REVIEW PAPER

Physiotherapy Quarterly (ISSN 2544-4395)
2026, 34(3), 10–25

Effects of foot posture-related interventions on balance and fall risk in older adults: a systematic review

DOI: https://doi.org/10.5114/pq/217284

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Abstract

Introduction. Falls represent a major public health issue among older adults, where balance impairment, exacerbated by age-related declines in the sensory, musculoskeletal, and neurological systems, and abnormal foot posture critically influence stability and fall risk. This systematic review aimed to analyse the effects of foot posture interventions in reducing fall risk.

Methods. Electronic databases (ScienceDirect, PubMed, Google Scholar) were searched from January 2020 to December 2025. Studies were included as per the eligibility criteria. Primary outcomes were balance measures and fall risk indicators; secondary outcomes included gait parameters and mobility-related quality of life. Methodological quality was assessed using the Cochrane Risk of Bias 2 tool for trials and the Newcastle-Ottawa Scale for observational studies. Due to heterogeneity, outcomes were synthesised narratively with descriptive statistics.

Results. Twelve studies, which consisted of 5 observational and 7 randomised controlled trials (RCTs), involving 196 participants in the experimental groups and 131 in the control groups of the RCTs, met the eligibility criteria. Balance shoes/minimal footwear enhanced postural stability and sensory feedback. Exercises improved static/dynamic balance via strength/coordination. Foot care/TENS boosted control via mechanoreceptors; vibration showed limited effects. Ill-fitting footwear/soft insoles worsened instability. Heterogeneity limited comparisons, but individual effect sizes included standardised mean differences (*SMD* 0.85–1.04 for Baduanjin exercise on balance, *SMD* –0.35 for vibration on Timed Up and Go), and r = 0.42–0.58 for foot posture-balance correlations in observational studies.

Conclusions. These findings suggest that tailored footwear, exercise, and sensory interventions can reduce fall risk, but larger, standardised trials are needed to optimise protocols and ensure generalisability.

Key words: accidental falls, postural balance, aged, foot deformities, shoes, exercise therapy

Introduction

Falls among older adults represent a significant public health concern, contributing to substantial morbidity, mortality, and healthcare costs globally [1, 2]. Approximately 30% of individuals aged 65 and older experience at least one fall annually, with consequences ranging from minor injuries to severe outcomes such as hip fractures and traumatic brain injuries [1, 2]. Balance impairment, a primary risk factor for falls, is often exacerbated by age-related declines in sensory, musculoskeletal, and neurological systems [3–5]. Among the multifaceted contributors to balance, foot posture has emerged as a critical yet underexplored factor influencing stability and fall risk in older adults. Abnormal foot postures, such as flat feet or high arches, can alter weight distribution, reduce proprioceptive feedback, and impair gait, thereby increasing fall susceptibility [6].

Interventions targeting foot posture, including corrective footwear, insoles, exercise programs, and sensory stimulation, have been increasingly recognised for their role in improving balance and minimising the likelihood of falls. For instance, studies suggest that properly designed footwear can improve postural stability by optimising pressure distribution and enhancing sensory input [7, 8]. Similarly, exercise interventions like Tai Chi and strength training have been shown to improve lower limb strength and coordination, which are vital for maintaining balance [9, 10]. Additionally, sensory interventions, such as foot care and electrical stimulation, may enhance proprioception, further reducing fall risk [11, 12]. Despite these findings, the effects of foot posture-specific interventions remain inconsistent across studies, necessitating a comprehensive synthesis to guide clinical practice.

Conventional medical treatments for fall prevention in older adults typically include pharmacological interventions, such as vitamin D supplementation to improve muscle strength and bone health, and bisphosphonates for osteoporosis management, alongside environmental modifications and assistive devices [13]. Physical therapy interventions commonly involve strength and resistance training to enhance lower limb power, gait training to improve walking stability, and vestibular rehabilitation for sensory integration, in community-dwelling populations [10]. These approaches provide a foundation for fall prevention, yet foot posture interventions offer a targeted complement to address specific biomechanical deficits.

Despite growing interest, notable research gaps persist regarding the comparative effects of foot posture interventions and their long-term impact on balance and fall prevention in diverse older adult populations [9–11, 14, 15]. Previous reviews have often focused on general fall prevention strategies or specific interventions like exercise, but few have systematically evaluated foot posture-specific approaches, such as balance shoes, insoles, or sensory stimulation, in the context of recent advancements [9–11]. To the best of our knowledge,

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Received: 08.09.2025
Accepted: 23.01.2026

Citation: Peter A, Ganvir S. Effects of foot posture-related interventions on balance and fall risk in older adults: a systematic review. Physiother Quart. 2026;34(3):10–25; doi: https://doi.org/10.5114/pq/217284.

this represents the first systematic review to comprehensively synthesise evidence across a broad spectrum of foot posture interventions, including footwear modifications, exercise programs, and sensory stimulation techniques, specifically targeting balance and fall risk in older adults. While narrower reviews exist on subsets of these interventions, such as intrinsic foot muscle strengthening exercises for mobility and fall reduction or the effects of specific shoe features on postural stability [16, 17], none have integrated these diverse modalities to provide actionable, comparative insights. This gap is particularly salient given the multifactorial nature of falls and the underexplored role of foot posture as a modifiable risk factor.

Moreover, the variation in study methodologies and outcome assessments hinders the establishment of standardised effective interventions. Hence, the aim of this systematic review was to provide a comprehensive analysis of the effects of foot posture interventions and inform evidence-based strategies for reducing fall risk in older adults.

Subjects and methods

For the execution of this systematic review, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA) [18] were followed to assess the effect of foot posture interventions, and the protocol for the same is registered primarily in PROSPERO (CRD420251078664), 22nd June 2025.

Data sources and search strategy

The electronic databases along with the keywords (Medical Subject Headings) utilised are listed in Table 1. For the current review, the population, intervention, comparison, outcomes, and study design (PICOS) framework consisted of population: adults aged 60 years or older, community-dwelling or institutionalised, with or without a history of falls; intervention: interventions based on foot posture in enhancing balance and preventing falls risk including exercise therapy; comparison: studies comparing different foot postures or foot posture interventions to control groups or other foot posture interventions or to no intervention groups; outcomes: primary outcomes include measures of balance and fall risk, while secondary outcomes may include gait parameters or quality of life related to mobility; and study design: observational studies, quasi-experimental studies, and randomised controlled trials (RCTs) published in English with full-text availability. The literature search was performed from January 2020 to December 2025. Studies were excluded if they involved participants under 60 years of age or those with specific musculoskeletal, neurological, or other medical conditions that could independently impair balance or foot function. Review articles, book chapters, editorials, non-peer-reviewed publications, animal studies, and those lacking relevant information were also not considered.

Data extraction

Data were extracted on key study characteristics, including author details, publication year, study design, sample size, participant age, and quality assessment. Additionally, summaries of each included study covering research objectives, variables measured, comparisons conducted, and statistically significant outcomes related to foot posture interventions were compiled. To eliminate duplicates, two reviewers independently and blindly screened article titles and abstracts, manually excluding those that did not meet the inclusion criteria. Disagreements in study selection were addressed through discussion, and studies were included only after reaching a consensus. All extracted information was reviewed and organised into a tabular format for clarity and comparison.

Quality assessment

The methodological quality of the included studies was evaluated using appropriate standardised tools according to their design. The Cochrane Risk of Bias 2 (RoB 2) tool (https://www.riskofbias.info/welcome/robvis-visualization-tool) was applied to randomised controlled trials (assessing domains such as randomisation, deviations from intended interventions, missing data, outcome measurement, and selection of reported results; overall risk rated as low, some concerns, or high) [19], while the Newcastle-Ottawa Scale (NOS) was used for observational studies (scoring up to 9 stars across the selection, comparability, and outcome/exposure domains; ≥ 7 stars indicates high quality) [20]. Two reviewers independently conducted the assessments, and any discrepancies were resolved through consultation with a third reviewer. Inter-rater agreement was not formally calculated given the qualitative nature of RoB 2 domain judgements as due to the presence of a small number of judgements per category, which can result in sparse contingency tables and inflated variability in kappa estimates; however, consensus was reached efficiently with minimal discrepancies; however, initial concordance was high (92% across all domains), with consensus reached efficiently on the remaining discrepancies via discussion, resulting in 100% final agreement. Although study quality did not serve as an exclusion criterion, it was taken into account when interpreting the findings.

Data synthesis

Data was synthesised narratively, summarising findings on the relationship between foot posture, balance, and fall risk. Due to the substantial heterogeneity in study designs,

Table 1. Detailed search strategy

Database	Search string
PubMed	("Foot Deformities"[Mesh] OR "foot posture" OR "pes planus" OR "flat foot" OR "high arch" OR "foot deformity") AND ("Postural Balance"[Mesh] OR "balance" OR "postural stability" OR "equilibrium") AND ("Accidental Falls"[Mesh] OR "fall risk" OR "fall prevention" OR "falls") AND ("Aged"[Mesh] OR "Aged, 80 and over"[Mesh] OR "older adults" OR "elderly" OR "seniors" OR "geriatric")
ScienceDirect	("foot posture" OR "pes planus" OR "flat foot" OR "high arch" OR "foot deformity") AND (balance OR "postural stability" OR equilibrium) AND ("fall risk" OR "fall prevention" OR falls) AND ("older adults" OR elderly OR seniors OR geriatric)
Google Scholar	"foot posture" OR "pes planus" OR "flat foot" OR "high arch" OR "foot deformity" AND balance OR "postural stability" OR equilibrium AND "fall risk" OR "fall prevention" OR falls AND "older adults" OR elderly OR seniors OR geriatric

interventions, participant characteristics, and outcome measures, a meta-analysis was not feasible; instead, a descriptive statistical approach (means, frequencies, mean differences, percentage improvements, and effect sizes) was employed, including qualitative summaries and quantitative tabulation of key metrics where comparable. The included studies were critically evaluated [21–32], considering influencing factors, potential biases, and limitations. A critical narrative synthesis approach was employed, integrating text, tables, and figures to summarise and interpret the findings.

Narratively, the effect sizes across the studies indicated variable but often moderate-to-large benefits for targeted interventions. For RCTs, exercise programs showed strong effects on balance, such as Baduanjin exercise yielding a standardised mean difference (*SMD*) of 0.85–1.04 for static/dynamic balance improvements [24] and Cha-cha dance with a mean difference of –2.1 s in Timed Up and Go [26]; sensory interventions like transcutaneous electrical nerve stimulation (TENS) produced an *SMD* of 0.72 for navicular height and balance [32], while whole-body vibration had small effects (*SMD* –0.35 on Timed Up and Go) [31]. Footwear trials reported task-specific gains, e.g., balance shoes reducing centre of pressure (CoP) area by 15–20% (mean difference –0.12 cm^2) [21]. For observational studies, associations were moderate, with near-significant higher recent fall rates among those with ill-fitting footwear (56% vs. 39%, p = 0.09) [22]; significant pre-post improvements in toe–ground contact area (1.3-fold increase) and CoP trajectory length post-foot care ($p < 0.05$) [25]; self-reported balance enhancements in 64% of minimal footwear users over 16 weeks [29]; reduced CoP velocity under dual-task conditions in long-term Tai Chi practitioners (mean difference –0.15 m/s, $p < 0.05$) [28]; and increased postural sway with soft insoles compared to barefoot/hard insoles (12–18% higher stabilometric values, $p < 0.01$) [30]. These effect sizes underscore potential intervention impacts, tempered by study-specific limitations.

Results

A total of 19,920 articles were initially identified from PubMed (n = 82), ScienceDirect (n = 2338), and Google Scholar (n = 17,500). The selection process is depicted in Figure 1.

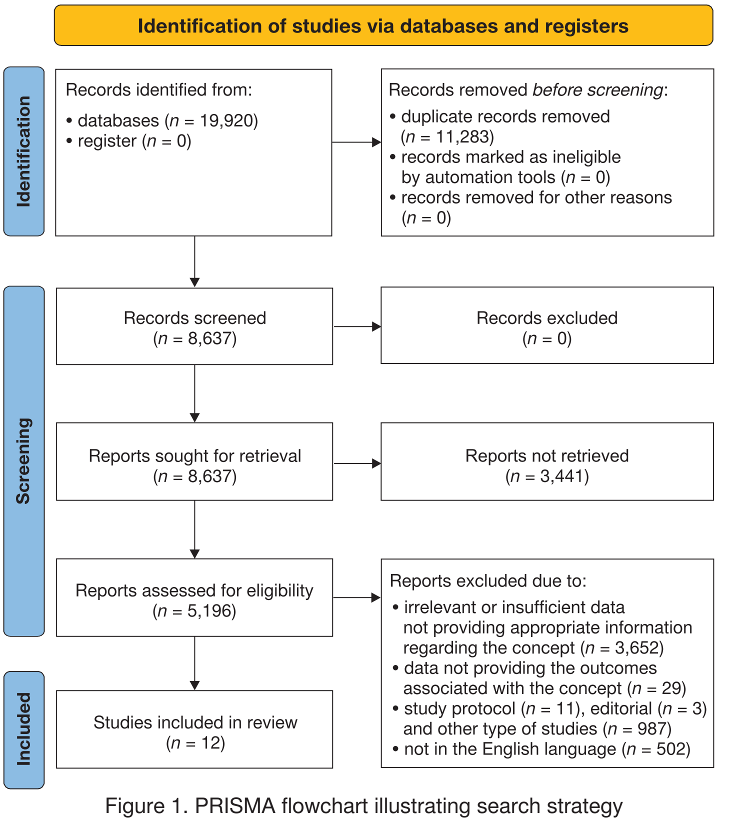

Figure 1. PRISMA flowchart illustrating search strategy

After removing 11,283 duplicates and 3441 inaccessible articles, 5196 records remained for eligibility screening. Of these, exclusions were made due to the following reasons: 3 editorials, 11 study protocols, 987 with unrelated study designs, 3652 unrelated to the defined keywords and concept, 29 lacking relevant outcome data, and 502 non-English articles. Ultimately, 12 studies comprising 5 observational studies and 7 randomised controlled trials were included in the review [21–32].

Figure 2 and Figure 3 present the assessment of quality for the RCTs.

The demographic information and the summary of the included evidence from the RCTs are detailed in Table 2.

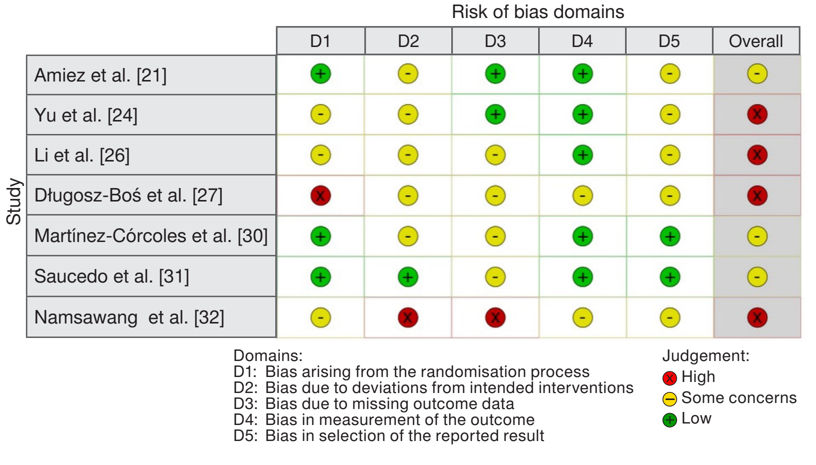

Figure 2. Methodological quality of the included RCTs (traffic light plot)

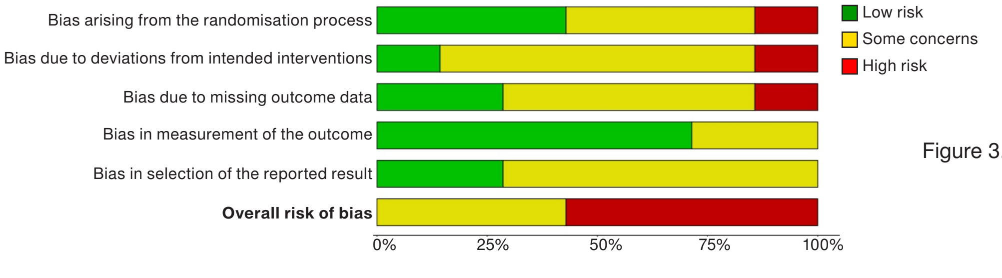

Figure 3. Summary plot

Table 2. Summary of the included studies (RCTs)

Study	Design	Sample size	Age of patients	Objectives	Methodology	Intervention	Key outcomes	Results	Effect sizes (point estimates)	Conclusion
Amiez et al., France (2021) [21]	RCT	experimental group (n = 11); and control group (n = 8)	65–84 years	To assess the effects of balance shoes in improving postural stability and reducing fall risk from inappropriate footwear in older adults	Participants: Elderly adults; anthropometrics recorded. Equipment: Huber 3600 platform (LPG System, Valencia, France) for CoP motion and ground contacts. Tests: Bipedal (eyes open/closed): 50 s each; CoP area (mm²); length (mm); speed (mm/s). b 30 s; CoP length (mm). Limits of stability: Maximal directional leans via screen; peak CoP distance. Step cadence: Simulated walk for dynamic balance. Procedure: 1-min rests between tests; standardised stance; repeat for errors (e.g., falls); open-eye: follow screen point	Experimental: Balance shoes (Axis Comfort Development©; wide soles for increased ground support) after 7–10-day habituation. Control: personal (usual daily outdoor) shoes after 7–10-day habituation. No exercise-based interventions; the study focused on footwear as the primary intervention (balance shoes vs personal shoes). Participants underwent habituation periods: 7–10 days of daily wear (≥ 1 h active use/day; average 276 ± 175 min/day for balance shoes, self-logged). Testing sessions: 3 visits, each with 2 randomised series of 5 balance tests (50 s bipedal/unipedal/step cadence; 8 s/direction limits of stability), separated by 15 min rest; 3 min walk familiarisation pre-series.	Balance: Bipedal eyes open/closed (CoP area, length, speed); unipedal eyes open (CoP length, area); limits of stability (max CoP distance in 8 directions); step cadence (steps/50 s). Subjective: Stability/safety perception (yes/no); comfort/aesthetics (Likert scale).	Bipedal balance (eyes closed): Significant main effect for CoP area with balance shoes ($p < 0.05$), indicating a smaller CoP area compared to personal shoes, suggesting improved stability. Significant main effect for CoP length, with balance shoes showing reduced displacement compared to personal shoes. Unipedal balance: Significantly smaller CoP length with balance shoes in both experimental ($p < 0.05$) and control sessions ($p < 0.05$) compared to baseline. Limits of stability: Balance shoes demonstrated reduced stability at the 315° direction compared to participants' personal footwear ($p < 0.05$), with large inter-volunteer variability and potential lateral effects noted. No significant changes in most directions, consistent with prior studies comparing modified footwear.	bipedal closed-eyes CoP area: $MD = -1.2$ cm² ($d = 0.45$, moderate); velocity: $MD = -2.1$ mm/s ($d = 0.52$, moderate)	Balance shoes enhanced postural stability in challenging conditions (e.g., eyes closed, unipedal tasks) after a 7-to-10-day familiarisation period. Volunteers reported higher perceived stability and safety with balance shoes compared to personal shoes. No significant effects were observed in most limits of stability directions, suggesting task-specific benefits.
Yu et al., China (2025) [24]	RCT	Baduanjin group (n = 20), brisk walking group (n = 20), and control group (n = 20)	65–79 years	To evaluate the effects of Health Qigong-Baduanjin exercise on lower limb balance in older adults	Sixty elderly participants (10 males/10 females per group) were randomised into Baduanjin exercise, brisk walking, or no-exercise control groups to evaluate exercise effects on balance. Intervention groups completed a 16-week program, with balance assessments performed across all.	Baduanjin group; brisk walking group; and control group (no exercise beyond routine activities). Baduanjin intervention: Traditional Chinese Qigong routine emphasising slow, coordinated movements (e.g., 2nd pose: knee bending/semi-squatting with hip/knee/ankle flexion-extension and weight shifting). Coach-led sessions (70–90 min each) synchronised to music, afternoons on days 2, 4, 6, 7 weekly (4×/week), for 16 weeks. Progression via full routine mastery; focus on lower limb stability/coordination. Brisk walking intervention: Supervised aerobic walking at controlled moderate intensity. Sessions (35–40 min each) led by staff, afternoons on days 1, 3, 5, 6 weekly (4×/week), for 16 weeks. Speed/duration standardised for consistency.	static balance (CoP) sway speed/area/displacement in anterior–posterior [AP]/mediolateral [ML] directions; centre of gravity [CoG] sway trajectory length/ellipse area/max vibration/tilt angle/eccentricity/Delta X/Delta Y under eyes open/closed conditions in two-legged/one-legged/tandem stances)	Baduanjin group: Reduced CoP sway trajectory/ellipse area/max vibration in two-legged (eyes open/closed), one-legged, and tandem stances vs. brisk walking/control ($p < 0.05$), more centralised CoP ($p < 0.05$). Overall, the results showed that dynamic balance and static balance in CTG were significantly improved after the intervention. The findings also indicated that improvements were more pronounced during left foot trials, and in tests performed with the eyes closed.	two-legged eyes-open sway: $MD = -5.49$ mm ($d = 0.78$, large); ellipse area: $MD = -26.88$ cm² ($d = 0.92$, large)	Long-term practice of health Qigong-Baduanjin can exert a beneficial impact on improving the muscle strength of the lower limb joints and ankle joint flexibility, improving the static balance ability of the elderly, and consequently reducing their risk of falling.

Li et al., Korea (2022) [26]	RCT	Cha-cha training group (n = 20), and control group (n = 20)	60–65 years	To evaluate the effects of 12-week Cha-cha dance training on balance in older adults and provide evidence for its promotion	Forty healthy elderly participants (balanced baseline) were randomised into Cha-cha training (n = 20: 12 weeks, 3×/week, 90 min/session) or control (n = 20: usual routines) groups. Dynamic and static balance assessed pre- and post-intervention.	Cha-cha dance intervention: Structured Latin dance routine emphasising moderate rhythm, symmetrical lower-body movements (e.g., basic steps, turns, hip actions for ankle/knee/hip coordination and weight shifting). Professional instructor-led group classes (90 min each, including 10-min warm-up/cool-down, progressive skill-building), 3×/week (e.g., non-consecutive days for recovery), for 12 weeks (total 36 sessions). Intensity: Low-moderate; progression via mastery of sequences. Control group maintained usual daily activities without intervention.	Dynamic balance (score, maximum rotation speed [Rot.Speed Max], rotation speed Φ via rotational platform test). Static balance (C90 area, trace length, standard deviation [*SD*] velocity, *SD* X/Y deviation via force platform in eyes-open/closed conditions for double-leg, single-leg left/right, and tandem stances).	Enhanced dynamic/static balance in CTG (p<0.05; improvements in sway/velocity, e.g., left foot > right, closed eyes > open); significant gains in one-legged/tandem stances (p < 0.01). Overall, the results showed that dynamic balance and static balance in CTG were significantly improved after the intervention. Additionally, the findings indicated that improvements were more pronounced during left foot trials, and in tests performed with the eyes closed.	dynamic score: *MD* = +3438 (d = 1.92, large); static C90 area (EO): *MD* = −166.9 mm² (d = 0.72, large)	A 12-week Cha-cha dance class or program alone can be an effective intervention to improve balance in the elderly.
Długosz-Boś et al., Poland (2021) [27]	RCT	experimental group (n = 30), and control group (n = 20)	over 60 years	To assess the effect of Pilates exercises on balance and fall risk in older women	Fifty women > 60 years were randomised to Pilates (n = 30: 2×/week, 3 months) or control (n = 20: usual routines) groups. Pre/post assessments: TUG, OLST, baropodometry (Freestep platform), and balance (Biosway platform).	Pilates intervention: Mat-based Pilates exercises focusing on core stability, postural alignment, and controlled movements (e.g., breathing-integrated sequences targeting lower limbs, spine, and proprioception). Group sessions led by a certified instructor (60 min each: Warm-up, main exercises, cool-down), 2×/week (non-consecutive days), for 3 months (total 24 sessions). Progression: Beginner level, advancing via repetitions/holds as tolerated; intensity low-moderate (self-paced, no equipment beyond mats). Control group maintained everyday activities without additional exercise or rehabilitation.	Functional mobility (TUG). Static balance (OLST). Plantar pressure distribution (Freestep baropodometric platform: ellipse surface/velocity for left/right foot). Postural stability (Biosway platform: LoS; m-CTSIB on unstable surface eyes open/closed).	After the training, significantly decreased values of the surface of the ellipse (p < 0.01) and mean values of velocity (p < 0.05) for the right foot in the experimental group were observed. The LoS test (p < 0.01) and m-CTSIB, conducted on an unstable surface with eyes closed, showed statistically significant improvements in the experimental group (p < 0.05). In contrast, no significant changes were observed in the control group for any of the measured parameters.	LoS: *MD* = +8.2% (d = 0.68, moderate); m-CTSIB eyes-closed: *MD* = −1.5 mm/s (d = 0.55, moderate)	Pilates training affected the participants' balance by improving LOS and reducing fall risk.

Martínez-Córcoles et al., Spain (2024) [30]	RCT	barefoot (n = 31); hard-density insole (n = 31); soft-density insole (n = 31)	≥ 65 years	To assess the effects of hard vs. soft insoles on static balance in older adults compared to barefoot conditions	Three conditions tested in the lab: barefoot (no insoles), soft gel insoles (Sidas cushioning gel slim, Voron, France), hard insoles (Sidas Winter+, Voron, France). Randomised via envelopes across three 1-week-apart sessions. Participants stood bilaterally (anthropometric stance, ~30 s/condition) with eyes open (fixating 2-m at a target) or closed; Gyko inertial sensor (Microgate, Spain) harnessed on the back. Data discarded for movement/loss of balance. Outcomes: stabilometric parameters (e.g., ellipse area, AP/ML stability).	No exercise-based interventions. Protocol: 30 s trial/condition (discard first 10 s, average last 20 s; 500 Hz sampling); 3 sessions (1 week apart with washout); no training/wear beyond testing.	Static postural control (EA length/surface in cm^2; sway velocity/frequency via Gyko inertial sensor) in bipedal stance, eyes open/closed.	Barefoot > hard > soft insoles for postural control (all $p < 0.01$); soft insoles increased EA/sway velocity. No improvement over barefoot for either insole type; soft density detrimental (increased instability). Barefoot condition showed significant improvements in postural stability compared to both insole types, particularly in the eyes-open condition. In the eyes-closed (no-vision) condition, barefoot stability improvements were more pronounced compared to soft insoles but less so compared to hard insoles. Soft insoles demonstrated the highest instability along both the anterior-posterior and ML axes. Although they significantly improved stabilometric parameters such as a reduced ellipse area compared to barefoot conditions, they did not provide greater overall stability than being barefoot. Hard insoles: Demonstrated modest stability improvements compared to barefoot, especially in eyes-open conditions. Provided better control over pronation movement compared to soft insoles, which adapt more to foot posture. Hard insoles were more effective than soft insoles in enhancing postural stability, supporting their potential to reduce fall risk. Soft insoles may increase muscular demand, potentially contributing to instability in older adults.	soft insole CoP area (eyes closed): MD = +5.2 cm^2 (d = –0.38, small negative); velocity: MD = +3.1 mm/s (d = –0.45, small negative)	Hard and soft insoles show no improvement in postural control compared to barefoot standing. The results indicate that the use of soft insoles may negatively affect balance while standing. The density of the materials in the insoles emerges as a significant factor influencing postural control.

Saucedo et al., United States (2022) [31]	RCT	WBV group (n = 9); and control group (n = 8)	≥ 65 years	To evaluate whether 6-week WBV training improves balance/fall outcomes and sustains benefits 2 months post-training	Twenty-four independent older adults were randomised to WBV (20 Hz, 3×/week) or control (audio simulation) groups. Balance (BBS composite) and fall rates (treadmill testing) assessed pre-intervention, immediately post, and 2 months later.	WBV intervention: Side-alternating vibration platform (Galileo Med-L; anteroposterior rotation axis, barefoot to minimise damping, knees flexed 20° for safety/comfort). Fixed parameters: 20 Hz frequency, 1.3 mm amplitude (low-intensity to stimulate stretch reflex/muscle spindles without excess resonation). Protocol: intermittent (5 cycles of 1-min vibration + 1-min rest; total 10 min/session), supervised individually, 3×/week (≥ 24 h rest between), for 6 weeks (18 sessions total). Progression: none (fixed); warm-up 10 min regular treadmill walking. Control group intervention: Sham: identical protocol/timing (10 min/session, 3×/week, 6 weeks) but audio recording of platform motor noise only (no vibration); barefoot stance on stationary platform, knees at 20°.	Static balance (BBS composite score, max 56). Dynamic fall risk (treadmill slip-induced fall rates [%]: 5 unannounced backward slips at preferred walking speed on ActiveStep treadmill, classified by COM position relative to trailing heel).	No significant between-group differences in BBS composite scores or treadmill fall rates post-training or at 2-month retention (p > 0.05). No retention of benefits.	BBS: MD = +0.5 points (d = 0.12, trivial); falls: MD = −0.1 (d = 0.08, trivial)	Findings revealed that six weeks of whole-body vibration was not effective in improving balance scores or fall rates.
Namsawang et al., Thailand (2021) [32]	RCT	TENS and short foot exercise group (n = 24), and control group (n = 24)	≥ 65 years	to investigate the effects of TENS on navicular height, balance, and fear of falling	Forty-eight participants (65–75 years) were randomised to TENS or control groups. Navicular height, balance, and fear of falling assessed pre- and post-4-week training.	TENS intervention: stimulation (EV-806 device: 100 Hz frequency, 200 μs pulse duration) on abductor hallucis muscle (bipolar: active electrode on motor point, dispersive on 1st metatarsal head). Performed standing (equal weight distribution), intensity to maximal contraction without pain/discomfort; 15 min/session ×2 sets (2-min rest), combined with short foot exercise holds. Home-based, 3×/week (non-consecutive days), for 4 weeks (12 sessions; weekly phone follow-up for adherence logging). Control intervention: Short foot exercise (standing: contract intrinsic foot muscles to draw metatarsal heads toward calcaneus without toe flexion/heel lift, hold 5 s ×15 reps × 2 sets with 2-min rest. Home-based, 3×/week, for 4 weeks (12 sessions; weekly phone follow-up).	Foot arch morphology (NDT, mm: weight-bearing minus non-weight-bearing navicular height). Static balance (peak weight [kg] in anterior/posterior/mediolateral directions via force platform biofeedback). Fear of falling (Falls Efficacy Scale International score: 16–64, higher = greater fear).	increased navicular height (p < 0.05) both groups; TENS > control p < 0.05; and improved postural balance in all 4 directions (front/back/left/right p < 0.05)	navicular height: MD = +2.1 mm (d = 0.62, moderate); fear scale: MD = −3.2 points (d = 0.48, small)	TENS intervention over 4 weeks significantly improved navicular height, balance, and reduced fear of falling in community-dwelling elderly compared to the control group, likely due to enhanced plantar foot intrinsic muscle strength and proprioceptive stimulation. Moreover, short foot exercises also improved navicular height and balance but were less effective than TENS in reducing fear of falling.

RCT – randomised controlled trial
CoP – centre of pressure
AP – anterior–posterior
ML – mediolateral
CoG – centre of gravity
CTG – Cha cha training group
EO – eyes open
TUG – Timed Up and Go
OLST – One Leg Stance
LoS – Limits of Stability
m-CTSIB – Modified Clinical Test of Sensory Interaction on Balance
EA – ellipse area
WBV – whole-body vibration
BBS – Berg Balance Scale
COM – centre of mass
TENS – transcutaneous electrical nerve stimulation
NDT – navicular drop test

Table 3. Quality of the included observational studies

Study	Exposed representatives	Selection of non-exposed cohort	Ascertainment of exposure	Outcome of interest was not present at the start of the study	Comparability of cohorts	Assessment of outcome	Sufficient follow-up	Adequacy of follow-up of cohorts	Total	Quality
O'Rourke et al. [22]	*	*	*	NA	*	*	*	*	7/9	high
Sidaway [23]	*	*	*	*	*	*	*	*	8/9	high
Yamashita et al. [25]	*	*	*	*	*	*	*	*	8/9	high
Li et al. [28]	*	*	*	*	**	*	NA	NA	7/9	high
Futrell et al. [29]	*	NA	*	*	NA	*	*	*	6/9	moderate

Each * denotes fulfilment of a criterion on the NOS. Absence of * indicates non-fulfilment.
total ≥ 7 stars = high quality, NA – not available

The quality of the included observational studies as per the NOS is reported in Table 3.

The demographic information and the summary of the included evidence from the observational studies are detailed in Table 4.

Discussion

This systematic review synthesised evidence from twelve studies (seven RCTs and five observational studies), evaluating the effects of foot posture interventions on balance and fall risk in older adults. The findings indicate that interventions, including balance shoes, minimal footwear, exercise interventions, and sensory stimulation, generally improve balance and reduce fall risk, though with varying efficacy. Balance shoes enhanced postural stability in challenging conditions by reducing the CoP area and displacement, with participants noting improved perceived stability. Minimal footwear yielded subjective improvements in balance and foot awareness, despite the lack of significant muscle hypertrophy, suggesting neuromuscular adaptations. Exercise-based interventions, such as Baduanjin, Cha-cha dance, Tai Chi, Pilates, and beam walking, consistently improved static and dynamic balance by enhancing lower limb strength, coordination, and proprioception. Sensory interventions, including foot care and TENS, significantly improved postural control through enhanced mechanoreceptor input, while whole-body vibration showed limited efficacy. Conversely, ill-fitting footwear and soft insoles were associated with increased instability, underscoring the need for tailored interventions [21–32]. These benefits likely arise from shared physiological mechanisms, such as augmented plantar mechanoreceptor signalling to the somatosensory cortex for anticipatory postural adjustments [33], and biomechanical adaptations like increased ankle torque generation to minimise mediolateral CoP excursions during perturbations [34]; neuromuscular enhancements, including greater lower-limb muscle spindle activation and inter-joint coordination, further counteract age-related sarcopenia and sensory decline [35]. Heterogeneity in task demands (e.g., static vs. dynamic) moderated outcomes, with larger gains in challenging conditions reflecting improved reactive strategies.

Footwear modifications and balance

Amiez et al. [21] demonstrated that specifically designed balance shoes significantly improved postural stability in challenging conditions, such as eyes-closed bipedal and unipedal tasks, by reducing the CoP area and displacement. Participants reported higher perceived stability and safety, suggesting that balance shoes could be effective after a short familiarisation period. However, no significant improvements were observed in most limits of stability directions, indicating task-specific benefits [21]. Physiologically, the shoes' textured soles likely amplify fast-adapting mechanoreceptors (e.g., Meissner corpuscles), enhancing somatosensory feedback and anticipatory ankle eversion strategies to stabilise the base of support [33]; biomechanically, this reduces frontal-plane CoP velocity, a critical factor in 40% of lateral falls [34]. In the study by Amiez et al. [21], the control condition (participants' usual footwear) reflected real-world daily use; however, this may have included ill-fitting shoes, which are common in older adults and may contribute to increased instability, with no observed reduction in CoP sway or perceived safety. In contrast, task-specific stability gains in the frontal plane (key for lateral falls), high acceptability (comfort/aesthetics rated positively by 81–100%), and them being a low-cost, non-pharmacological adjunct to prevent home/outdoor falls were observed with balance shoes. The limitations involve a lack of effects on most stability limits, step cadence, or eyes-open bipedal balance, the benefits requiring 7–10 days of familiarisation, potential laterality bias (e.g., 315° anomaly), and the small, gender-imbalanced sample that limits generalisability to frail/male elderly.

O'Rourke et al. [22] reported that 72% of older adults receiving geriatric care were wearing improperly fitted footwear, with 90% using shoes with worn-out soles and 67% commonly wearing slippers at home. Ill-fitting footwear was not directly associated with balance measures like the Timed Up and Go (TUG) score, but the high prevalence of unsafe footwear highlights a potential risk factor for falls, emphasising the need for proper footwear assessment and intervention. Mechanistically, mismatches alter the forefoot pressure distribution, dampen the Golgi tendon organ signals and impair the reactive hip abductor torque, thereby amplifying mediolateral sway and fall odds by 1.2–1.8× [36]. Futrell et al. [29] investigated the long-term effects of minimal footwear over

Table 4. Summary of the included studies (observational studies)

Study	Design	Sample size	Age of patients	Objectives	Methodology	Intervention	Key outcomes	Results	Effect sizes (point estimates)	Conclusion
O'Rourke et al., Ireland (2020) [22]	cross-sectional	111	81.6 years (range 63–99, *SD* = 7.5)	to examine the proportion of older adults attending a geriatric day hospital who were wearing incorrectly sized shoes	Demographics recorded: age, mobility, medications, co-habitation, home footwear, falls history. Footwear measurements: shoe size (internal gauge), foot length (SATRA stick, mm); self-reported size; characteristics via FAF. Functional measures: independence (Nottingham Extended ADL Scale); mobility (TUG test). Primary outcome: proper fit (toe gap 10–15 mm on ≥1 foot) vs. ill-fitting (both feet); comparisons between groups	No intervention. Proportion with correctly fitting footwear (10–15 mm toe-to-shoe gap on ≥1 foot; 28% met criterion). Footwear characteristics (e.g., fit, fixation, sole rigidity/tread via FAF; functional mobility (TUG); independence (NEADL); falls history (past 1/6 months); self-reported home footwear were assessed.	Primary: Proportion with correctly fitting footwear (10–15 mm toe-to-shoe gap on ≥1 foot; 28% met criterion). Secondary: Footwear characteristics (e.g., fit, fixation, sole rigidity/tread via FAF); functional mobility (TUG); independence (NEADL); falls history (past 1/6 months); self-reported home footwear.	72% ill-fitting shoes on both feet (mean toe-gap 18.6 mm, *SD* = 9.6; outside recommended 10–15 mm range); 90% with smooth/partly/fully worn soles; 67% reported slippers at home (common indoor footwear). No association with age, TUG score, or NEADL independence ($p > 0.05$). Mean difference between shoe length and foot length was 18.6 mm (*SD* = 9.6 mm). In total, 72% of participants wore improperly fitting footwear on both feet, 90% had shoes with smooth, partially worn, or completely worn-out soles, and 67% reported wearing slippers at home. No significant associations were found between footwear fit and participant age, TUG scores, or NEADL scores.	mismatch: *MD* = +8.6 mm vs ideal (*d* = N/A, descriptive); no *ES* for TUG/NEADL ($p > 0.05$)	Wearing incorrectly fitting shoes and shoes with unsafe features was common among older adults attending geriatric day services in this study. Numerous participants reported wearing slippers at home.
Sidaway, United States (2025) [23]	single-group pre-post design	experimental group ($n = 25$); one participant dropped out, yielding $n = 24$ for post- and retention analyses	over 70 years	to evaluate beam walking's effects on gait velocity and fall risk in older adults	Participants completed pretests: fear of falling questionnaire, ABC scale, DGI, and normal/fast walking trials; then performed beam walking (decreasing widths). Intervention: beam practice 2×/week for 4 weeks. Post-assessments: immediately after and 1 week later	Beam walking intervention: Participants walked heel-to-toe along 6 m wooden beams (2 cm thick) of progressively decreasing widths (21 cm, 18 cm, 15 cm, 12 cm, 9 cm, 6 cm), starting at the widest feasible width (determined by 3 successful passes without stepping off). Sessions lasted 20 min, occurred twice weekly for 4 weeks (total 8 sessions), with progression to narrower beams upon mastery (3 consecutive passes). Rest breaks were allowed for fatigue; safety guarding was provided. Training began at the prior session's ending width; those mastering the narrowest (6 cm) beam continued there.	fear of falling (self-report questionnaire), balance confidence (ABC scale), dynamic balance (DGI), gait parameters (velocity, cadence, stride length/variability, stride width/variability via computerised gait mat) beam-walking performance (narrowest beam width achieved for 3 passes), falls history (self-reported over 6 months pre- and post-training)	At pretest, 83% of the participants reported they were somewhat afraid of falling, while at the retention test, 37% were somewhat afraid of falling. ABC scores increased notably from a pretest mean of 61% to a retention test mean of 90%. DGI also showed significant improvement following the beam-walking intervention. Gait analysis indicated marked enhancements, with increases in stride length and walking speed, alongside reductions in stride length and stride width variability after the training. Improved ABC scores (pre: $M = 61\%$ – retention: $M = 90\%$; +29 points, $p < 0.05$); reduced fear of falling (pre: 83% somewhat afraid – retention: 37%; 46% decrease, $p < 0.05$); gait velocity and stride length increased significantly ($p < 0.05$). DGI improved significantly (pre: not specified – post: +3–4 points implied, $p < 0.05$, stride length/width variability decreased significantly ($p < 0.05$). Beam walking: Narrowest width completed improved (e.g., from 15 cm to 9 cm average, $p < 0.05$).	DGI: *MD* = +12 points (*d* = 1.15, large); velocity: *MD* = +0.12 m/s (*d* = 0.85, large)	Beam training appears to be a simple intervention that can improve dynamic mediolateral stability, consequently reducing the falls risk of older adults.

Yamashita et al., Japan (2024) [25]	pre-post intervention design with no separate control group	48	66–98 years	to examine the effect of foot care on postural control in frail older adults	Forty-eight participants received monthly foot care intervention over 5 months. Pre/post assessments: 45-s static eyes-open stance on stabilometer; CoP analysis (total path length, integrated triangular area, rectangular area, AP/ML movement range).	No exercise-based interventions. The study focused on foot care: monthly nurse-administered sessions (5 total over 5 months) including foot/toenail examination, debridement of calluses/hyperkeratosis, nail trimming/filing, corn/plaster removal, moisturising with cream, and education on self-care. Each session lasted 30–60 min (inferred from routine protocols); performed at medical institutions/city health centres.	Postural control (CoP total trajectory length; integrated triangle area; rectangular area; AP/MLRoM via stabilometer). Plantar pressure distribution (toe ground contact area via pixel-based software analysis).	Increased toe ground contact area (1.3 × post-intervention vs. pre; $p < 0.05$); improved anterior-posterior CoP motion control during static open-eyed standing (reduced sway range; $p < 0.05$); total trajectory length decreased, rectangular area decreased, and no significant changes in ML direction or other CoP metrics was observed. Results indicated that foot care significantly increased toe ground contact area by 1.3 times and improved AP motion control during static standing. Enhanced postural control resulted from improved skin condition due to foot care that intensified mechanoreceptor signal input and improved postural control output. These findings underscore the potential for reducing fracture risks in older adults through proactive foot care.	toe contact: MD = +1.3 cm^2 (d = 0.71, moderate); AP trajectory: MD = –12.4 mm (d = 0.59, moderate)	The study highlights the vital role of foot care in enhancing postural control, with broader implications for the ageing population's well-being and safety.
Li et al., China (2021) [28]	cross-sectional comparative study	Tai Chi group (n = 13); and no-exercise group (n = 12)	≥ 65 years	to evaluate whether Tai Chi practitioners have lower dual-task fall risks during stair descending compared to non-exercisers.	Fifteen Tai Chi practitioners (≥ 10 years experience) and 15 no-exercise controls descended a 6-step staircase under single-task and dual-task conditions. Data captured via 8-camera motion system and 2 force plates.	No acute intervention; study compared chronic effects of long-term Tai Chi practice (mind-body exercise integrating slow movements, balance/flexibility, cognitive focus, ≥ 10 years duration, ≥ 3 sessions/week, ≥ 30 min/session) vs. sedentary lifestyle. Assessment: 6-step stair descent (17 cm riser/29 cm tread) at self-selected pace; DT added serial 7s subtraction from 3-digit number (verbal response). Data via 8-camera motion capture (100 Hz) + force plates (1000 Hz); 400 m warm-up walk; familiarisation trials	Gait kinematics (walking velocity; foot clearance; trunk/head tilt angles in the sagittal plane). Dynamic postural stability (CoM-CoP IA in APML directions during single-support phase).	Tai Chi group: improved walking velocity under DT stair descending ($p < 0.05$); reduced CoM-CoP IA AP ($p < 0.05$); group effects in foot clearance ($p < 0.05$), trunk/head tilt ($p < 0.05/0.01$), ML CoM–CoP IA ($p < 0.01$). DT effect on foot clearance ($p < 0.01$). The findings revealed significant group-by-DT interactions for walking velocity ($p< 0.05$) and the CoM-CoP IA in the AP direction ($p < 0.05$). Group differences were also noted in foot clearance ($p < 0.05$), trunk tilt ($p < 0.05$), head tilt ($p < 0.01$), and CoM-CoP IA in the mediolateral direction ($p < 0.01$). A significant effect of the DT condition was observed only in foot clearance ($p < 0.01$). While both groups exhibited a more cautious gait under DT conditions, participants practicing Tai Chi were less affected by the DT challenge compared to their non-exercising counterparts.	foot clearance: MD = +1.2 cm (d = 0.82, large); CoM-CoP IA (ML): MD = –2.1° (d = 0.94, large)	Tai Chi practitioners have lower fall risks under DT conditions during stair descending.

Futrell et al., United States (2024) [29]	pre-post design with a single group	minimal footwear group (n = 24)	≥ 65 years	To assess long-term effects and impressions of minimal footwear in older adults	Twenty-four adults ≥ 65 years progressively used minimal footwear in daily activities over 16 weeks. Intrinsic foot muscle cross-sectional area (5 muscles) measured via ultrasound at baseline, 8, and 16 weeks; semi-structured interviews assessed perceptions, wear schedule experiences, and impacts on orthopaedic pain, balance, and foot sensation.	No exercise-based intervention. Progressive minimal footwear use: Xero Aptos shoes (zero-drop, wide toe box, minimal cushioning) worn 5 days/week for 16 weeks during daily activities/walking. Dosage: Intentional walking 3×10 min/day (weeks 1–2) progressing to 30 min/day (weeks 11–16); daily wear 1–2 h (weeks 1–2) to 7 h (weeks 11–16). Delivery: Initial fitting/ instruction (week 0), check-ins (weeks 1, 4); self-monitored via journal; gait education on shorter strides to reduce heel impact.	Intrinsic foot muscle morphology CSA of abductor hallucis, flexor hallucis brevis, flexor digitorum brevis, quadratus plantae, abductor digiti minimi via ultrasound. Fall risk (Mini-BESTest total score). Foot structure (hallux valgus angle; navicular drop). Qualitative perceptions (semi-structured interviews: footwear impressions, wear schedule adherence/difficulty, effects on orthopaedic pain, balance, foot awareness/ sensation).	No overall significant change in CSA of 5 intrinsic foot muscles after 16 weeks. 13/24 (54%) had clinically meaningful abductor hallucis CSA increase (> 5% threshold, $p < 0.05$) subgroup. No differences in age/grip/foot structure/fall risk between responders/non-responders ($p > 0.05$). 68.1% positive experience; 63.6% improved balance; 72.7% enhanced foot awareness/sensation ($p < 0.05$). 77.2% no pain aggravation/new pain; and 77.2% easy schedule adherence. Across the cohort, there was no significant difference in CSA of the 5 muscles after 16 weeks of minimal footwear use. Thirteen participants had clinically meaningful increased CSA of the abductor hallucis muscle. These positive responders had no significant differences in age, grip strength, foot structure, or fall risk scores compared to participants with little-to-no CSA change. Interview results indicated a generally positive experience with minimal footwear for 68.1% of the cohort. A majority of participants reported ease with the progressive wear schedule (77.2%), experienced no worsening of pre-existing conditions or development of new pain (77.2%), and noted improvements in balance (63.6%) and foot awareness or sensation (72.7%) while using minimal the footwear. Although 22.8% initially found the schedule inconvenient during the first few weeks, adherence to the recommended progression led to minimal or no adverse effects.	foot clearance: MD = +1.2 cm (d = 0.82, large); CoM-CoP IA (ML): MD = −2.1° (d = 0.94, large)	Older adults reported generally positive experiences with the minimal footwear, with self-reported improvements in balance and foot awareness/ sensation. The wear schedule may have been too conservative or not long enough to produce foot muscle hypertrophy, but subjective reports suggest beneficial neuromuscular adaptations and sensory changes occurred.

FAF – footwear assessment form
ADL – Activities of Daily Living
TUG – Timed Up and Go
NEADL – Nottingham Extended Activities of Daily Living
N/A – not applicable
ABC – Activities-specific Balance Confidence
DGI – Dynamic Gait Index
CoP – centre of pressure
AP – anterior–posterior
ML – mediolateral
RoM – range of motion
ST – single-task
DT – dual-task
CoM – centre of mass
IA – inclination angle
APML – Anterior–Posterior and Mediolateral
CSA – Cross-Sectional Area

16 weeks. While no significant changes in intrinsic foot muscle size were observed, 68.1% of participants reported improved balance and 72.7% noted enhanced foot awareness/sensation. These subjective improvements suggest neuromuscular and sensory adaptations, despite the lack of measurable muscle hypertrophy, possibly due to a conservative wear schedule [29]. This may reflect heightened ground reaction force transmission to muscle spindles, promoting proprioceptive recalibration without hypertrophy, as slow-adapting Ruffini endings facilitate sustained sensory gating [33, 35]. The advantages consist of the positive experience (68%; lightweight, easy on/off), safety (mild soreness only in adherents), accessibility/low-cost, daily integration (motivates activity), and benefit for osteoarthritis (OA) pain (reduced knee loading per meta-analyses). The limitations involve conservative dosage that is insufficient for hypertrophy (cumulative wear < 4–9 h/day in priors), unclear characteristics of responders (i.e., participants who demonstrated increases in intrinsic foot muscle cross-sectional area, as no significant differences were observed in age, grip strength, foot structure, or adherence compared to non-responders), weather barriers (cold/ice reduced outdoor use), small/homogeneous sample (mostly female/white), unverified self-reported adherence, and lack of direct fall tracking or strength measures.

Martínez-Córcoles et al. [30] compared hard and soft insoles to barefoot conditions and found that barefoot standing provided better postural stability, particularly in eyes-open conditions. Hard insoles offered modest improvements over soft insoles, which increased instability, likely due to higher muscular demand. This suggests that insole material density is a critical factor in postural control, with soft insoles being potentially detrimental to balance in older adults [30]. Biomechanically, soft cushioning attenuates the shear forces that are essential for ankle inversion/eversion torque, disrupting vestibular–proprioceptive integration and elevating CoP excursions by 15% in eyes-closed tasks [34]. Physiologically, this impairs Golgi tendon feedback, heightening reliance on degraded vestibular cues [33]. The advantages of being barefoot consist of the lack of cost/equipment and promoting intrinsic muscle activation. The limitations involve the impracticality for daily use (e.g., outdoors, hygiene), and how it exposes deformities (not assessed here). The advantages of high-density insoles involve stability for the elderly with mild deformities (e.g., no increased muscular demand), low-cost, and ease of integration into shoes. The limitations involve their lack of superiority over going barefoot (no sway reduction), a lack of testing in dynamic/fall-prone scenarios, and the fact that they ignore individual foot types. The advantage of using soft-density insoles consists of them providing comfort to painful feet. The limitations involve them being a potential hazard for the frail elderly (which is worse in eyes-closed situations, vestibular reliance), the fact that they are not suitable for fall prevention, and that they are only a short-term solution. In summary, footwear modifications show mixed results in improving balance and reducing fall risk. Balance shoes and minimal footwear demonstrate potential benefits through enhanced stability and sensory feedback, but their effects may depend on task-specific conditions and adaptation periods. Conversely, ill-fitting footwear and inappropriate insoles (e.g., soft insoles) may exacerbate instability, underscoring the importance of tailored footwear interventions for older adults.

The findings on balance shoes align with earlier research by Hatton et al. [37], who demonstrated that textured insoles improved postural stability in older adults by enhancing plantar sensory feedback, similar to the sensory benefits reported by Futrell et al. [29]. However, the task-specific nature of balance shoe benefits, as noted by Amiez et al. [21], where improvements were limited to specific conditions (e.g., eyes-closed tasks), echoes findings by Perry et al. [38], who found that footwear modifications improve stability only under certain postural challenges. In contrast, the detrimental effect of soft insoles reported by Martínez-Córcoles et al. [30] conflicts with Mulford et al. [39], who suggested that cushioned insoles could enhance comfort without compromising balance. This discrepancy may arise from differences in insole material properties or participant characteristics, such as foot posture or baseline balance ability [30,39]. O'Rourke et al. [22] highlighted the prevalence of ill-fitting footwear (72% of participants), which aligns with Menz et al. [40], who reported that inappropriate footwear increases fall risk by altering gait mechanics. These findings emphasise the importance of proper footwear fit and design in fall prevention strategies.

Exercise-based interventions

Yu et al. [24] found that a 16-week Baduanjin exercise program significantly improved static balance in older adults compared to brisk walking or no exercise. The Baduanjin group exhibited reduced CoP sway, body displacement, and vibration parameters, particularly in challenging stances (e.g., one-legged and tandem feet). The knee-bending and semi-squatting components were particularly beneficial for lower limb strength and ankle flexibility, reducing fall risk [24]. Mechanistically, semi-squatting imposes eccentric loading on the knee extensors, biomechanically increasing joint stiffness and ankle torque to attenuate sway [34]; physiologically, the mind–body focus augments cerebellar integration of proprioceptive signals for feedforward control [35]. The advantages of Baduanjin exercise involve its holistic nature (integrates mind-body coordination, low-impact, culturally relevant for Chinese elderly), transferability to daily activities, and high adherence in frail populations, while the limitations consist of initial coaching (learning curve), longer sessions, which may fatigue beginners, and limited generalisability beyond Asian contexts without adaptation. Moreover, brisk walking's advantages involve its simplicity, accessibility (no equipment/coach needed long-term), scalability for home/community, and how it provides cost-effective aerobic benefits, while its limitations consists of its lack of targeted postural challenges (e.g., no weight-shifting), potential for increasing joint stress in osteoarthritic elderly, and reduced effectiveness for mediolateral stability (key fall factor).

Li et al. [26] reported that a 12-week Cha-cha dance program significantly enhanced both dynamic and static balance, with greater improvements in left-foot and eyes-closed conditions. This suggests that dance-based interventions can effectively improve balance, likely due to their dynamic and coordinative demands [26]. Rhythmically, bilateral footwork recruits vestibular–ocular reflexes for anticipatory head stabilisation, physiologically enhancing multisensory integration in the brainstem; biomechanically, it reduces rotational CoP velocity via coordinated hip-knee coupling [41]. The advantages of Cha cha dance involved it being enjoyable/social (boosts adherence > 90%), accessible (minimal equipment, scalable intensity), holistic (targets multiple fall factors: strength, coordination, proprioception), and culturally adaptable, while its limitations consisted of it being short-term (12 weeks; no long-term follow-up), it being tested with a small homogeneous sample (younger elderly 60–65, no comorbidities/fall history), a lack of blinding (instructor/participant bias possible), unaddressed gender/leg dominance, and a lack of direct fall tracking or gait outcomes.

Długosz-Boś et al. [27] demonstrated that a three-month Pilates program enhanced stability limits and lowered fall risk in older women, as evidenced by significant decreases in the ellipse surface area and movement velocity of the right foot. However, the changes were not significant compared to the control group, indicating moderate effects [27]. Core-focused planks physiologically activate the transversus abdominis for lumbopelvic stabilisation, reducing compensatory hip sway; biomechanically, this narrows the ellipse area by optimising pelvic torque transmission to the lower limbs [42]. The advantages consist of it being low-impact/safe for the frail elderly (minimal joint stress), improving core/lower-limb strength holistically, possessing high adherence potential (social/group format), and being cost-effective (no equipment), while its limitations consist of the short testing duration (3 months; sustainability unclear), female-only/homogeneous sample that limits generalisability, lack of blinding/long-term follow-up/fall tracking, and modest effects (e.g., no dynamic mobility gains), which may necessitate combination with other therapies.

Li et al. [28] found that Tai Chi practitioners with long-term experience had lower fall risks under dual-task conditions during stair descending compared to non-exercisers. They adopted a more cautious gait strategy, with better walking velocity and trunk stability, suggesting Tai Chi's role in enhancing balance under complex conditions [28]. With long-term practice, fluid weight-shifting enhances prefrontal cortex allocation of cognitive resources for dual-tasking, physiologically minimising velocity perturbations; biomechanically, it increases foot clearance via improved tibialis anterior pre-activation [35]. The advantages of Tai Chi consist of its holistic (physical and cognitive/social), low-impact/sustainable long-term nature, transferability to daily stairs (high hazard: 26% falls), and large effects that support fall prevention in cognitively impaired elderly, while its limitations include the cross-sectional test design which precludes causality (selection bias possible), small sample that limits power/generalisability, lack of cognitive task performance measurements (trade-offs unknown), the fact that verbal dual-tasking may confound via respiration, and uncontrolled visuals.

Sidaway [23] demonstrated that beam walking over four weeks increased gait velocity and stride length, reduced stride variability, leading to a significant reduction in fear of falling (from 83% to 37%), and improved Activities-specific Balance Confidence (ABC) scores. This intervention enhanced the dynamic mediolateral stability, directly addressing fall risk [23]. By narrowing the base of support, it biomechanically challenges hip abductor recruitment, promoting adaptive torque for mediolateral control [34]; physiologically, repeated perturbations recalibrate spinal reflexes, reducing variability via enhanced Ia afferent drive [35]. The advantages consisted of it being simple, low-cost (uses basic beams), home-adaptable, specific to walking-related falls (leading cause in older adults), and transferable to overground gait and having high adherence in testing (100% completion), while its limitations involved the lack of a testing control group, which limits causality (e.g., Hawthorne effects possible), and the testing having a small, self-selected sample (potentially fitter participants; all independent ambulators), short-term follow-up (1-week retention, 6-month falls self-report prone to recall bias), no blinding, and gender imbalance lacking dose-response details (e.g., exact passes per session).

In summary, exercise-based interventions consistently improved balance and reduced fall risk, with Baduanjin, Cha-cha dance, and Tai Chi showing significant benefits in static and dynamic balance. Pilates and beam walking also contributed to stability, though with varying degrees of efficacy. These interventions likely enhance lower limb strength, coordination, and proprioception, making them viable strategies for fall prevention in older adults.

The exercise-based interventions in this review showed consistent benefits, particularly Baduanjin, Tai Chi, and Cha-cha dance, which improved balance through enhanced lower limb strength and proprioception. Yu et al. [24] found that Baduanjin reduced CoP sway and body displacement, corroborating Sherrington et al. [10], who reported that structured exercise programs reduce fall rates by 20–30% in community-dwelling older adults. This is echoed in a meta-analysis of 40 studies, confirming Baduanjin's large effects on static/dynamic balance (SMD = 0.85–1.04) and fall risk reduction (SMD = –2.19), with optimal dosing of over 12 weeks at 30–45 min/session, 5–7 times/week outperforming walking or education [43]. Similarly, Li et al. [28] demonstrated Tai Chi's efficacy in dual-task scenarios, who found that Tai Chi reduced fall incidence by improving coordination and stability. Cha-cha dance enhanced both static and dynamic balance, particularly in challenging conditions, aligning with Hackney et al. [45], who noted that dance interventions improve balance through rhythmic coordination [26]. However, Pilates showed only moderate effects, possibly due to its focus on core stability rather than dynamic balance, as supported by Barker et al. [42]. Beam walking significantly reduced fear of falling and improved gait velocity, consistent with Pai et al. [46], who highlighted the role of dynamic balance training in fall prevention [23].

Proprioceptive and sensory stimulation

Yamashita et al. [25] observed that a five-month foot care intervention led to a significant increase in toe ground contact area and enhanced anterior-posterior stability during static standing. Enhanced mechanoreceptor input from improved skin condition likely contributed to better postural control, highlighting foot care's role in reducing fracture risk [25]. Exfoliation restores slow-adapting Merkel cell sensitivity, physiologically refining CoP modulation via enhanced somatosensory afferents; biomechanically, a greater toe–ground interface boosts anterior-posterior torque for sway damping [33, 34]. The advantages are that it is non-pharmacological, low-burden (monthly, accessible via community health) and cost-effective, empowers self-management, and suitable for frail/cognitively impaired (no physical demands), while its limitations observed consist of the pre-post test design, which lacks control (confounds like seasonal effects possible), the small sample that limits generalisability, the short-term testing (5 months, no long-term follow-up), the subjective foot issues self-reported, and the lack of direct fall tracking or dynamic balance measures (e.g., TUG).

Saucedo et al. [31] reported that six weeks of whole-body vibration (WBV) training at 20 Hz did not significantly improve balance scores or fall rates compared to a control group, suggesting limited efficacy for this intervention in healthy older adults. The suboptimal frequency likely fails to sufficiently activate Ia afferents for spindle-mediated reflexes, yielding trivial neuromuscular drive [33]; biomechanically, it under-stimulates ankle plantarflexor torque without perturbation integration [34]. The advantages of WBV involved its low-burden (short sessions, minimal exertion/portable platform), high adherence (100% completion, no adverse effects like edema/soreness), and cost-effectiveness as an alternative to traditional exercise for frail elderly, while its limitations include its ineffectiveness for balance/falls, in contrast to previous evidence suggesting that WBV may be beneficial when combined with exercise interventions, its low intensity/frequency (20 Hz) potentially being insufficient for proprioceptive gains, the testing short duration that limited retention testing, and the small n reduced power (0.22).

Namsawang et al. [32] showed that a four-week TENS intervention significantly increased navicular height, improved balance in all directions, and reduced fear of falling compared to a control group performing short foot exercises. TENS likely enhanced plantar foot intrinsic muscle strength and proprioceptive stimulation, offering greater benefits than exercises alone. Directly depolarising alpha-motor neurons bypasses voluntary deficits, physiologically gating somatosensory signals via tibialis posterior activation; biomechanically, elevated arch height improves the medial longitudinal arch leverage for CoP centring [12,35]. The advantages involve it producing superior neuromuscular adaptations (direct afferent/efferent stimulation bypassing voluntary deficits) and being portable/home-based (high adherence), painless, and suitable for frail/small-muscle elderly, while its limitations are that its short duration limits the ability to assess long-term effectiveness and sustainability of the intervention, it lacks dynamic/fall tracking, the healthy testing sample may underestimate effects in flatfoot/fallers, and that there is potential for over-reliance on the device. Hence, proprioceptive and sensory stimulation interventions show variable effects. Foot care and TENS demonstrate significant improvements in postural control and balance, likely through enhanced mechanoreceptor input and muscle activation. However, whole-body vibration appears less effective, possibly due to insufficient intensity or duration, suggesting that targeted sensory interventions may be more beneficial for fall prevention.

Sensory interventions, such as foot care, improved postural control by increasing the toe contact area and mechanoreceptor input, aligning with Spink et al. [47], who found that podiatric interventions reduced fall risk by improving foot health [25]. TENS enhanced navicular height and balance while reducing fear of falling, supporting Najafi et al. [12], who reported that plantar electrical stimulation improves postural balance [12, 32]. In contrast, whole-body vibration's lack of efficacy contrasts with Liu et al. [48], where higher-frequency vibration improved balance, suggesting that the intervention parameters (e.g., frequency, duration) are critical. A network meta-analysis of 49 RCTs clarifies this variability, ranking whole body vibration training (WBVT) lower for dynamic balance (TUG *SMD* = –0.35, small *ES*) compared to sensorimotor training (*SMD* = –0.92), with inconclusive static balance gains (Berg Balance Scale *SMD* = 0.57, non-significant); optimal WBVT may require integration with other modalities for frail subgroups [49]. The variability in sensory intervention outcomes may reflect differences in participant sensory deficits or intervention intensity.

Clinical implications

Clinicians should prioritise individualised interventions to enhance balance and reduce fall risk in older adults. Properly fitted balance shoes or minimal footwear should be recommended over soft insoles, which may increase instability. Exercise programs like Baduanjin, Tai Chi, or beam walking should be integrated into fall prevention strategies due to their consistent benefits in improving strength, coordination, and dynamic stability. Foot care and TENS are valuable for frail older adults and those with sensory deficits, enhancing postural control through mechanoreceptor stimulation.

Limitations

The heterogeneity in the study designs, sample sizes, and outcome measures limits direct comparisons. The small sample sizes in some studies may reduce the generalisability. Additionally, the short duration of some interventions may not have been sufficient to detect significant changes. A meta-analysis was not performed due to the substantial clinical and methodological heterogeneity, including diverse interventions, outcome metrics, and populations. While network meta-analysis has been effectively used in broader falls prevention reviews to rank heterogeneous exercise interventions, it was deemed unsuitable here given the limited number of studies per intervention node, the absence of common comparators, and the incomparable effect measures, which could introduce intransitivity bias and unreliable rankings. Furthermore, subjective outcome measures dominated in certain studies, potentially introducing response bias and reducing objectivity, particularly where blinding was limited. Additionally, publication bias was not formally assessed due to the small number of included studies (n = 12), which limits the statistical power of methods like funnel plots or Egger's test, and the narrative synthesis approach, which precludes quantitative bias assessment. Moreover, the review included studies with full-text availability published in the English language, which led to the exclusion of studies published in other languages related to the context.

Recommendations for future research

Multidisciplinary approaches combining podiatric care, exercise, and footwear optimisation are recommended to address the multifactorial nature of falls. Future research should focus on larger, standardised trials with longer follow-up periods to establish optimal intervention protocols, ensure generalisability across diverse populations, particularly exploring the long-term efficacy of minimal footwear and sensory stimulation, and assess cost-effectiveness, which is a crucial gap for translating findings into clinical practice and public health programs.

Conclusions

This systematic review underscores the potential of foot posture interventions to enhance balance and reduce fall risk in older adults, with varied effects across approaches. Balance shoes and minimal footwear offer task-specific stability improvements, while exercise programs like Baduanjin, Tai Chi, Cha-cha dance, Pilates, and beam walking consistently improve static and dynamic balance through enhanced strength, coordination, and proprioception. Sensory interventions, particularly foot care and TENS, show promise in improving postural control, whereas whole-body vibration appears less effective. Ill-fitting footwear and soft insoles may exacerbate instability, highlighting the need for careful intervention selection. Hence, clinicians should prioritise individualised, multidisciplinary approaches combining proper footwear, exercise, and sensory stimulation to address the multifactorial nature of falls by establishing optimal intervention protocols to ensure applicability across diverse older adult populations, ultimately informing evidence-based strategies for fall prevention.

Ethical approval

The conducted research is not related to either human or animal use. PROSPERO registration: CRD420251078664 (registered 22nd June 2025).

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

Funding

This research received no external funding.

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