Balance: A SMART Balance Master	balance or flexibility since all the above parameters decline with age.
Wu, (2021), US	$N = 23$ Mean age: Tai chi group=80.5 (6.8); Control group = 79.1 (5.1)	24-forms of Tai Chi; three sessions per week, 60 min per session, 12 weeks period	No intervention	Balance: Single leg stance test, Biodex Balance System SD, Timed Up and Go Test	BALANCE significantly improved Single Leg Stance Test (5.4 ± 18.0 vs.− 8.2 ± 10.3 s, $p = 0.049$).
Xiao, (2014), China	$N = 72$ Mean age: 65.4(6.9)	Tai Chi softball (TCSB); three sessions per week, 1–2 h per session, 12 months period	No intervention	Static balance measures (unipedal and tandem stance; Dynamic balance measures: Timed Up-and-Go	TCB intervention was effective for community-dwelling elderly persons in improving balance performance in relation to falls.
Yıldırım, (2016), Turkey	$N = 60$ Mean age: Tai chi group=62.9 (6.5); Control group = 64.4 (7.5)	Yang style of Tai Chi; three sessions per week, 60 min per session, 12 weeks period	Combined exercise prescription	Balance: Single Leg-Stance-Eyes Open (SLS-EO), Single Leg-Stance Eyes Closed (SLS-EC),	Both exercise groups yielded better results in dynamic balance assessments (TUG and BBS) at the 12th week ($p < 0.05$).
Zhang, (2006), China	$N = 84$ Mean age: Tai chi group=70.2 (3.6); Control group = 70.6 (4.9)	24-forms of Tai Chi; three sessions per week, 60 min per session, 8 weeks period	Usual physical activity	Balance: one-leg stance	The intensive TCC training program improved balance in the elderly with low balance ability.
Renkun ZHU (2021), China	$N = 48$ Mean age: Tai chi group: 67.4 (4.0) Lyengar yoga group: 66.8 (13.7) Control group: 66.6(4.0)	Tai Chi, 4 sessions per week, 60 min per session, 16 weeks	Lyengar yoga group; Control group: general education	Muscle strength: isokinetic dynamometer Balance: one-legged stand with eyes closed	Tai chi and Iyengar yoga can improve strength, balance, and balance confidence among older people.
Zhou, (2015), China	$N = 43$ Mean age: Tai chi group=60.63 (2.65); Control group = 60.80 (2.91)	Yang style of Tai Chi; four sessions per week, 60 min per session, 24 weeks period	No intervention	Balance: Good Balance system	24 weeks of Tai Chi intervention improved the efficiency of older women in body control in dynamic situations

3.3. Intervention characteristics

Studies utilised a variety of Tai Chi styles, including Yang-style of Tai Chi (15 studies), Tai Chi softball (2 studies), 24-form Tai Chi (6 studies), Sun-style Tai Chi (2 studies), 12-form Tai Chi (2 studies), 8-form Tai Chi (2 study). Thirty studies did not state the type of Tai Chi intervention conducted.

The length of intervention of Tai Chi intervention varied from $\leq$8 weeks ($n = 9$), 8–16 weeks ($n = 26$) and $\geq$16 weeks ($n = 24$), with the most predominant being 12 weeks (12 studies) followed by 16 weeks (8 studies) and 8 weeks (6 studies). Different frequencies were reported in the study, ranging from one session per week to five sessions per week with a gradual increase. Twenty-four studies employed two sessions per week as the most common frequency of intervention, followed by three sessions per week, which was used in 14 studies. The duration of the sessions ranged from 15 to 120 min. The most common class duration was 60 min (35 studies). There was one study that did not report class duration (Mortazavi et al., 2018). All studies did not report any adverse events or complications associated with Tai Chi exercise, suggesting that it is a safe and low-risk activity.

Inactive controls used in the studies included daily activities, usual care, wellness, or balance education. Active controls groups consisted of lower extremity training, Taekkyon, yoga, Otago, Poi, Square-Stepping Exercise and light exercise programs (normal walking, brisk walking training, resistance exercise, stretching, treadmill-based reactive balance training, dance).

The attendance rates for Tai Chi classes ranged from 68 % to 100 %, while control groups ranged from 56 % to 100 %. There was a wide range of reasons for absences, including illness, time conflict, transportation challenges, fatigue, and vacations.

3.4. Outcome characteristics

To evaluate balance in elderly participants, our meta-analysis incorporated a variety of assessments: the Time Up and Go test was the most frequently utilised, representing 32.4 % of all studies, followed by the Single Leg Balance test at 24.3 %, and Berg's Balance Test at 13.5 %. Less commonly used tests included the TBGA and Functional Reach Test, each accounting for 5.4 % of the studies, and the Short Physical Performance Battery and the Falls Efficacy Scale each contributing 2.7 %.

For muscle strength assessment, the Grip Muscle Strength test was included in 27.2 % of studies, making it the most common strength evaluation tool. This was followed by the Chair Rise Test at 22.7 %, and the Sit to Stand Test at 18.2 %. Less frequently used were the Concentric Knee Joint Muscle Strength test and the BiodexSystem3Pro Isokinetic Limb Muscle Strength Testing, which were employed in 4.5 % of studies, respectively. These diverse tools allowed us to comprehensively analyse how Tai Chi affects both balance and muscle strength in the elderly population.

3.5. Quality assessment

The Cochrane "Risk of Bias" assessment tool (Fig. 2) was used to review the full texts of eligible papers for quality and suitability. An acceptable method of random sequence generation (i.e., computer generated) was used in 26 studies, eight studies were judged as being at high risk of bias and the remaining studies were judged as being at unclear risk due to insufficient information to determine randomisation methods. Most studies (60 %) did not report allocation concealment and were judged as unclear. Fifteen studies were judged as having a low risk of bias for allocation concealment since allocation was blinded. All trials

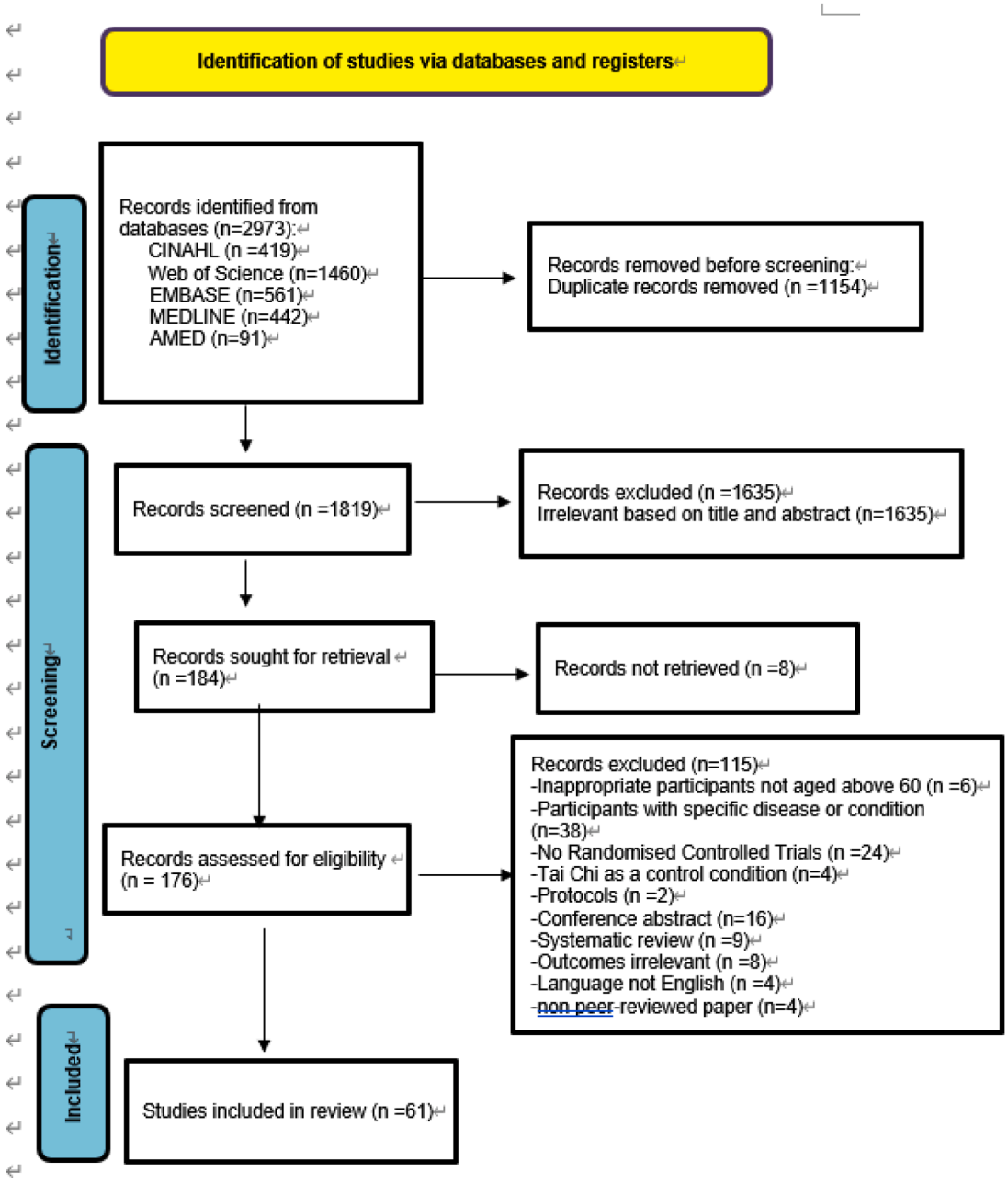


Fig. 1. Studies selection process.

were at high risk of performance bias (ie, no blinding of participants to the intervention and outcomes). Most studies (55 %) were rated as unclear for detection bias (i.e., blinding of outcome assessor) due to insufficient information provided in the studies. Twenty studies were at low risk of detection bias, with the remaining three studies were at high risk. A majority of studies (86 %) were judged as having a low risk of attrition bias, while three studies were rated as having a high risk due to high dropout rates or some participants being excluded from the analysis. The overall level of bias was unclear in 68 % number of studies due to their lack of outcome measure description, and two studies were rated as having a high risk of bias because some outcome measures were not reported.

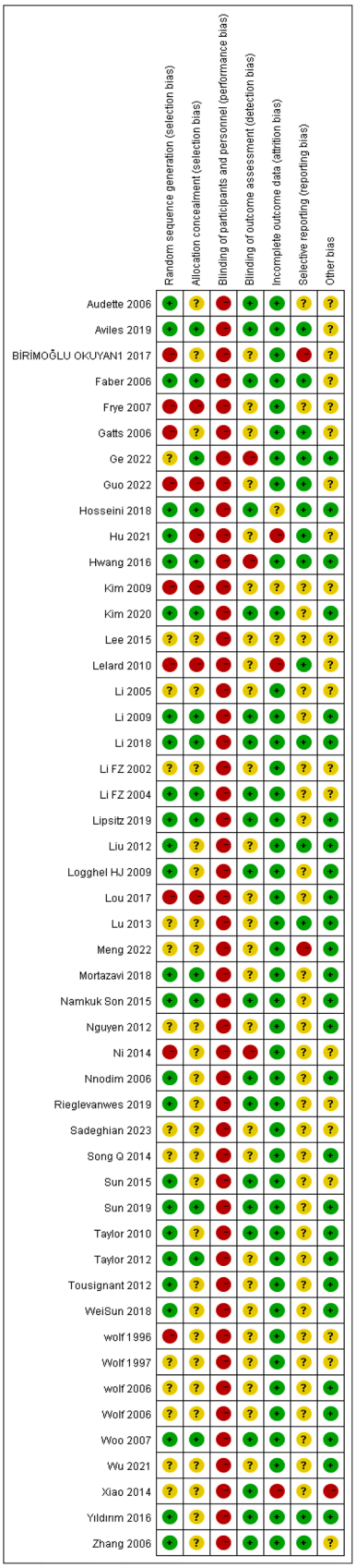
3.6. Meta-analysis

Thirty-seven studies assessing balance and 22 studies assessing strength were included in the meta-analysis. Data used for meta-analysis are attached as supplementary tables (Appendix 2).

3.6.1. Balance

Assessments like single leg balance, Time up and go, Berg's balance test, TBGA, and short physical performance battery were included in the meta-analysis. The result revealed a statistically significant positive effect of Tai Chi on the general balance of elderly participants, as demonstrated by a combined SMD of 0.40 (95 % CI: 0.05 to 0.75), with a P-value of 0.03, indicating a beneficial impact compared to control interventions (Fig. 3).

In review of the statistical results, the studies included in the analysis exhibited considerable heterogeneity (I^2= 96 %), which suggests a substantial variation in the effect sizes across studies. This heterogeneity could be attributable to differences in study design, participant characteristics, or measurement tools. Despite the variability, the test for overall effect size (Z-score of 2.24) indicates the robustness of the overall positive outcome. The CI for individual studies crosses the line of no



Risk of bias assessment. +: low risk of bias; -: high risk of bias; ?: unclear risk of bias.

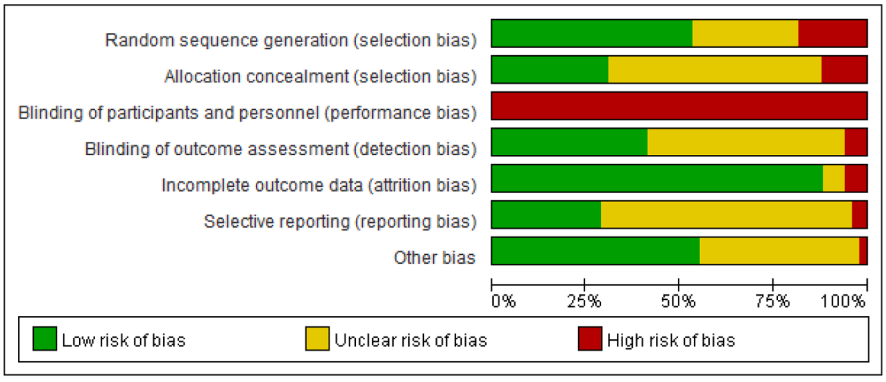


Fig. 2. Cochrane risk of bias summary plot of the included RCTS.
Risk of bias assessment. +: low risk of bias; -: high risk of bias; ?: unclear risk of bias.

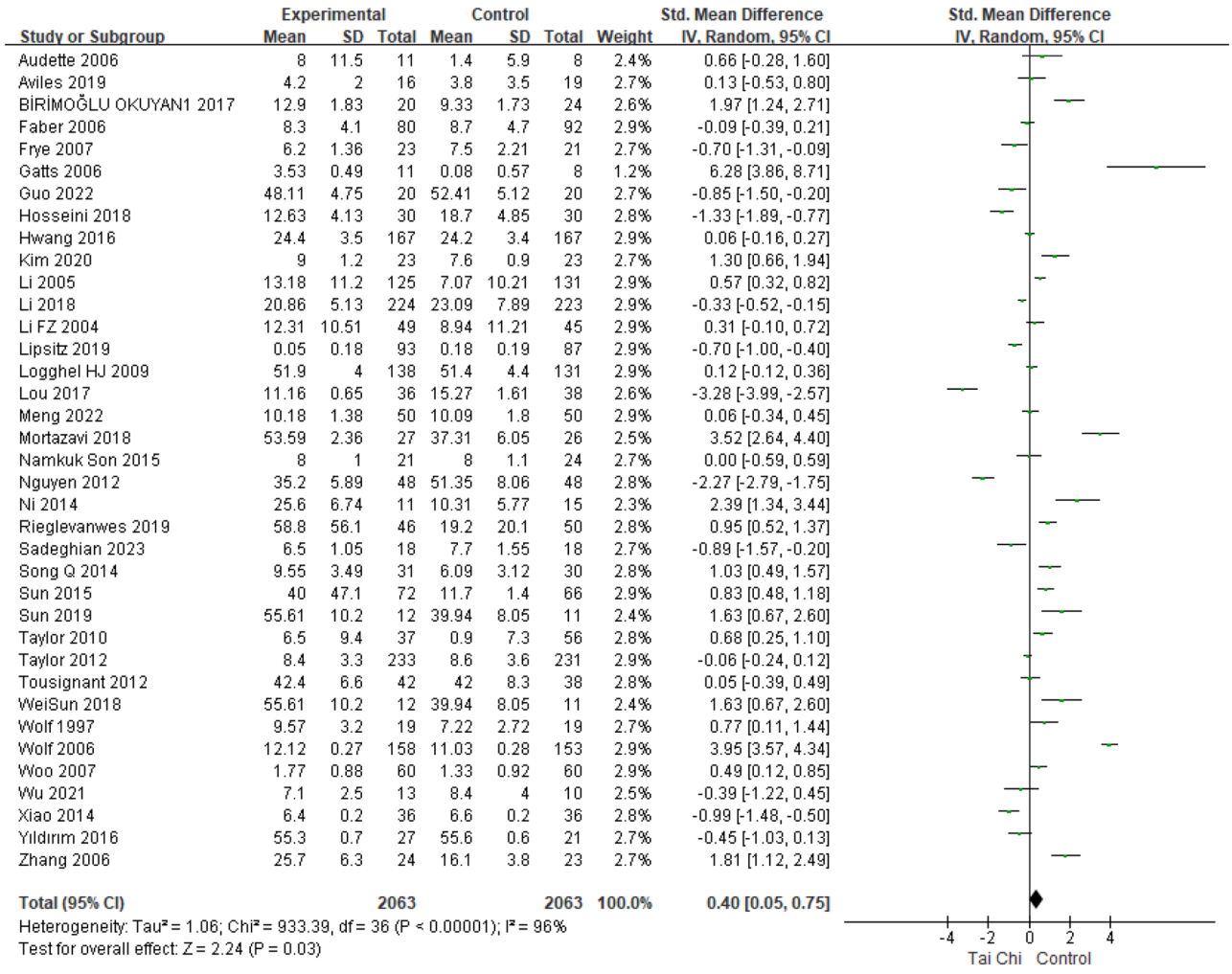


Fig. 3. Forest plot of comparison of effectiveness of Tai Chi on balance.

effect (SMD = 0), suggesting that while Tai Chi appears generally beneficial, the strength of evidence varies, and not all studies may have achieved statistically significant results independently. Overall, our findings demonstrated a positive effect favouring Tai Chi as an intervention to enhance balance among the elderly.

3.6.1.1. Short term effect of Tai Chi on balance. The results for interventions (<8 week) suggested a non-significant effect of Tai Chi on balance enhancement (SMD = 0.10, 95 % CI: -1.11 to 1.31, $P = 0.87$) (Fig. 4). This effect size may be attributed to the limited duration of Tai Chi practice, which might be insufficient for participants to develop and retain the strength and coordination required to improve balance. The substantial heterogeneity (I^2= 96 %) could be reflective of varied methodological approaches, different balance assessment tools used, or heterogeneous participant demographics across the studies.

3.6.1.2. Medium term effect of Tai Chi on balance. During the medium-term period, a significant positive effect of Tai Chi was observed (SMD = 0.74, 95 % CI: 0.22 to 1.26, $P = 0.005$) (Fig. 5). The magnitude of this effect suggests that the 8 to16 week period is potentially encouraging

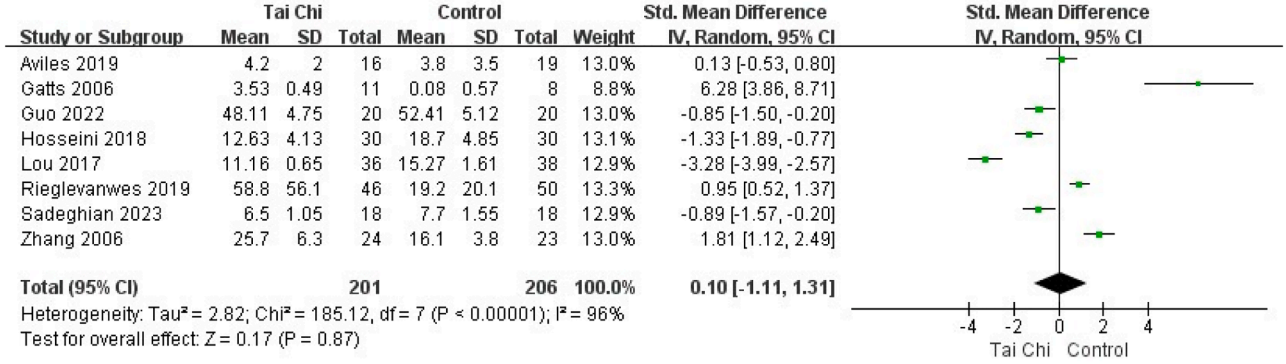


Fig. 4. Forest plot of comparison of short-term effect of Tai Chi on balance.

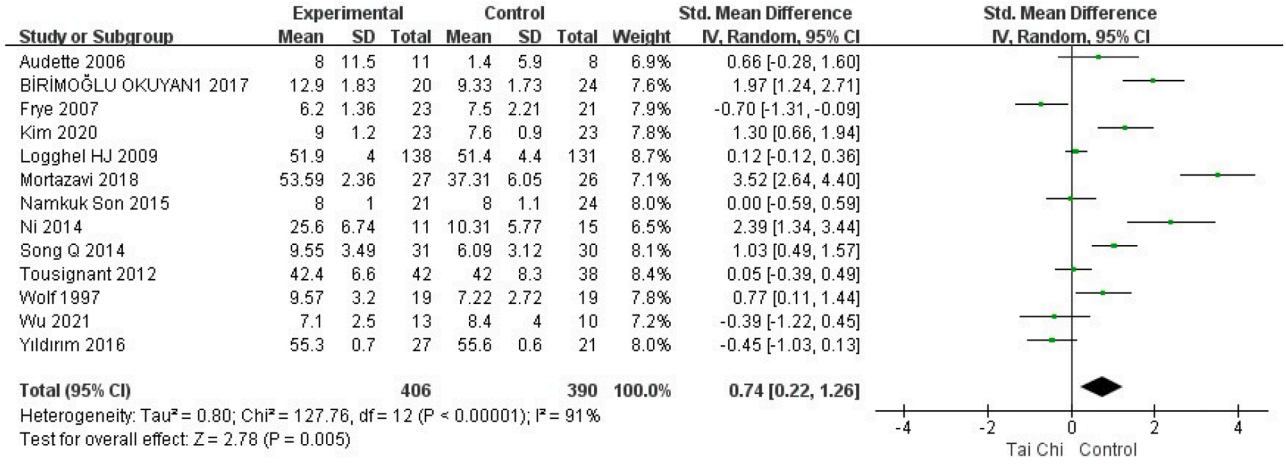


Fig. 5. Forest plot of comparison of Medium-term effect of Tai Chi on balance.

the cumulative benefits of Tai chi in balance. The high heterogeneity (I^2= 91 %), while indicative of variability in study results, does not diminish the observed positive trend, which is largely consistent across the contributing studies.

3.6.1.3. Long term effect of Tai Chi on balance. In the analysis of long-term effect from Tai Chi, the positive trend continued with an SMD of 0.34 (95 % CI: -0.17 to 0.84), although the test for overall effect was not statistically significant (P = 0.19) (Fig. 6). This persistence in the direction of effect size favouring Tai Chi could suggest a sustained benefit of the practice. However, the absence of statistical significance and the very high heterogeneity (I^2= 98 %) may be influenced by a range of factors including participant adherence, intensity of Tai Chi practice, and different training protocols among the studies.

3.6.2. Strength

Fig. 7 presents the results on the influence of Tai Chi on elderly muscular strength, as tested by Grip muscle strength, Sit to Stand test, Chair rise test, Concentric Knee joint muscle strength, and BiodexSystem3Pro isokinetic limn muscle strength testing. The combined analysis resulted in a SMD of 0.43 (95 % CI: 0.01 to 0.84), achieving statistical significance (Z = 2.03, P = 0.04). This indicates that Tai Chi has a favourable effect on muscular strength when compared to control groups. However, high heterogeneity (I^2= 96 %) suggests that the reported effect sizes are not consistent across studies and may be influenced by diverse factors such as differences in Tai Chi styles, intervention duration, frequency, as well as variation in the methods used to assess strength. Despite these variations, the overall analysis suggests that Tai Chi is potentially beneficial in enhancing muscular strength among the elderly, which is a critical component of overall balance and fall prevention.

3.6.2.1. Short term effect of Tai Chi on strength. Fig. 8 shows the results from a meta-analysis assessing the short-term effects (<8 weeks) of Tai Chi on strength. The SMD is 1.43, with a 95 % CI from -0.61 to 3.47, indicating a potentially large effect size. However, the test for overall effect is not statistically significant (Z = 1.37, P = 0.17), which might be reflective of the small number of studies or variability in the methodologies employed.

3.6.2.2. Medium term effect of Tai Chi on strength. The meta-analysis for medium-term strength outcomes (8–16 weeks) indicates a small SMD of 0.26 with a 95 % CI from -0.26 to 0.78 (Fig. 9). Despite the positive direction of the effect, the overall effect is not statistically significant (P = 0.33), suggesting that while there may be a trend towards improved strength with Tai Chi practice in the medium term, the results are not

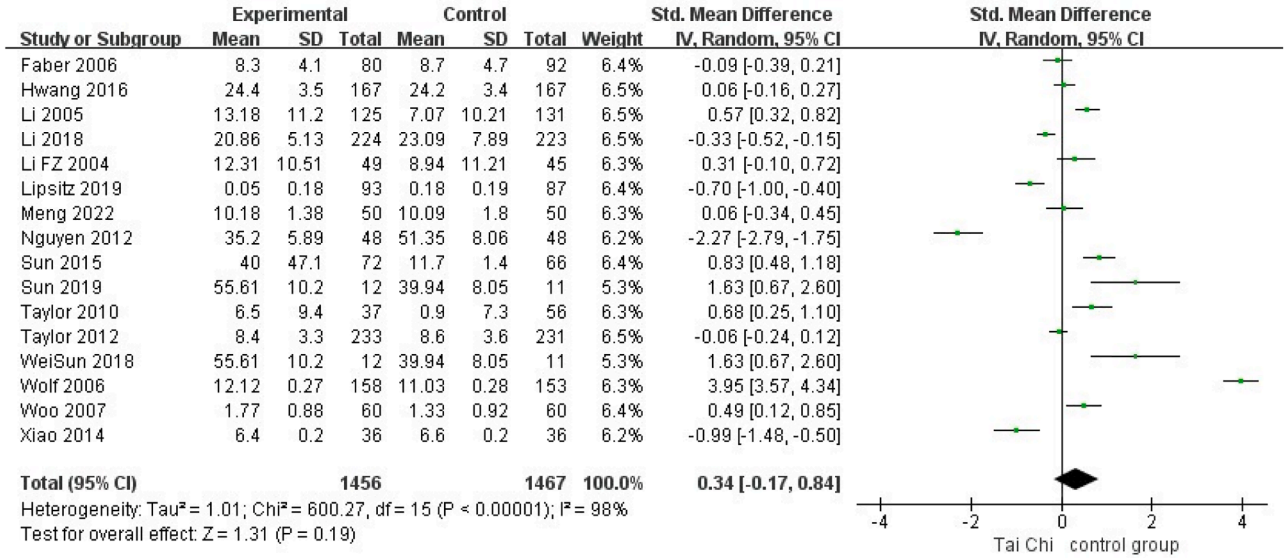


Fig. 6. Forest plot of comparison of Long-term effect of Tai Chi on balance.

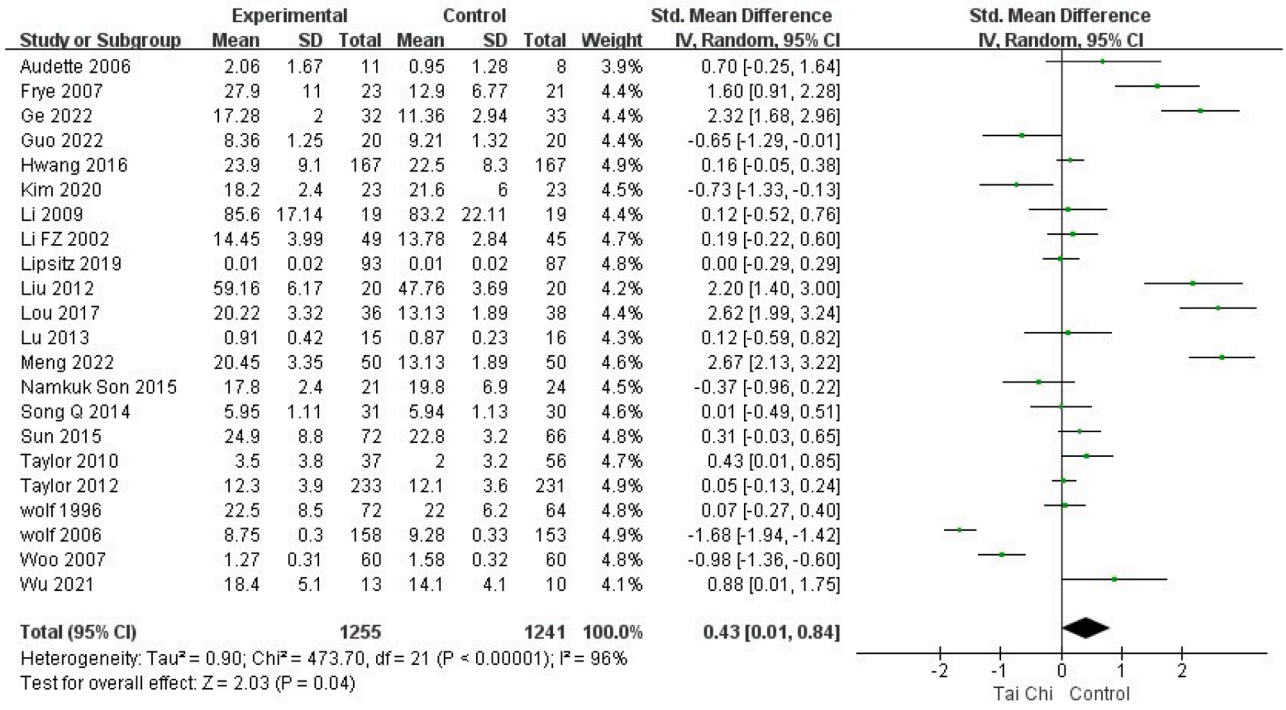


Fig. 7. Forest plot of comparison of effectiveness of Tai Chi on muscular strength.

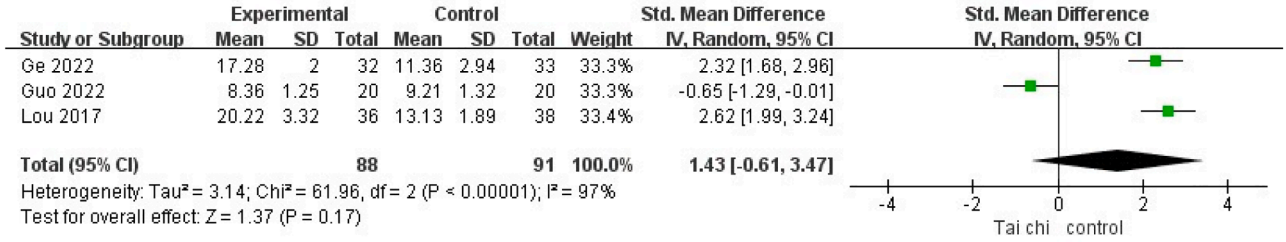


Fig. 8. Forest plot of comparison of short-term effect of Tai Chi on muscular strength.

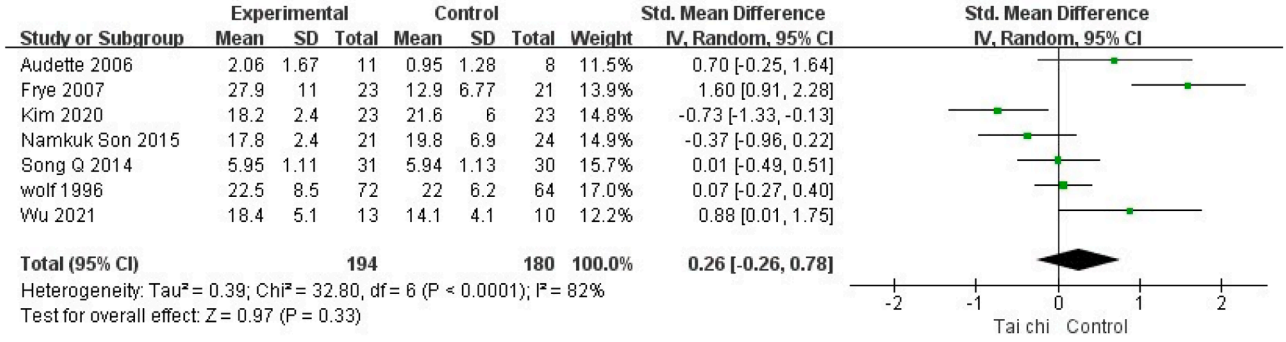


Fig. 9. Forest plot of comparison of medium-term effect of Tai Chi on muscular strength.

conclusive. The heterogeneity among the included studies is considerable (I^2= 82 %), which implies that the individual study results are quite varied.

3.6.2.3. Long term effect of Tai Chi on strength. For the long-term Tai Chi effects on strength, the meta-analysis shows a similar small SMD of 0.27 with a 95 % CI from -0.26 to 0.79 (Fig. 10). Although the long-term impact of Tai Chi on strength shows a positive trend, the effect does not achieve statistical significance ($P = 0.32$), indicating an uncertain benefit from sustained practice. The heterogeneity remains high ($I^2 = 97$ %), indicating substantial variability across studies.

3.6.3. Assessment of publication bias in balance and strength measures

The meta-analysis revealed significant improvements in both balance and strength among the elderly following Tai Chi intervention. To assess the reliability of these findings, we examined potential publication bias using funnel plots for both balance and strength measures. The funnel plot for balance measures (Fig. 11) demonstrates a generally

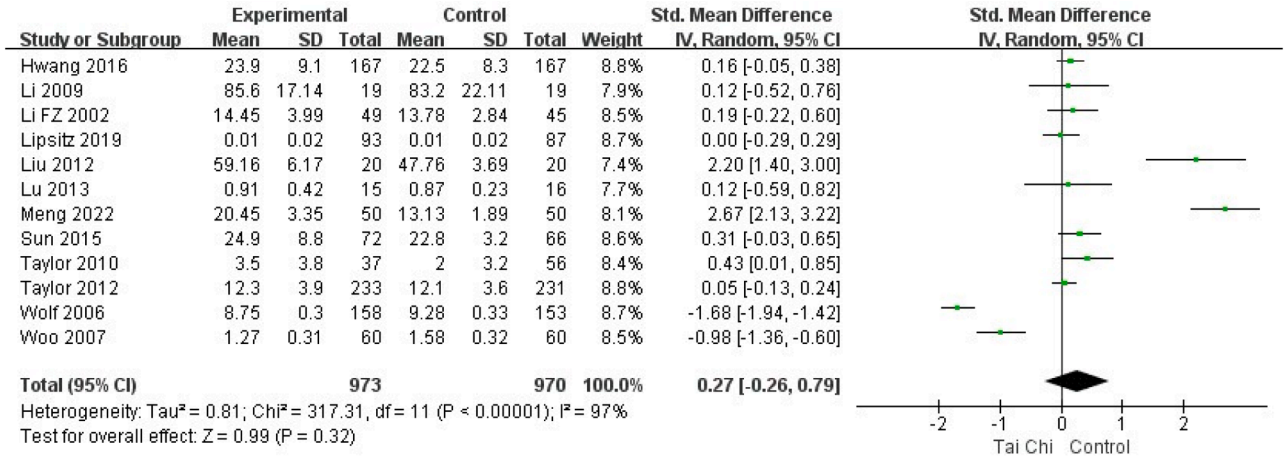


Fig. 10. Forest plot of comparison of long-term effect of Tai Chi on muscular strength.

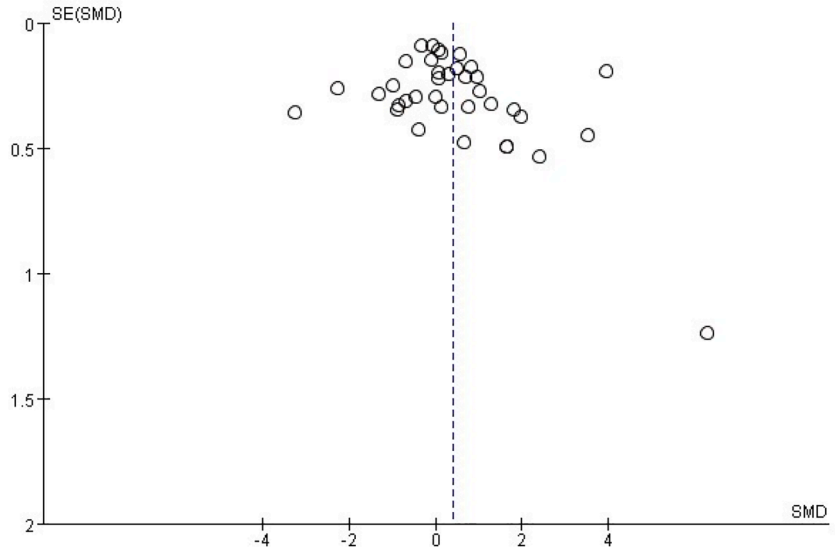


Fig. 11. Funnel plot of comparison of the effect of Tai Chi on balance.

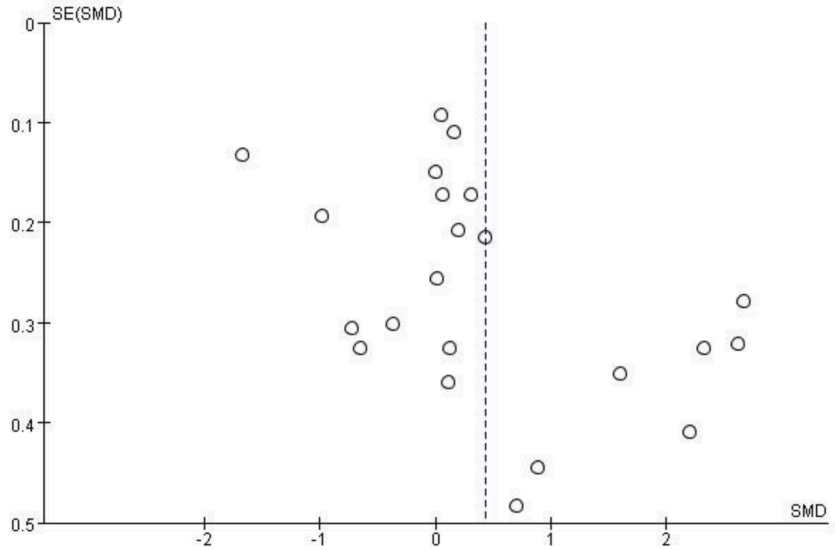


Fig. 12. Funnel plot of comparison of the effect of Tai Chi on muscle strength.

symmetric distribution around the central line, suggesting a low risk of publication bias, despite the presence of one outlier with a high effect size and standard error. This indicates that the overall findings for balance are likely robust and minimally affected by bias. In contrast, the funnel plot for strength (Fig. 12) measures reveals some asymmetry, with a clustering of studies showing positive effect sizes on the right side of the plot, which may indicate potential publication bias. This asymmetry implies that studies with positive strength outcomes might be overrepresented, necessitating careful interpretation of these results.

4. Discussion

4.1. The overall effectiveness of Tai Chi on balance and strength

This meta-analysis synthesised data from 37 studies assessing the impact of Tai Chi on balance among elderly participants. The results demonstrated a statistically significant positive effect, with a combined SMD of 0.40 and a 95 % CI of 0.05 to 0.75 ($P = 0.03$). This significant finding supports the efficacy of Tai Chi in enhancing general balance in elderly populations. Furthermore, the moderate effect size (SMD=0.40), with a statistically significant P-value (0.03), indicates a meaningful improvement in balance that could significantly reduce the risk of falls, a prevalent concern among the elderly. These results aligns with the findings by You et al. (2021) which noted similar improvements in postural control with Tai Chi practice.

In addition to balance, our analysis included assessments of muscular strength, utilising metrics such as grip muscle strength and chair rise tests etc. The results revealed a statistically significant enhancement in muscular strength, with a combined SMD of 0.43 and a CI from 0.01 to 0.84 ($P = 0.04$). This aligns with findings from Yang et al. (2021) who observed notable improvements in strength among elderly Tai Chi practitioners. Our results contribute to the growing body of evidence suggesting that Tai Chi is beneficial not only for improving balance but also for enhancing muscular strength, which is essential for mobility and independence in elderly individuals.

The significant improvements in both balance control and muscular strength suggest that Tai Chi could serve as an important tool in elderly care programs, particularly for enhancing balance and strength-related components critical for daily activities and preventing falls. These benefits underscore the potential of Tai Chi as a multifaceted intervention aimed at improving overall physical health and reducing fall risk among seniors.

4.2. Influence of intervention duration

Our findings indicate that the impact of Tai Chi on elderly balance varies significantly depending on the duration of the intervention. Short-term interventions (less than 8 weeks) did not show statistically significant improvements. However, medium-term interventions (8–16 weeks) resulted in significant enhancements, while long-term interventions (more than 16 weeks) demonstrated a positive trend, though these were not statistically significant.

The non-significant results observed in short-term interventions may be due to the insufficient time for participants to adapt physically and neurologically to Tai Chi practices (Pan et al., 2018). In contrast, medium-term interventions appear to be of adequate duration for participants to both learn the movements and experience the physiological changes associated with improved muscle activities and neuromuscular coordination. There is a positive trend with respect to long-term effects. However, further analysis taking into account frequency, adherence, and specific characteristics of Tai Chi are required to understand the relationships. Similar to findings from Wang, Collet and Lau (2004), our medium-term results highlight significant benefits, supporting the notion that sustained practice between 8 weeks and 16 weeks is crucial for tangible improvements in elderly balance. However, unlike Hong, Li and Robinson (2000) who reported favourable effects of long-term Tai Chi on the promotion on balance control, our study suggests a plateau, highlighting the potential variability in long-term adherence and intervention effectiveness.

Previous research has generally indicated that Tai Chi provides moderate to significant improvements in muscular strength among elderly populations. Studies by Song et al. (2014) and Wehner et al. (2021) reported that regular Tai Chi practice leads to significant enhancements in both upper and lower body strength, aligning with our analysis which shows a favourable effect on muscle strength (SMD = 0.43, $P = 0.04$).

Contrasting our findings, Bagiartana (2022) found significant improvements in lower leg muscle strength within 8-week Tai Chi program, suggesting that even short-term interventions can be effective. This differs from our results which short-term effects were large but not statistically significant (SMD = 1.43, $P = 0.17$), possibly due to the greater variability and fewer studies in our meta-analysis. This indicates that while there may be potential for Tai Chi to improve strength in short term, more consistent and rigorous studies are necessary to confirm these effects. During the medium-term period, our findings indicated a smaller effect size (SMD = 0.26) with no statistical significance ($P = 0.33$) and moderate heterogeneity ($I^2 = 82$ %). This suggests that while there is a trend towards improved muscular strength, the benefits of Tai Chi may not be substantial enough over this period to be conclusively measured across different studies. The observed variability could be due to differences in the intensity or style of Tai Chi practiced, highlighting the need for standardisation in future research protocols. In addition, our meta-analysis of long-term Tai Chi impacts shows a positive but non-significant effect on muscular strength (SMD = 0.27, $P = 0.32$) in the elderly for periods extending beyond 16 weeks. In contrast, the study of Ma et al. (2023) reported significant improvements in lower extremity strength following Tai Chi practiced for a long term (over 5 years). The discrepancy in outcomes might stem from the different lengths of what is considered "long-term," suggesting that more extended periods could be necessary to achieve measurable benefits from Tai Chi. This highlights the importance of intervention duration in Tai Chi studies and suggests a potential for greater benefits with longer practice.

4.3. Heterogeneity in outcome measures

Combining data from different measurement instruments could introduce heterogeneity. Balance outcome instruments varied across studies; for instance, the 'Time Up and Go' (TUG) test used in some studies while the 'One-Leg Stand' (OLS) test employed in others (Appendix 3). Data from 12 studies were analysed using the TUG test, which measures the time taken to stand from a seated position, walk three meters, return, and sit down, thereby serving as an indicator of functional mobility. Meanwhile, data from 9 studies were used for the OLS test, which assesses the ability to maintain balance on one leg, a key measure of static balance. The subgroup analysis including TUG test, which assesses multiple components of balance, showed a non-significant effect on balance (SMD = -0.33, 95 % CI: -0.77, 0.11; $P = 0.14$) with high heterogeneity ($I^2 = 93$ %). In contrast, the OLS test of subgroup analysis, a more direct assessment of balance, exhibited a significant effect (SMD = 1.01, 95 % CI: 0.66, 1.37; $P < 0.00001$) with moderate heterogeneity ($I^2 = 75$ %). The discrepancy in heterogeneity may be attributed to the multifaceted nature of the TUG test, potentially introducing variability, as opposed to the specific balance challenge posed by the OLS test (Criter & Honaker, 2016).

Similarly, the subgroup analysis (Appendix 3) for the Grip muscle strength test (27.2 % of studies) and Chair rise test + Sit to Stand test (40.9 % of studies) revealed SMD of 0.62 (95 % CI: -0.09 to 1.32; $P = 0.09$) and 0.30 (95 % CI: -0.54 to 1.14; $P = 0.48$), respectively. Both analyses showed high heterogeneity ($I^2 = 96$ % for grip strength and $I^2 = 97$ % for Chair rise test + Sit to Stand test), indicating significant variability across studies. This variability may be due to differences in participant demographics, Tai Chi styles, intervention frequency, the

varying methods used for assessment. These findings suggest that while Tai Chi has the potential to improve muscle strength, the significance of its effects may be influenced by a range of factors, underscoring the need for more standardized approaches in future research.

4.4. Practical recommendations

Based on our findings, we recommend the incorporation of Tai Chi into physical activity programs for the elderly as a strategy to enhance balance and muscular strength. Our meta-analysis indicates that Tai Chi, particularly when practiced over medium to long durations (8–16 weeks), significantly improves both balance and strength. Therefore, health practitioners should consider structuring Tai Chi sessions to last for at least 8 weeks with a minimum frequency of two sessions per week. Such programs should be tailored to meet the varying physical capabilities of elderly participants, possibly by modifying Tai Chi styles and adjusting the intensity to individual needs. Continuous assessment should be integral to these programs, allowing for adjustments based on participant feedback and evolving research insights. This approach not only maximises the health benefits but also promotes greater adherence and satisfaction among participants, ultimately contributing to the reduction of fall risks and the enhancement of mobility and independence in the elderly population.

4.5. Strength and limitations

The primary advantage of our study lies in its comprehensive meta-analysis approach, incorporating data from 37 studies on balance and 22 studies on strength. This extensive dataset allows for a detailed understanding of Tai Chi's effects across different populations and settings. By incorporating various assessment tools, including the Time Up and Go test, Berg's Balance Test, and muscle strength measurements, we provide a broad perspective of the physical benefits of Tai Chi. Furthermore, the meta-analysis of intervention durations—from short to long-term—adds valuable insights into how the duration of Tai Chi practice influences its effectiveness. This differentiation is critical as it guides practitioners in designing Tai Chi programs that are not only effective, but also tailored to meet the longevity needs of elderly participants, potentially enhancing adherence and outcomes over time.

However, our study still has some limitations. The most significant challenge is the high level of heterogeneity observed across the included studies ($I^2 = 96$ % for balance and 91 % for strength), which points to variability in Tai Chi styles, participant demographics, intervention lengths, and outcome measures. This heterogeneity complicates the task of generalising our results to all elderly populations and settings. Additionally, the limited data on long-term effects beyond 16 weeks, which were not statistically significant, suggests a gap in our understanding of the sustained impacts of Tai Chi. This is compounded by the potential for publication bias, where studies showing positive effects of Tai Chi are more likely to be published than those with negative or inconclusive results, potentially influencing our analysis towards more positive outcomes. Moreover, the variability in Tai Chi protocols, including differences in session frequency, duration, and style, further challenges the identification of the most effective practices, making it challenging to suggest certain Tai Chi approaches to individuals.

4.6. Recommendation of the future research

Future research should focus on standardising Tai Chi protocols to reduce the high heterogeneity observed in our study, thus clarifying which length of practice yield the most benefit for elderly balance and strength. There is a positive trend with respect to long-term effects. However, further analysis taking into account the frequency, adherence, and specific characteristics of Tai Chi are required to understand the relationships. Additionally, future work should include more diverse participant demographics and rigorous RCTs to enhance the generalisability and reliability of findings. Investigating the physiological and psychological mechanisms underlying Tai Chi's benefits will further our understanding of its impact. Finally, integrating Tai Chi with other interventions and assessing its influence on health care utilization could provide a holistic view of its role in elderly health maintenance and preventive care strategies. These efforts will significantly contribute to optimising Tai Chi as a therapeutic tool for improving elderly well-being.

5. Conclusion

This meta-analysis has demonstrated that Tai Chi offers significant benefits for improving balance and strength among the elderly, particularly when practiced over medium to long-term periods. While the results reveal variability in effectiveness due to factors such as intervention frequency and Tai Chi style, the overall evidence supports the integration of Tai Chi into exercise regimens for the elderly to enhance physical health and reduce the risk of falls. Despite some limitations in study heterogeneity and duration, the findings underscore Tai Chi's potential as a valuable component of preventive health care strategies for ageing populations. Future research should focus on standardising intervention protocols and extending study durations to fully capture the long-term benefits and optimise Tai Chi programs for elderly care.

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CRediT authorship contribution statement

Lina Nan: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Diana Grunberg:** Writing – review & editing, Supervision, Methodology. **Sinha De Silva:** Writing – review & editing, Supervision, Methodology. **Divya Sivaramakrishnan:** Writing – review & editing, Visualization, Supervision, Resources, Project administration, Methodology, Conceptualization.

Declaration of competing interest

There are no conflicts of interest to declare.

Data availability

The data has been included as an appendix file: Appendix 2. Raw data.xlsx

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Supplementary materials

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