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REVIEW ARTICLE (META-ANALYSIS)

Effects of Tai Chi on Lower Limb Proprioception in Adults Aged Over 55: A Systematic Review and Meta-Analysis

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Abstract

Objective: To summarize and critically evaluate the effects of Tai Chi on lower limb proprioception in adults older than 55.

Data Sources: Seven databases (Scopus, PubMed, Web of Science, SPORTDiscus, Cochrane Library, Wanfang, CNKI) were searched from inception until April 14, 2018.

Study Selection: Eleven randomized controlled trials were included for meta-analysis.

Data Extraction: Two independent reviewers screened potentially relevant studies based on the inclusion criteria, extracted data, and assessed methodological quality of the eligible studies using the Physiotherapy Evidence Database (PEDro).

Data Synthesis: The pooled effect size (standardized mean difference [SMD]) was calculated while the random-effects model was selected. Physiotherapy Evidence Database scores ranged from 5 to 8 points (mean=6.7). The study results showed that Tai Chi had significantly positive effects on lower limb joint proprioception. Effect sizes were moderate to large, including ankle plantar flexion (SMD=−0.55; 95% confidence interval [95% CI], −0.9 to −0.2; $P=.002$; $I^2=0\%$; n=162), dorsiflexion (SMD=−0.75; 95% CI, −1.11 to −0.39; $P<.001$; $I^2=0\%$; n=162), nondominant or left knee flexion (SMD=−0.71; 95% CI, −1.10 to −0.41; $P<.001$; $I^2=25.1\%$; n=266), dominant or right knee flexion (SMD=−0.82; 95% CI, −1.06 to −0.58; $P<.001$; $I^2=33.8\%$; n=464).

Conclusions: There is moderate to strong evidence that suggests that Tai Chi is an effective intervention to maintain and improve lower limb proprioception in adults older than 55. More robust multicenter studies including oldest-old participants, with longer follow-ups and validated outcome measures, are needed before a definitive conclusion is drawn.

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Proprioception is the ability to sense the position and movement of the body in space by integrating the sensory signals arising from the mechanoreceptors in the muscles, joints, and ligaments.[1,2] Proprioception plays a vital role in human movement control, which is fundamental for daily activities.[3,4] Research has shown that proprioceptive function declines with increasing age,[5-7] and this age-related decline in proprioception may affect balance control and increase falls risk in older people.[8,9] Notably, falls are the leading cause of disability and injury deaths among older people,[10] which has put a substantial health care burden on the society.[11] Therefore, seeking effective intervention strategies to maintain and improve proprioceptive ability is critically needed.

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Physical activity or exercise has been shown to be effective in attenuating the regression of proprioception of the elderly.[12] Tai Chi is a moderate-intensity, mind-body physical activity, which involves mental focus on coordinated movement control and smooth shift of body weight from single-leg stance to double-leg support alternately.[13] The positive effects of varying magnitudes of Tai Chi on strength,[14] flexibility,[15] balance,[16] and cardiorespiratory function[17] in older people are well-documented in previous studies.

Researchers have recently shifted their attention to investigating the effects of Tai Chi on lower limb proprioception in aging population. A number of observational[18-23] and empirical studies[24-27] have found encouraging results that Tai Chi training may enhance lower limb proprioception in the elderly. However, no systematic review has been conducted to date to synthesize the emerging literature; thus, a definitive conclusion regarding the effects of Tai Chi on lower limb proprioception still remains unclear. Accordingly, this review sets out to critically evaluate the effects of Tai Chi training on lower limb proprioception in older people. The findings of this systematic review provide evidence-based recommendations to health professionals, such as geriatricians, primary care physicians, sports physicians, rehabilitation medicine specialists, physical therapists, and fitness trainers for attenuating and improving proprioceptive abilities in older people.

Methods

The process of the present study is in accordance to the Preferred Reporting Items for Systematic Review and Meta-Analysis statement.[28]

Search methods

Both Chinese (Wanfang and CNKI) and English (Scopus, PubMed, Web of Science, SPORTDiscus, Cochrane Library) databases were systematically searched by the lead author (L.Z.) on April 14, 2018. To include as many studies as possible, no publication date was limited. Three groups of search terms were integrated for the literature search: (1) Tai Chi, TaiChiQuan, Taiji, TaijiChaun, Chinese traditional exercise, or traditional Chinese exercise; (2) proprioception, proprioceptive, joint position, position reproduction, position matching, joint reposition, position sense, movement sense, kinesthesia, or sensorimotor; (3) old, older, aged, elderly, or senior. Furthermore, other potential studies were retrieved from reference lists of other reviews and selected articles.

Inclusion criteria and trial selection

Because this is the first review to synthesize research findings regarding the effects of Tai Chi on proprioception in the elderly, we attempted to include peer-review studies with different study designs, such as randomized controlled trial (RCT), controlled trial with no randomization, trial with pretest-posttest design, and cross-sectional study. In addition, participants in the selected trials must be 55 years old or above,[29] and at least 1 joint proprioception of the lower limb was measured as outcome. Although performing meta-analysis was only limited to RCTs (table 1), the key information of other studies was also described in table 2. Case study, case series, review studies, unpublished documents (dissertation and thesis), and book chapters were excluded. The lead author (L.Z.) initially screened the identified records and removed those irrelevant and duplicated documents according to the title and abstract. Full-text assessment of the remaining studies was independently carried out by 2 investigators (L.Z. and C.L.) to determine whether they met the inclusion criteria. Any eligibility-related discrepancies between the 2 investigators were discussed with the third assessor (J.H.) until a consensus was reached.

List of abbreviations:

95% CI	**95% confidence interval**
DF	**dorsiflexion**
PF	**plantar flexion**
RCT	**randomized controlled trial**
SMD	**standardized mean difference**
TTDPM	**threshold to detection of passive motion**

Risk of bias of all selected RCTs

We assessed risk of bias of all selected RCTs using the modified 10-item Physiotherapy Evidence Database scale.[30-32] Assessment of these items involved eligibility criteria, randomization, allocation concealment, similar baseline, blinding of assessors, >85% retention rate, intention-to-analysis, between-group comparison, point measure and measures of variability, and isolated Tai Chi intervention (table 3). Double-blinded RCTs are strictly speaking the most reliable source of evidence; however, sometimes double-blinding (blinding of participants and instructors) can be impractical and difficult during an exercise intervention. Given this fact, these items were not considered in this systematic review. In addition, eligibility criteria were not considered for scoring, as suggested by Maher et al,[33] which resulted in a maximum of 9 points. Notably, we did not use the sum score to summarize the study quality of the selected trials, but assessed each individual item, as suggested by Da Costa et al.[34]

Data extraction and synthesis

Data extraction was independently performed by 2 investigators (L.Z. and X.P.) using 2 structured tables. Table 1 included the data of all eligible RCTs, and the key information of other non-RCTs was extracted in table 2. Data extracted in table 1 were study characteristics (the first author, publication year, study location, language of publication), participant characteristics (sample size and attrition rate, health status, sex, mean age/age range), intervention program (training dosage, qualification of Tai Chi instructor, duration, total training hours, compliance with Tai Chi intervention), and proprioceptive outcome measured. The main difference between table 1 and table 2 is that table 2 briefly reports research findings, whereas table 1 does not because their findings were used to calculate the pooled effects sizes.

For the selected RCTs we synthesized the quantitative data of proprioception, regardless they were extracted from Chinese or English journal articles, using the Comprehensive Meta-Analysis Software version 2.0.[a] If the quantitative data (mean, standard deviation, the number of participants per group) were not reported in the published paper, the lead author (L.Z.) contacted the corresponding author of the study to request data needed. Both random-effects model and 95% confidence interval (95% CI) were selected. The pooled effect size (standardized mean difference [SMD]) was obtained to reflect the magnitude of Tai Chi intervention effect on proprioception in the elderly. Heterogeneity of the selected RCTs was assessed using percentage of the I^2 (25% = small, 50% = moderate, 75% = large

Table 1 Summary in study characteristics of the selected randomized controlled trials

Study		Participant Characteristics					Intervention Program				Proprioceptive Outcome
Reference	Location, Language	n, AT (%)	Health Status	Sex, Women (%)	Mean Age (y)	BW (kg)/ height (cm)	Training Dosage (TC Style, Qualified Instructor)	Duration (wk)	Total h	CTCI (%)	Instrument: Joint Proprioception
Li et al (2008)[24]	China* (English)	50, 20	Healthy	50	65.25	67.8/164	TC: 4 × 60 min/wk (24-Yang style, yes) CG: unaltered lifestyle	16	64	92	TTDPM for a dominant leg: ankle (M value of PF/DF); knee (F and E)
Chang et al (2016)[25]	China (English)	52, 17	Healthy	100	60.21	62.8/158	TC: 4 × 60 min/wk (24-Yang style, yes) CG: waitlist	24	96	92	TTDPM for a random measure of left or right: ankle (PF and DF); knee (F and E)
Liu et al (2012)[26]	China (English)	60, 30	Healthy	57	68.91	59/165	TC: 2 × 45 min/wk (24-Yang style, yes) CG1: 2 × 45 min/wk (PET) CG2: unaltered lifestyle	16	24	NR	Passive JPR for bilateral legs - left and right: ankle (M value of inversion/eversion)
Zhang et al (2015)[27]	China (English)	60, 13.3	Healthy	100	62.09	65.1/159	TC: 5 × 60 min/wk (24-Yang style, yes) CG1: 5 × 60 min/wk (brisk walking) CG2: 5 × 60 min/wk (TV or newspapers)	16, 8	80	NR	TTDPM for a dominant leg in a random order: ankle (PF and DF)
Wang et al (2016)[38]	China (Chinese)	40, 0	Healthy	42.5	56.25	60/161	TC: 5 × 60 min/wk (24-Yang style, yes) CG: unaltered lifestyle	16	80	NR	X-sens 3-dimensional positional measuring system for bilateral sides (left and right) of knee flexion
Yan et al (2014)[39]	China (Chinese)	70, 0	Healthy	47	64.66	59/166	TC: 4 × 45 min/wk (24-Yang style, yes) CG: 4 × 45min/wk (brisk walking)	16	48	NR	Passive JRP for dominant and non-dominant legs: knee flexion (30, 45, 60 degrees)
Liu et al (2012)[40]	China (Chinese)	60, 0	Healthy	51.7	59.35	59.8/164	TC: 4 × 40 min/wk (24-style, yes) CG: 4 × 40 min/wk (brisk walking)	12	32	NR	Active JRP for dominant and nondominant legs of knee flexion
Chen et al (2012)[41]	China* (English)	40, 42.5	Visually impaired	NR	84.27	NR	TC: 3 × 90 min/wk (8-Yang style, yes) CG: 3 × 90 min/wk (music percussion)	16	72	NR	Passive JPR for a dominant leg: knee flexion (30 degrees)
Zhu et al (2017)[42]	China (English)	46, 13	Knee osteoarthritis	100	64.55	25.1^{BMI} (kg/m^2)	TC: 3 × 60 min/wk (24-Yang style, yes) CG: 1 × 60 min/wk (wellness education)	24	72	NR	TTDPM for left and right legs: Knee (extension and flexion)
Schmid et al (2013)[36]	USA (English)	40, 0	Knee osteoarthritis	75	65	29.9^{BMI} (kg/m^2)	TC: 2 × 60 min/wk (10-Yang style, yes) CG: 2 × 60 min/wk (wellness education)	12, 48	24	85	Passive JPR for a dominant leg: Knee flexion (30, 45, 60 degrees)
Sungkart et al (2017)[37]	Tailand (English)	66, 10.6	Mild cognitive impairment	83.3	67.9	23.8^{BMI} (kg/m^2)	TC: 3 × 50 min/wk (10-Yang style, yes) CG: reading material related to cognitive impairment and fall prevention	15	37.5	88	Passive JPR for a dominant leg: Knee flexion

Abbreviations: AT, attrition rate; BMI, body mass index; BW, body weight; CTCI, compliance with Tai Chi intervention; CG, control group; E, extension; F, flexion; JPR, joint position reproduction; M, mean; TC, Tai Chi; PET, proprioceptive exercise training.

* Hong Kong.

Table 2 Summary of cross-sectional studies and trial with pretest-posttest design

Reference, Study Design	Location, Language	Study Participants	Intervention Group	Frequency and Duration of Intervention	Outcome Measured	Finding Related to Joint Proprioception of Lower Limb (Unit: Degree)
Xu et al (2004),[18] CSS	China* (English)	Healthy, mean age 66, mean 164 cm/67 kg	TC (n=21) S/R (n=20) CG (n=27)	TC: 90 min/d for ≥4 y S/R: ≥60 min/d for ≥4 years CG: no regular exercise for >4 y	Dominant leg: ankle and knee (TTDPM)	Baseline: TC group (1.21±0.33) could detect a significantly smaller amount of motion than CG (1.95±0.66) (P=.001) and S/R group (1.78±0.82) (P=.022). TC group showed a significantly lower mean threshold for detection of passive motion on knee flexion than CG (P=.026), but not S/R group (P=.597).
Tsang et al (2003),[19] CSS	China* (English)	Healthy, mean age 71, mean 155 cm/58kg	TC (n=21) CG (n=21)	TC: ≥90 min weekly for ≥3 y; CG: morning walks or stretching exercises	Dominant leg: knee (passive JPR)	Baseline: TC group showed a significantly smaller absolute angle error (2.1±1.2) than CG (4.0 ± 3.4) (P=.023).
Fong et al (2006),[20] CSS	China* (English)	Healthy, mean age 55, height/weight (NR)	TC1 (n=16) TC2 (n=16) CG (n=16)	TC1: 3 × 60-120 min weekly for 1-3 y TC2: 3 × 60-120 min weekly for 3 mo CG: no previous experience in TC	Dominant leg: knee (active JPR)	Baseline: Both long- and short-term TC groups showed significantly better knee joint reposition accuracy. Their degree of error was 50% less than that of the CG (P=.01 and P=.027, respectively).
Guo et al (2014),[21] CSS	China† (English)	Healthy, mean 64, mean 159 cm/58 kg	TC (n=16) CG (n=9)	TC: mean 9 y CG: regular physical activity, but TC	An ipsilateral leg: ankle (passive JPR)	Baseline: TC group showed less absolute mean error on dorsal flexion (3.51±1.89 vs 5.34±3.58, P=.11) and plantar flexion 2.74±1.56 vs 4.01±2.59, P=.23)
Cavegn et al (2015),[22] TPP	USA (English)	Patients with type 2 diabetes, mean 65, mean 163 cm/79 kg	TC (n=8)	TC: 3 × 60 min weekly for 8 wk TC group showed less absolute mean error	Bilateral legs: ankle (JPR)	At 8 weeks: TC group showed significantly smaller absolute mean error in ankle proprioception in patients with type 2 diabetes, with large effect sizes (Cohen's d): 1.7 (RDF), 1.8 (RPF), 1.4 (LDF), and 1.5 (LPF).
Tsang et al 2003[23]	China* (English)	Healthy, mean 69, mean 162 cm/64 kg, Except youth control (mean age 20.3)	TC (n=12) GF (n=11) CG: (n=12) YG (n =12)	TC: 90 min weekly for ≥ 3 y GF: 90 min weekly for ≥ 3y in golf CG: some morning walks or stretching YG: exercised regularly for ≥120 min weekly	Dominant leg: Knee (passive JPR)	Baseline: TC practitioners (1.7±1.3) and golfers (1.3±0.7) showed significantly better knee joint proprioception and made less absolute angle errors than the control elderly (3.9±3.1) (P=.001). Their proprioceptive acuity was actually comparable to that of the young control (1.1±0.5).

Abbreviations: CG, control group; CSS, cross-sectional study; GF, golfer; LDF, left dorsal flexion; LPF, left plantar flexion; RDF, right dorsal flexion; RPF, right plantar flexion; S/R, swimmer/runner; TC, Tai Chi; TPP, trial with pretest-posttest design; YG, young control.

* Hong Kong.

† Taiwan.

Table 3 Summary of methodological quality for all randomized controlled trials according to the modified PEDro scale

Reference	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Sum Score
Li et al (2008)[24]	1	1	0	1	0	0	0	1	1	1	5
Chang et al (2016)[25]	1	1	0	1	0	0	0	1	1	1	5
Liu et al (2012)[26]	1	1	0	1	0	0	0	1	1	1	5
Zhang et al (2015)[27]	1	1	0	1	0	1	0	1	1	1	6
Wang et al (2016)[38]	1	1	0	1	0	1	1	1	1	1	7
Yan et al (2014)[39]	1	1	0	1	0	1	1	1	1	1	7
Liu et al (2012)[41]	1	1	0	1	0	1	1	1	1	1	7
Chen et al (2012)[41]	1	1	0	1	1	0	1	1	1	1	8
Zhu et al (2017)[42]	1	1	0	1	1	1	1	1	1	1	8
Schmid et al (2013)[36]	1	1	1	1	0	1	1	1	1	1	8
Sungkart et al (2017)[37]	1	1	1	0	1	1	1	1	1	1	8

NOTE. Item 1, eligibility criteria; item 2, randomization; item 3, concealed allocation; item 4, similar baseline; item 5, blinding of assessors; item 6, more than 85% retention; item 7, missing data management (intention-to-treat analysis); item 8, between-group comparison; item 9, point measure and measures of variability; item 10, isolated Tai Chi intervention; 1, explicitly described and present in details; 0, absent, inadequately described, or unclear.

heterogeneity).[35] Also, publication bias was assessed according to the Egger's regression intercept test and the funnel plot.

For studies on ankle joint proprioception, movement directions (plantar flexion [PF], dorsiflexion [DF], inversion, and/or eversion) of the ankle measurement varied across 4 selected studies[24-27]; thus, only PF and DF reported in the 3 of 4 studies were used to calculate the pooled effect size. One trial that reported ankle inversion or eversion proprioception was not included.[26] Although Li et al[24] reported a mean value of PF or DF combined, it was separately used for 2 meta-analyses of PF and DF. To decrease the unit-analysis error, if there was a study with more than 1 control group, the sample size of the Tai Chi groups was equally divided for 2 comparisons, with means and standard deviations of the Tai Chi groups remained unchanged.

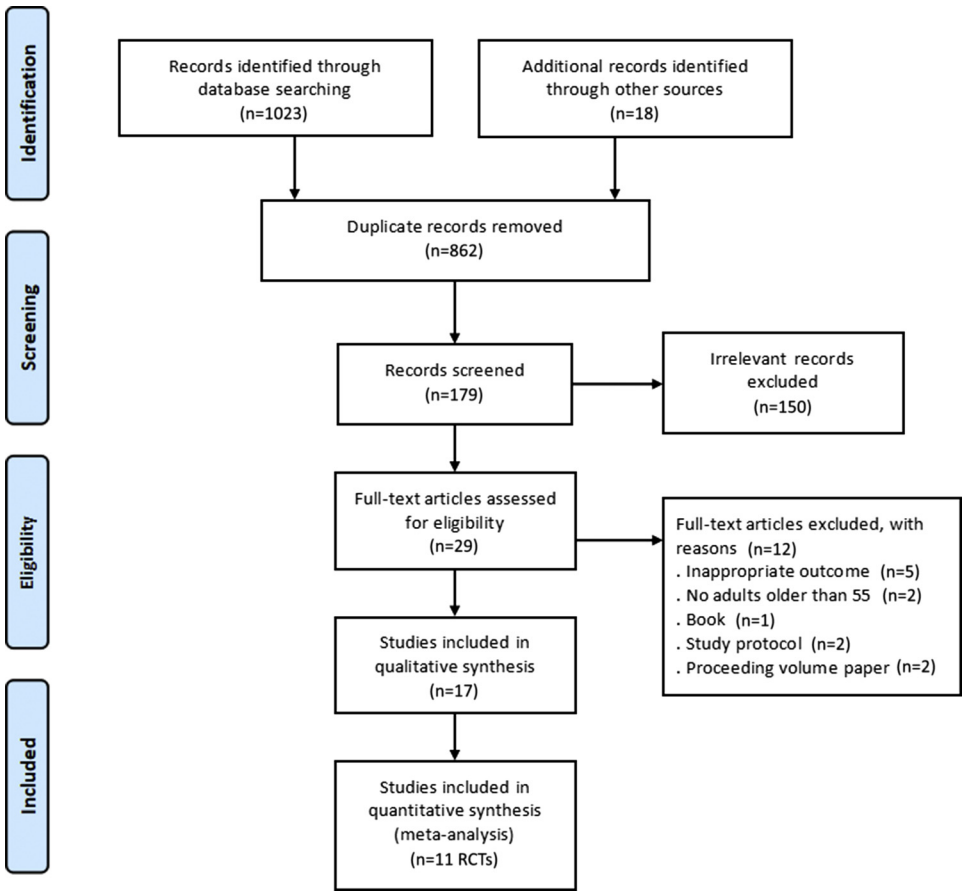

Fig 1 The flow of literature search and eligible study selection.

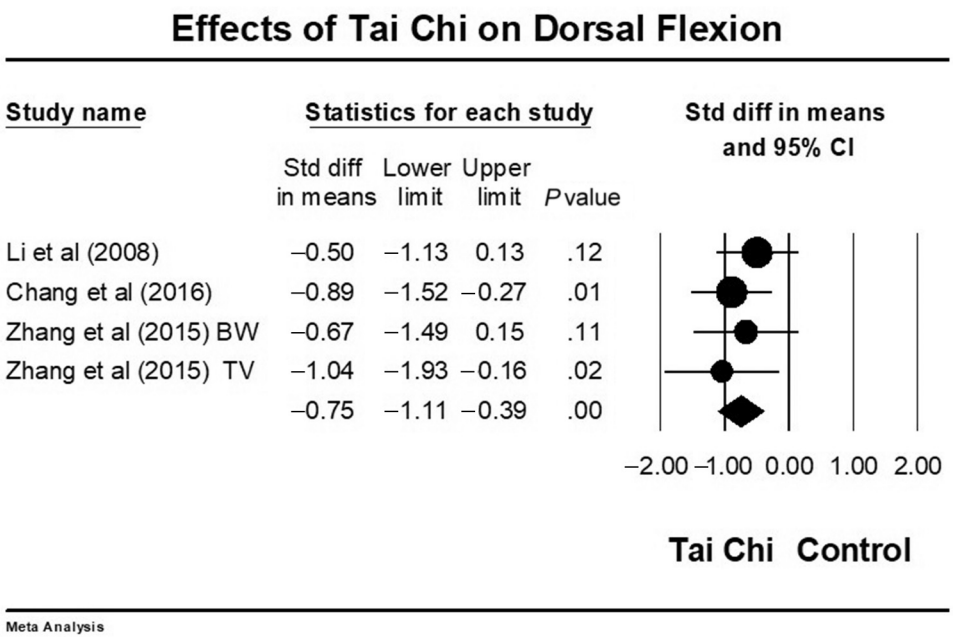

Fig 2 Effect of Tai Chi on DF (BW, brisk walking; TV, television watching).

For studies on knee joint proprioception, outcome measures reported also varied in direction (extension and flexion), degree (30, 45, and/or 60), and side (bilateral legs and ipsilateral-dominant leg). Similarly, we selected the most frequently reported knee flexion in 30 degrees. For those studies reporting bilateral lower extremities because most people are usually right dominant, we selected the quantitative data of right side and combined with dominant leg reported in the studies for meta-analysis. The same method was applied to the left and nondominant leg.

Results

Literature search

The flow of literature search and eligible study selection are summarized in fig 1. We first removed 862 records including duplicates from the initial 1041 searching records by screening authors, publication year, and title of each document, followed by screening of the remaining abstracts, and 150 irrelevant records were excluded. A total of 29 full-text articles were assessed against the predetermined eligibility criteria and 12 (inappropriate outcome = 5; no adults older than 55 = 2; book = 1; study protocol = 2; proceeding volume paper = 2) were excluded. Seventeen articles including 11 RCTs, 5 cross-sectional studies, and 1 trial with pretest-posttest design were included in qualitative synthesis. Only 11 RCTs were finally considered for meta-analysis.

Study characteristics

Table 1 includes 11 RCTs that evaluated the effects of Tai Chi on proprioceptive outcome of lower limb in the elderly. Studies with randomized controlled design were published between 2008 and 2017. Nine of the selected RCTs were conducted in China (including Hong Kong) and 1 RCT in the United States[36] and 1 in Thailand.[37] Eight of them were published in peer-reviewed English journals, and the rest were published in peer-reviewed Chinese-language journals. In total, 584 study participants (mean age 56.3-84.3) were included in the 11 eligible RCTs, with relatively high attrition rate, ranging from 10.6% to 42.5%. Healthy participants were recruited in 7 trials,[24-27,38-40] and other 4 trials included participants with either visual impairment[41] or knee osteoarthritis,[36,42] or mild cognitive impairment.[37] Percentage of female participants was 42.5%-100%, whereas the trial by Chen et al[41] did not report the number of female participants. Seven studies reported mean body weight (59-67.8 kg) and height (158-166 cm) separately, whereas 3 studies used body mass index, including 25.1,[42] 29.9,[36] and 23.8 kg/m^2.[37] The classic 24-Yang style Tai Chi routine was the most frequently used exercise intervention,[24-35,38-40,42] followed by 2 trials with 10-style Tai Chi,[36,37] 1 one study reported a modified 8-Yang style Tai Chi.[41] Intervention duration in Tai Chi were 12,[36,40] 15,[42] 16,[24,26,27,38-40] and 24 weeks.[25,42] Of the selected RCTs, only 2 trials reported follow-up periods and they were 8[27] and 48 weeks.[36] Total practice hours in Tai Chi were calculated, ranging from 24 to 96 hours. Notably, only 4 studies reported compliance rate with Tai Chi intervention and they were 85%,[36] 88%,[37] and 92%.[24,25] Adverse events during Tai Chi intervention did not occur across the selected RCTs.

Table 2 includes 6 English-language studies published between 2003 and 2017; 5 were conducted in the greater China region (Hong Kong and Taiwan)[18-21,23] and 1 in the United States.[22] Of them, 5 used cross-sectional design and 1 with pretest-posttest design.[22] All but 1 study[22] focused on healthy participants aged 55-71 on average. Other information was clearly described in table 2.

Methodological quality of randomized contrails

The methodological quality of the 11 selected RCTs was summarized in table 3. Quality scores ranged from 5 to 8 points,

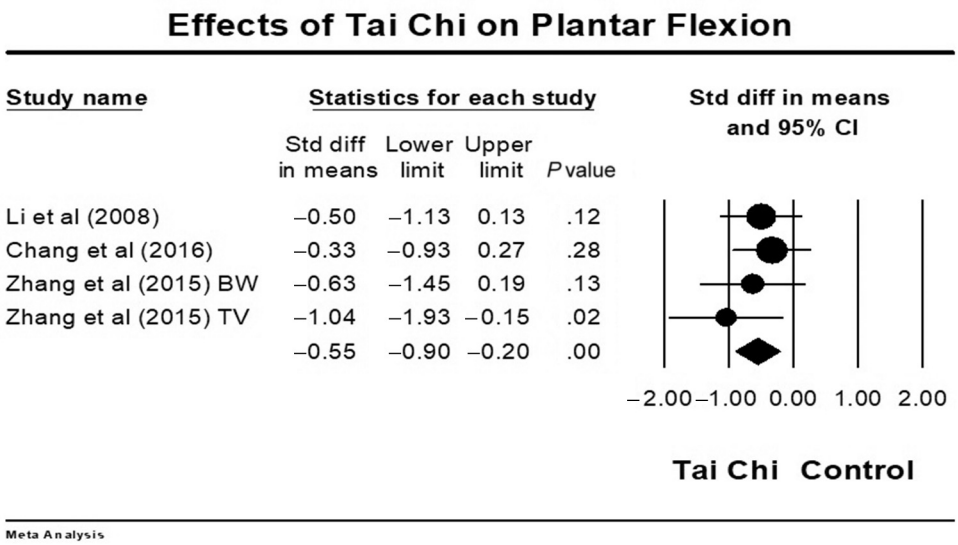

Fig 3 Effects of Tai Chi on PF (BW, brisk walking; TV, television watching).

with a mean of 6.7. It is worth noting that 9 and 8 of the studies failed to use allocation concealment[24-27,38-42] and blinding of assessors,[24-27,36,38-40] respectively. In addition, while attrition rate or missing data emerged in 4 studies, the researchers failed to apply *intention-to-treat analysis method* for missing data.[24-27]

Meta-analysis of outcome measured

Three studies with 4 comparisons investigated the effects of DF, as measured by 2 different proprioceptive instruments (threshold to detection of passive motion [TTDPM] and joint position reproduction tests).[24,25,27] A higher negative value indicates better proprioception of DF. The aggregated result of 3 trials showed a significantly moderate effect of Tai Chi on DF (SMD = −0.75; 95% CI, −1.11 to −0.39; $P<.001$; $I^2=0\%$; n = 162) (fig 2), as compared to control groups. In addition, the aggregated result showed a significantly moderate effect of Tai Chi on proprioception of PF (SMD = −0.55; 95% CI, −0.9 to −0.2; $P=.002$; $I^2=0\%$; n = 162) (fig 3).

Eight studies[24,25,36-42] investigated the effects of Tai Chi on proprioception of dominant or right knee flexion, as measured by 3 different instruments (the X-sens 3-dimensional positional measuring system, the TTDPM, joint position reproduction test). Visual inspect of the funnel plot and a nonsignificant Egger's regression intercept ($P=.917$) suggests the presence of symmetric funnel plot (fig 4). For the proprioception of dominant or right knee flexion, the aggregated results showed significantly large effects of Tai Chi (SMD = −0.82; 95% CI, −1.06 to −0.58; $P<.001$; $I^2=33.8\%$; n = 464) (fig 5), as compared to control groups.

Five studies[25,38-40,42] investigated the effects of Tai Chi on proprioception of nondominant or left knee flexion, as measured by 3 different instruments (X-sens 3-dimensional positional measuring system, the TTDPM, joint position reproduction test). Visual inspect of the funnel plot and a nonsignificant Egger's regression intercept ($P=.602$) suggests the presence of symmetric funnel plot (fig 6). For proprioception of nondominant or left knee flexion, the aggregated results showed significantly moderate effects of Tai Chi (SMD = −0.71; 95% CI, −1.10 to − 0.41; $P<.001$; $I^2=25.1\%$; n = 266) (fig 7), as compared to control groups.

Discussion

To our knowledge, this is the first systematic review with meta-analysis to critically evaluate the effects of Tai Chi on lower limb proprioception of the adults aged 55 and older. Overall, the results of this systematic review indicated that Tai Chi as an intervention could improve lower limb joint proprioception of the elderly in good health and with special conditions (knee osteoarthritis, visual impairment, mild cognitive impairment). The magnitudes of these positive effects on most proprioceptive measures reported were moderate to large, such as PF (SMD = −0.55), nondominant or left knee flexion (SMD = −0.71), DF (SMD = −0.75), and dominant or right knee flexion (SMD = −0.83). No adverse events such as falls, Tai Chi–associated injuries, hospitalization required, or deaths were noted.

Previous reviews have shown that Tai Chi exercise are effective for falls prevention and balance control in older adults.[16,43] However, the mechanisms underlying these beneficial effects are not clear, because both falls and balance are affected by multiple factors, such as strength, vestibular, visual, and proprioceptive function. Our finding that Tai Chi exercise can improve lower limb proprioception provides a possible explanation for the reason why Tai Chi exercise can reduce falls and enhance balance in older people. This finding suggests that other forms of exercises that are specifically designed to improve lower limb proprioception may have a similar effect on falls prevention and balance control in older adults.

Effects of Tai Chi on ankle proprioception

The current meta-analysis showed an overall positive effect of Tai Chi on ankle proprioception in contraction of the DF. Of the 3 studies (including 4 comparisons), 2 comparisons (Tai Chi vs unaltered lifestyle and Tai Chi vs television watching)[24,27] showed

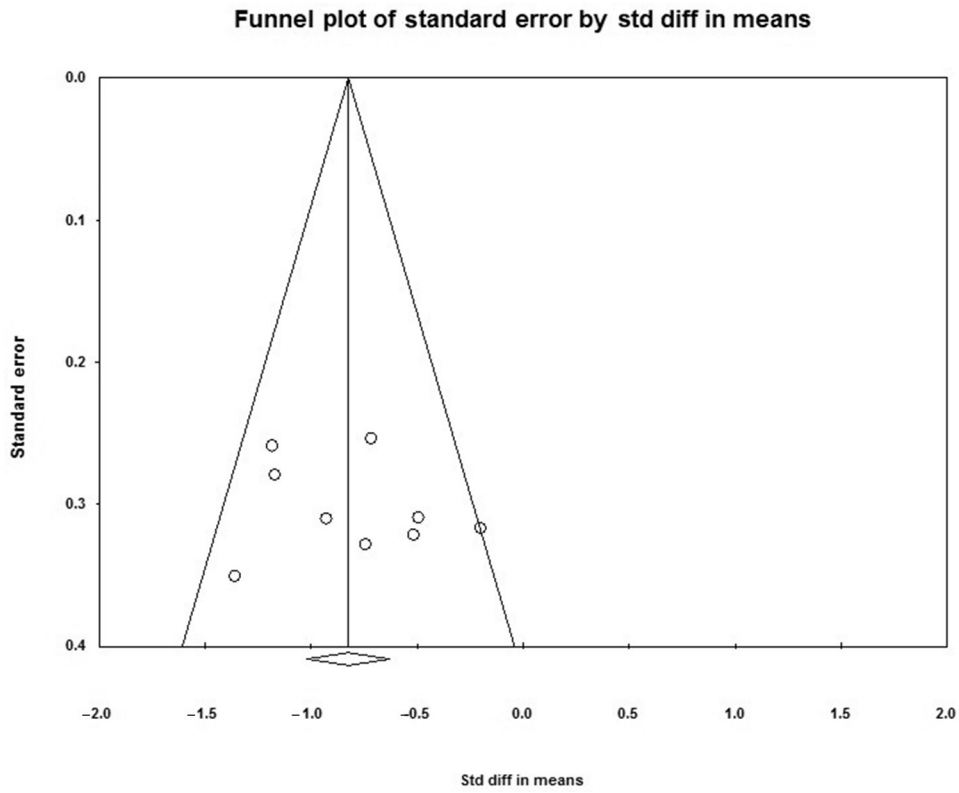

Fig 4 Funnel plot of publication bias for proprioception of dominant or right knee flexion.

significant positive results, whereas the other 2 (Tai Chi vs waitlist and Tai Chi vs brisk walking) presented positive effects.[24,27] These results suggest the importance of duration and mode of intervention in improving proprioceptive ability in older people. Specifically, the duration of Tai Chi intervention in 2 trials[24,27] was 16 weeks, totaling 64-80 hours, as compared to 24 weeks (96 training hours in total) reported by Chang et al.[25] Sixteen weeks Tai Chi intervention may be insufficient to achieve significantly positive effects on neural plasticity—related proprioceptive change. In addition, when the total training hours in the

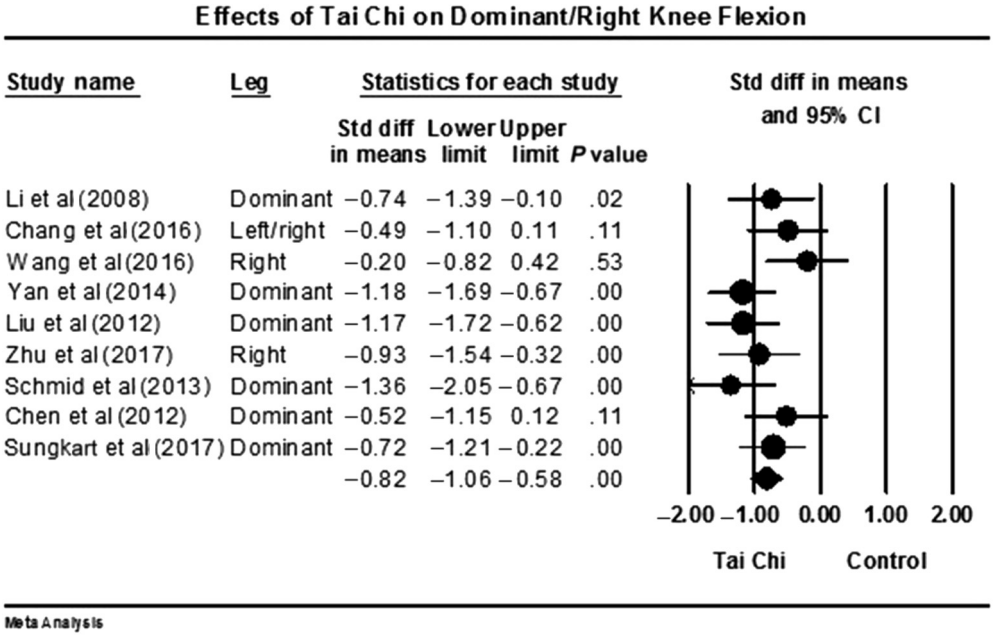

Fig 5 Effects of Tai Chi on proprioception of dominant or right knee flexion.

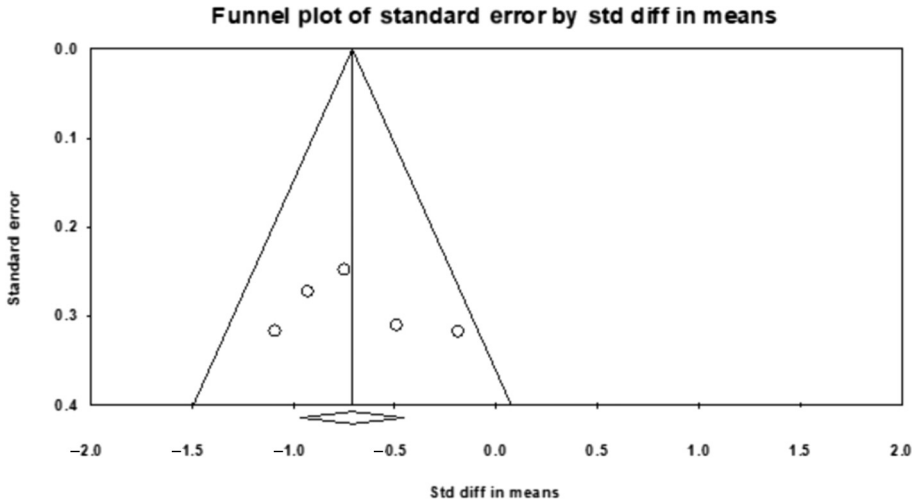

Fig 6 Funnel plot of publication bias for proprioception of nondominant or left knee flexion.

study by Zhang et al[27] was increased close to 96, a significantly positive effect was only observed in 1 comparison (Tai Chi vs television watching), but not Tai Chi versus brisk walking. This is presumably because compared to television watching, active control of repetitive ankle movement in brisk walking may improve ankle proprioception in DF after 80-hour training. This explanation is partially supported by 3 cross-sectional studies,[18,21,23] where Xu et al[18] found that older adults who participated in 90-minute Tai Chi per day for >4 years showed significantly better DF than those with sedentary lifestyle; but when compared to swimmers or runners,[18] regular physical activity participants,[21] or golfers,[23] the positive effects of Tai Chi were not significantly evident.

In this meta-analysis, the overall positive effect of Tai Chi training on proprioception in PF had just reached a moderate level (SMD = −0.55), smaller than that in DF (SMD = −0.75). This may be due to less challenge to PF control in Tai Chi exercise. When performing Tai Chi, the semi-squat and lunge positions are used in most movements, which require contraction tibialis anterior muscles. In Tai Chi training, the practitioners have to be aware of the position of the knee with relative to the ankle. For example, the knee should not be positioned over the toes during bow stance to avoid overloading to the knee joint. The joint position sense of DF may be enhanced by repeated practice. In addition, while shifting the body weight from double-stance to single-leg support, the ankle movement control involves heel strike to foot flat phase.[13] In comparison, the push off movement that involves ankle PF is less practiced. In this case, a maximum PF is not really trained, as compared to full dorsal flexion involved in Tai Chi form from the beginning to the end.

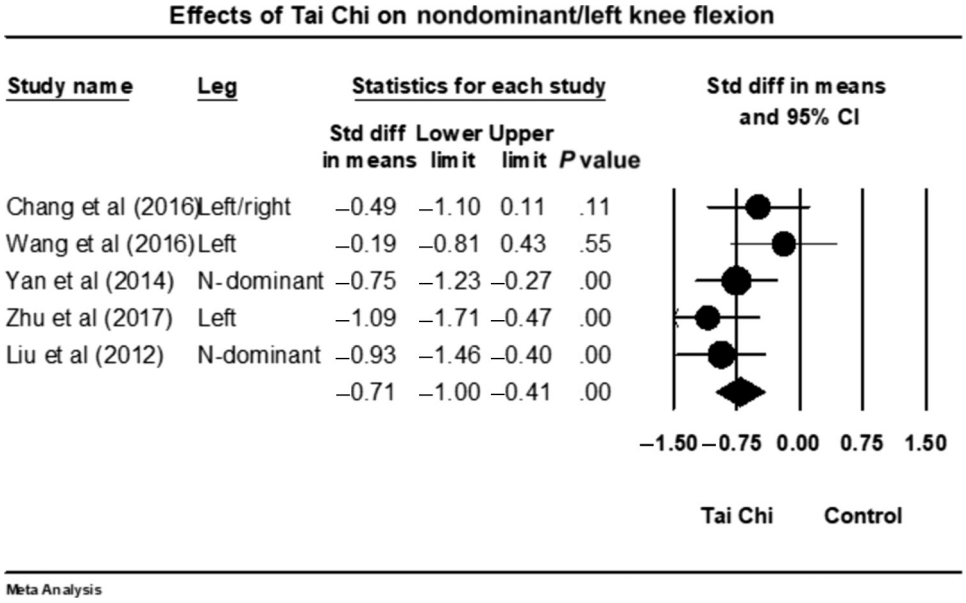

Fig 7 Effects of Tai Chi on proprioception of nondominant or left knee flexion (N-dominant, nondominant).

In ankle inversion or eversion, our previous studies[44,45] have found that ankle inversion proprioception is significantly associated with sport performance, suggesting that ankle inversion proprioception may play an essential role in balance control.[46] In the current systematic review, due to the fact that only 1 study reported significantly positive effects of 16-week Tai Chi training on the mean value of inversion or eversion combined, it is hard to draw a conclusion on the effect of Tai Chi on ankle inversion proprioception. Future studies on ankle proprioception in inversion and its relation to balance performance and falls risk in the elderly should be carried out to show clearer effects.

Effect of Tai Chi on knee joint proprioception

Knee movement control is fundamental for the elderly to maintain the center of gravity in activities of daily living. Results from this present review showed a moderate to large beneficial effect of Tai Chi training on proprioception in knee flexion in both dominant or right and nondominant or left legs. These positive effects observed in bilateral knee proprioception may highlight the feature of Tai Chi exercise that involves symmetrical and dynamic weight shifting and single-double stance in multiple directions, through precise control of both knees flexion and extension.[47] In addition, the significant improvement in bilateral knee proprioception may be achieved through a *common motor program* shared between 2 brain hemispheres.[48] Our bilateral proprioceptive study[48] showed that significant correlation exists between left and right knees, suggesting that proprioceptive improvement in 1 knee through Tai Chi exercise may also have a positive effect on the contralateral knee. In the current review, the 9 studies[24,25,36-42] that reported the dominant or right knee flexion proprioceptive measures were included in the meta-analysis. Six[24,36,37,39,40,42] showed significantly positive results of Tai Chi over controls (including passive or active intervention). Three other studies[25,38,41] showed a positive trend effect. A similar phenomenon is also observed in the studies investigating the nondominant left knee.[25,38-40,42] The mean value of left and right knees combined proprioception reported by Chang et al[25] may not truly reflect the effect of Tai Chi on specific proprioceptive change in 1 knee, which may be one of the reasons of failure in detecting a significant effect.

Issues on lower limb proprioceptive assessment in older people

There are 3 main methods for assessing lower limb proprioception: The TTDPM or joint position reproduction test and active movement extent discrimination assessment.[4] In this review, TTDPM and joint position reproduction were mostly used, and they seemed sensitive enough to detect the effects of Tai Chi on lower limb proprioception. However, these tests were usually conducted in non-weightbearing and their ecological validity has been questioned.[4] In their study, Wang et al[38] used an X-sens 3-dimensional positional measuring system to assess the effect of Tai Chi on knee proprioception. However, their result only showed a very small effect size which was not statistically significant. Further studies are needed to validate the X-sens 3-dimensional positional measuring system,[49] because it may provide another option for health professionals and researchers to assess proprioception for both clinical and research purposes.

Study limitations and future directions

Several study limitations were noted with this systematic review. First, 9 of 11 selected RCTs were conducted in China (including mainland China and Hong Kong). It remains unknown whether the results of this systematic review are generalizable to non-Chinese populations with different cultural backgrounds. International, multicenter studies are needed to confirm the results obtained from the present review. Second, 7 of the RCTs reported study participants in good health and these participants were mostly young-old. Therefore, the generalizability of the results to oldest-old (population above age 85)[50] and those with chronic diseases is limited. Accordingly, the beneficial effects of Tai Chi for enhancing lower limb joint proprioception in more specific populations require further investigation. Third, because of limited studies on hip proprioception, the current review only focused the proprioceptive ability at the ankle and knee. Our previous study has found proprioception is joint specific[48]; thus, it is still unknown if the beneficial effects on ankle and knee are also evident in the hip. In addition, the follow-up assessment was only conducted in 2 studies, so the interpretation of positive results from Tai Chi is limited to the immediate or short term. Furthermore, the compliance rate about Tai Chi intervention can best reflect the real training condition, but it was only reported in 3 studies. It is critical that future studies clearly describe their compliance rates. Finally, we find that there are a range of methodological flaws in study design, such as lack of allocation concealment, blinding of assessors, and intention-to-treat analysis. Specifically, outcome assessors were not blinded in 8 out of the selected studies, which can potentially lead to subjectivity and social desirability bias. Thus, the results of the present systematic review should be cautiously interpreted.

Conclusions

The results of this systematic review with meta-analysis suggest that Tai Chi may be a safe and effective intervention to maintain and improve lower limb proprioceptive function of adults older than 55 who are likely to reduce their risk of falling. More robust multicenter studies including different ethnic groups, oldest-old participants, with longer follow-ups, and validated outcome measures are needed before a definitive conclusion is drawn.

Supplier

a. Comprehensive Meta-Analysis Software, version 2.0; BioStat.

Keywords

Elderly; Lower limb; Proprioception; Rehabilitation; Tai Chi

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