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Review

The Effects of Ankle and Foot Exercises on Ankle Strength, Balance, and Falls in Older People: A Systematic Review and Meta-Analysis

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ABSTRACT

Objective. Ankle-foot control is essential to maintain balance and gait stability. However, there has been limited evidence on the effect of ankle-foot exercises on balance and falls in older people. This study aimed to summarize the effects of ankle-foot exercises on ankle flexibility and strength, balance, mobility, and falls in older people and to identify determining factors for ankle-foot exercises to improve balance and mobility.

Methods. Cumulative Index to Nursing and Allied Health Literature, Embase, PubMed, and Physiotherapy Evidence Database (PEDro) were searched to identify randomized controlled trials that studied the effects of ankle-foot exercises on ankle control, balance, and falls in older people. The PEDro scale was used to evaluate the methodological quality of the studies. Meta-analyses were done for similar outcomes. The quality of evidence was rated by GRADE.

Results. Sixteen papers ($n = 651$) were included. Meta-analyses showed that ankle-foot exercises significantly improved ankle plantarflexion strength (SMD = 0.35, 95% CI = 0.04 to 0.65, low-quality evidence), ankle flexibility (SMD = 0.48, 95% CI = −0.01 to 0.96, low-quality evidence), and balance in an eyes-open condition (SMD = 0.41, 95% CI = 0.19 to 0.70, low-quality evidence). There was no significant change in ankle dorsiflexion strength (SMD = 0.29, 95% CI = −0.24 to 0.82, very low-quality evidence), balance under eyes-closed condition (SMD = 0.41, 95% CI = −0.1 to 0.92, very low-quality evidence), and gait speed (SMD = 0.36, 95% CI = −0.24 to 0.96, very low-quality evidence). Two studies reported insignificant findings on fear of falling, fall incidence, and risk of falls.

Conclusions. Very low– to low-quality evidence showed that ankle-foot exercises effectively improve ankle plantarflexion strength, flexibility, and balance with eyes open, whereas no effect on falls was found. Improvements in balance and gait tend to be associated with improvements in ankle strength and flexibility. Toe-strengthening exercise and training 3 times per week appear to be important for improving balance.

Impact. This review suggested that ankle-foot exercises might improve balance in older people. Determining factors leading to improvement in balance and mobility were identified. It paves the ground for further research to study the effect of ankle-foot exercises on fall prevention.

Lay Summary. Ankle and foot exercises appear to be effective in improving ankle plantarflexion strength, flexibility, and balance performance in an eye-open condition. If you are an older adult who wants to improve your balance, your physical therapist may prescribe ankle and foot exercises as a supplemental component in a fall prevention program due to the observed improvements in balance and the safety and ease of the exercise.

Key words: Ankle and Foot; Balance; Exercise; Falls; Older Adults; Strength.

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INTRODUCTION

Falling is a common problem in older people. Approximately 1 in 3 community-dwelling older adults experience 1 or more falls annually.[1] Falling can also lead to accidental injuries, hospitalization, and hence a decline in functional status.[2,3]

Deficits in balance and gait are the major modifiable risk factors of falls.[4] Systematic reviews have reported that the odds of falling in older adults with gait deficits[5] (pooled odds ratio = 2.1, 95% CI = 1.82 to 2.33, $P < .05$) or balance deficits[6] (pooled odds ratio = 3.0, 95% CI = 2.05 to 4.93, $P < .05$) are significantly higher than their robust counterparts with good balance performance. These indicate that gait and balance disorders, which can be regarded as activity limitations,[7] should be modified to effectively prevent falls in older people.

Balance and gait problems in older adults can be attributed to various factors, such as normal age-related changes and specific impairments of body structure or functions in the neural and musculoskeletal systems.[8] Among these multiple etiologies, an emerging number of studies have suggested that impairments in the ankle and foot regions are major contributors to balance and gait dysfunctions in older adults.[9–11] An epidemiological study has revealed that up to 30% of older adults are affected by ankle and foot problems, such as decreased ankle or foot strength, range of motion (ROM), and sensation.[12] These problems could lead to poor ankle and foot control, which refers to the ability of ankle and foot muscles to react and co-contract promptly to generate timely postural responses. Ankle and foot control is crucial for maintaining balance and reducing the risk of falls in both quiet stances and after postural disturbance.[13] It is also vital for sustaining a normal gait pattern.[14]

Ankle and foot control involves other body functions such as ankle muscle strength, flexibility, joint proprioception, and muscle reaction time.[15] Deficits in these body functions can compromise reactive balance and functional ability,[13] which, in turn, are linked to an increased risk of falls. For example, a decrease in ankle strength and flexibility has been found to be associated with reduced accuracy of muscle motor output upon perturbation.[16] They have also been discovered to alter joint movement patterns and reflex-activated muscle activities.[17,18] Studies have found that ankle strength and flexibility of older people declined by 30% and 34%, respectively, when compared with young, healthy populations.[19,20] Moreover, epidemiological studies have corroborated that older fallers have 31% less ankle strength and 10% less ankle flexibility compared to their older non-faller counterparts.[21] These point to the possibility of reducing falls by improving balance (activity limitation), which could, in turn, be improved through mitigating the age-related decline in ankle control, strength, and flexibility (body functions).

Many attempts have been made to examine the effectiveness of ankle and foot exercises in fall prevention and in improving balance and mobility.[22,23] Ankle and foot exercises are defined as exercises that aim to improve strength, flexibility, and control of the ankle or foot regions. A randomized controlled trial (RCT) has shown that a 3-month ankle-foot tap dance program significantly reduced postural sway in an eyes-open condition.[24] Another RCT has shown that an ankle-foot functional training program significantly improved walking speed.[22] After searching through the evidence, only 1 related systematic review was published in 2013.[25] It included 7 studies with heterogeneous study protocols, which led to inconclusive results related to the effect of ankle and foot exercises on ankle strength and gait performance.[25] Therefore, the effect of ankle and foot exercises on fall-related outcomes remains unclear. As several new RCTs have been published, it is timely to conduct a systematic review of this field.

Therefore, this systematic review aimed to find out: (1) Do ankle and foot exercises improve ankle and foot functions including strength and flexibility (body function)? (2) Do ankle and foot exercises improve balance and gait performance (activity limitation)? (3) Do ankle and foot exercises reduce the risk of falls and fall incidence? (4) Is the change in balance and gait performance (activity limitation) associated with changes in ankle strength and flexibility (body function)? (5) What are the determining factors (ie, participant characteristics, type of exercise, and training dosage) that influence how ankle and foot exercises improve balance and mobility in older people?

METHODS

Data Sources and Search

A systematic review was conducted to investigate the effectiveness of ankle and foot exercises on ankle and foot functions, balance, mobility, and falls of older people. The research questions and the keywords were structured based on the 4 domains of the PICO (*Population*, *Intervention*, *Comparisons*, and *Outcomes*) framework, in which the *Population* was older people; the *Intervention* was the exercise training focused on ankle and foot regions; the *Comparisons* was the blank or sham control without special ankle and foot training; and the *Outcomes* was ankle strength and flexibility, balance, mobility, and falls. Electronic databases including Cumulative Index to Nursing and Allied Health Literature (CINAHL), Excerpta Medica Database (Embase), PubMed, and Physiotherapy Evidence Database (PEDro) were used to identify the papers from the inception to November 30, 2022. The search terms in all databases were identical and were checked by a librarian who specializes in searching. A sample search strategy for CINAHL is provided in Supplementary Materials, Appendix S1.

Study Selection

The titles and abstracts of papers retrieved from the search were screened independently by 2 researchers (either 2 from C.M.C., N.M.L., Y.N.M., M.H.N., L.C.W., or S.G.S.L.) to eliminate irrelevant papers. A pre-screening meeting was conducted among all researchers, including the principal investigator (F.M.H.L.), to clarify the selection criteria. After screening the first 20 entries, all researchers convened to clarify any uncertainties that had arisen before continuing with the screening process. After the screening, all unresolved discrepancies were settled by discussion with the principal investigator (F.M.H.L.) until a consensus was reached. The interrater reliability of the initial titles and abstracts scanning was "very satisfactory" with an agreement value (κ) of 0.927. The full texts of the remaining papers were further evaluated to assess their eligibility. Papers were included if they (1) recruited populations aged 60 or above; (2) investigated the effects of physical exercise that aims to improve control of the ankle or foot regions (ie, strength, flexibility, proprioception, or reaction time); (3) were able to single out

Table 1. Criteria Used to Downgrade and Upgrade Rating in the GRADE of Recommendation, Assessment, Development and Evaluation (GRADE) System[a]

GRADE Domain	Downgrade and Upgrade Criteria
Risk of bias	• For outcomes where meta-analysis was possible, more than half of the participants included in the primary analysis from trials with a PEDro score of <6: downgrade 1 level. • For outcomes with more than half of the participants from trials with a PEDro score <4: downgrade 2 level.
Inconsistency	• For outcomes where meta-analysis was possible, $I^2 > 50\%$ in the meta-analysis: downgrade 1 level.
Indirectness	• The participants, intervention, comparator intervention, outcome measure, or study design did not match between the included studies and the eligibility criteria for this review: downgrade 1 level.
Imprecision	• Participants included in the meta-analysis were less than 400, or the 95% CIs spanned zero and appreciable harm (SMD < -0.2) or appreciable benefit (SMD > 0.2): downgrade 1 level. • Participants included in the meta-analysis were less than 400, and the 95% CIs spanned both appreciable harm (SMD < -0.2) and appreciable benefit (SMD > 0.2): downgrade 2 level.
Publication bias	• $P < .1$ on the 2-tailed Egger's regression asymmetry test: downgrade 1 level.
Large effect	• SMD ≥ 0.8 in the meta-analysis: upgrade 1 level.
Plausible confounding	• Study design results in the presence of residual confounding that reduced the demonstrated effect: upgrade 1 level.
Dose-response gradient	• Response gradient was detected in meta-regression analysis: upgrade 1 level.

[a]See the Methods section for further details. Abbreviations: I^2 = heterogeneity index; PEDro = Physiotherapy Evidence Database; SMD = standardized mean difference.

the ankle and foot exercises; (4) measured ankle functions, balance, mobility, or falls; (5) were randomized controlled trials; and (6) published in English. Papers were excluded if they: (1) recruited participants with any neurological and/or musculoskeletal deficits; (2) adopted exercises that do not specifically target the ankle or foot regions (eg, Tai Chi, yoga, Pilates exercise, or hydrotherapy exercises). The protocol of this systematic review was pre-registered in PROSPERO (CRD42022287298).

Data Extraction and Quality Assessment

Participant characteristics (sample size, age, sex reported as male or female), intervention protocols (type of exercise, intensity, frequency, program duration, etc), the target outcomes and their means, and standard deviations (balance, mobility, falls, strength, flexibility) were extracted and checked by at least 2 authors (either 2 from C.M.C., N.M.L., Y.N.M., M.H.N., L.C.W., or S.G.L.) for further data synthesis. The methodological qualities of the studies were evaluated by the PEDro scale.[26,27] The scale ranges from 0 to 10. It consists of 10 questions regarding the internal validity and statistical information of the studies. The higher the PEDro score, the better the methodological quality of the study. The score of each paper was indicated on the PEDro website (https://search.pedro.org.au/). If the PEDro score of the paper was unavailable on the website, it was rated by the research team members. The quality of evidence for the outcomes with results of meta-analyses was rated by Grading of Recommendations, Assessment, Development, and Evaluations (GRADE).[28,29] The quality of evidence reflects the extent of confidence that the estimated pooled effect size is correct and is rated into 4 levels (ie, very low, low, moderate, and high).[28,29] Very low–quality evidence indicates that we have very little confidence in the effect estimates, while high-quality evidence indicates that we are highly confident that the estimates are close to the true effects.[30] The details of the downgrade and upgrade criteria for evidence level are presented in Table 1.

Data Synthesis and Analysis

The outcomes of the included studies were separated into 3 levels: ankle and foot strength and flexibility (body function), balance and gait performance (activity limitation), and falls (ie, fear of falling, risk of falls, and fall incidence). Meta-analyses were conducted if similar outcomes were used in 3 or more studies. The results of the meta-analyses were presented using forest plots (Review Manager 5.4.1, The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark). A P value of $\leq .05$ is considered statistically significant. The random-effects model was chosen in all meta-analyses due to the heterogeneity across the included studies on participants' characteristics, exercise protocols, and outcome measures. The standardized mean difference (SMD) was used when the outcomes combined in a meta-analysis were presented in different units. The SMD was calculated by dividing the mean difference in the target outcomes (eg, ankle plantarflexion strength) between the ankle and foot training group and the control group by the pooled standard deviation. The 95% CI of an SMD spanning zero indicates that there is no statistically significant difference between the 2 groups.[31] The heterogeneity of studies is presented as the inconsistency index (I^2), which describes the variation across studies that is caused by heterogeneity instead of chance. It is presented in percentage form and is computed by the formula $I^2 = 100\% \times (Q - df)/Q$, where Q is the Cochran heterogeneity statistic and df is the degrees of freedom.[32] An I^2 of 25%, 50%, and 75% indicate low, moderate, and high heterogeneity, respectively.[32] Sensitivity analysis or study-level investigation was conducted for meta-analysis with moderate and high heterogeneity to investigate the potential reasons causing the statistical and clinical heterogeneity. Narrative analysis was done if a meta-analysis was not possible for an outcome.

Role of the Funding Source

The funders played no role in the design, conduct, or reporting of this study.

RESULTS

There were 2735 records yielded from the search. Sixteen[22–24,33–45] papers (15 studies), published from 1999 to 2021, matched all eligibility criteria and were included in this review (Figure 1). Two papers[38,39] were generated from the same research study with 1 of them[38] being an interim report. In addition, 1 study[34] missed some necessary

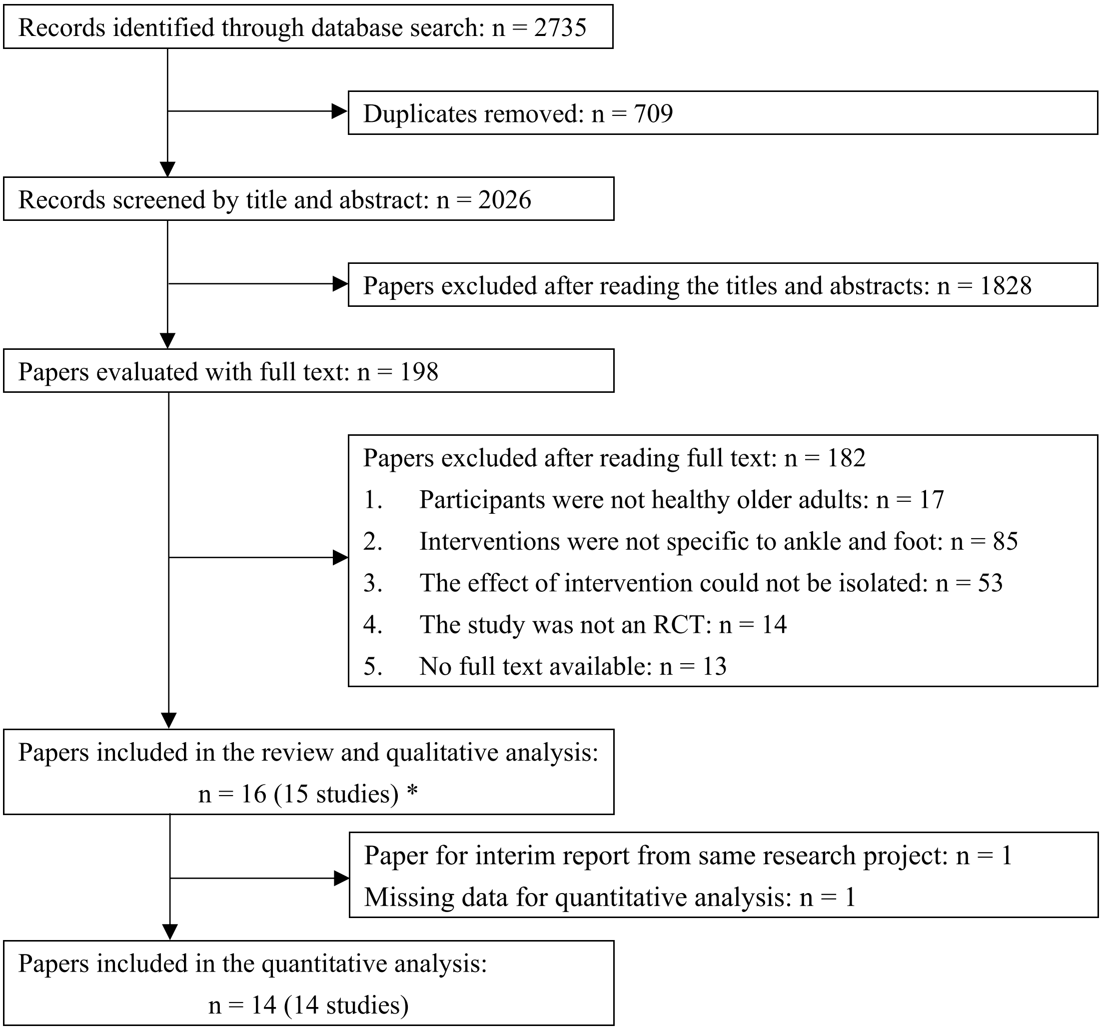

Figure 1. Flowchart of Paper Search. Abbreviation: RCT = randomized controlled trial. *Two papers[38,39] were generated from the same research study with 1[38] as an interim report.

data for meta-analysis. Therefore, 14[22–24,33,35–45] studies were included in meta-analyses (Figure 1). Furthermore, 3-arm RCTs[41,43] were separated into 2 comparisons in 4 meta-analyses (ie, plantarflexion and dorsiflexion strength, balance performance in eyes open and eyes closed). To avoid "double counting" of control participants from these studies in the meta-analyses, the participant numbers in the control group were allocated in proportion to the participant numbers in each intervention group.[46]

Study Characteristics

The sample sizes varied from 16 to 117, and a total of 651 participants were included in this systematic review. Other study characteristics including the mean age and source of the participants, type of ankle and foot exercises, and reported outcomes are summarized in Table 2. Detailed information for each study is presented in Supplementary Materials, Appendix S2.

Methodological Quality and Quality of Evidence

Six papers[22–24,37,41,45] were rated as good quality, 8 papers[33–36,39,40,43,44] were rated as fair quality, and 2 papers[33,38] were rated as poor quality. The PEDro score of each paper is outlined in Table 3.

A total of 6 meta-analyses were conducted based on targeted outcomes with heterogeneity ranging from low to high (Table 4, Figure 2), and the quality of evidence ranged from very low to low. The main reasons leading to the low quality of evidence were the low methodological quality of the included studies, an I^2 value over 50%, and the insufficient total sample size in the meta-analysis (Table 5).

Effects of Ankle and Foot Exercises on Targeted Outcomes

Ankle Plantarflexion Strength

Seven studies[34,35,39–42,44] evaluated ankle plantarflexion strength, of which one[34] did not report the required information for meta-analysis. Meta-analysis (6 studies, 7 comparisons, $n = 311$) revealed low-quality evidence that ankle and foot exercises significantly increased plantarflexion strength with low to moderate heterogeneity when compared with the control group (SMD = 0.35, 95% CI = 0.04 to 0.65, $P = .03$, $I^2 = 40\%$, Table 4, Figure 2A).

Ankle Dorsiflexion Strength

Four studies[36,39–41] assessed ankle dorsiflexion strength with an isokinetic dynamometer. Meta-analysis (4 studies, 5 comparisons, $n = 138$) provided very low–quality evidence that

Table 2. Characteristic of the Included Studies ($n = 15$)[a]

Characteristic	Studies, n (%)	References
Total sample size		
<50	10 (67%)	22–24, 33, 34, 36, 37, 39, 44, 45
≥50, <100	4 (27%)	35, 40–42
≥100	1 (6%)	43
Mean age (y)		
≥60, <65	1 (7%)	24
≥65, <75	7 (47%)	23, 36, 37, 42–45
≥75	7 (47%)	22, 33–35, 39–41
Sex		
Only female	3 (20%)	37, 41, 45
Only male	1 (7%)	36
Both	11 (74%)	22–24, 33–35, 39, 40, 42–44
Methodological quality (PEDro)		
<4 “poor”	1 (7%)	33
≥4, <6 “fair”	8 (53%)	34–36, 39, 40, 42–44
≥6, <8 “good”	6 (40%)	22–24, 37, 41, 45
Source of participants		
Community older adults	8 (53%)	23, 24, 37, 39–43
Nursing homes	4 (27%)	22, 33–35
Not mentioned	3 (20%)	36, 44, 45
Types of physical exercise		
Strength exercise	9 (60%)	33–36, 39, 41–43, 45
Stretching exercise	1 (7%)	37
Multi-component exercise	5 (33%)	22–24, 40, 44
Targeted outcomes[b]		
Plantarflexion strength	7	34, 35, 39–42, 44
Dorsiflexion strength	4	39–41, 44
Functional strength (5STS)	2	23, 24
Ankle flexibility	4	23, 24, 37, 40
Balance with eyes opened	8	23, 24, 33–36, 42, 43
Balance with eyes closed	5	23, 24, 33, 43, 45
Gait speed	5	22, 34, 35, 40, 44
Fall risk, incidence, fear of fall	2	34, 35

[a]Abbreviations: 5STS = five time sit to stand; PEDro = Physiotherapy Evidence Database. [b]Percentage was not provided as 1 study contained multiple targeted outcomes.

ankle and foot exercises did not significantly increase ankle dorsiflexion strength when compared with the control group with moderate heterogeneity (SMD = 0.29, 95% CI = −0.24 to 0.82, $P = .28$, $I^2 = 60\%$, Table 4, Figure 2B).

Sensitivity analysis was conducted according to the type of ankle and foot exercises. It was found that only Amiridis et al[36] adopted pure dorsiflexion strengthening exercise and yielded a significant improvement compared with the control group. All other studies[39–41] adopted a general ankle and foot strengthening program containing multiple muscle groups strengthening (eg, toes grasp or plantarflexion muscles) and yielded insignificant results compared with the control group. Upon excluding the study[36] that specifically performed dorsiflexion strengthening exercise, the meta-analysis remained insignificant with markedly reduced heterogeneity (SMD = 0.03, 95% CI = −0.31 to 0.37, $P = .85$, $I^2 = 0\%$).

Functional Strength

Two studies[23,24] ($n = 84$) used the 5 times sit-to-stand test as the outcome measure for functional strength. Both studies included a modified tap dance program on the ankle and foot as the intervention and compared it with a health education group. Only Zhao et al[23] demonstrated a significant improvement in the exercise group when compared with the control group.

Ankle Flexibility

Four studies[23,24,37,40] measured the changes in ankle flexibility. Two[23,24] assessed the active ROM of the ankle dorsiflexion and plantarflexion, while 2[37,40] assessed the passive ROM of ankle dorsiflexion. Meta-analysis (4 studies, $n = 159$) illustrated with low-quality evidence that ankle and foot exercises had a significant effect ($P < .05$) on improving ankle range of motion in the intervention group when compared with the control group with moderate heterogeneity (SMD = 0.48, 95% CI = −0.01 to 0.96, $P = .05$, $I^2 = 54\%$, Table 4, Figure 2C). Despite an extensive review of the studies, considering participants’ characteristics, training settings, and measurement methods, the source of the moderate heterogeneity observed in the meta-analysis remained undetermined.

Balance Performance

Nine studies[23,24,33–36,42,43,45] investigated the effect of ankle and foot exercises on static standing balance with eyes open or eyes closed on a firm surface, of which 8[23,24,33–36,42,45] studies measured with a double-leg stance, and 1 study[43] measured with a single leg stance. One study[37] assessed dynamic balance using the functional reach test (FRT) as an outcome measure with eyes open and reported an insignificant change after training. None of the studies measured balance ability with multi-item tools such as the Berg Balance Scale (BBS) or the Mini-BESTest.

Table 3. Physiotherapy Evidence Database (PEDro) Score of Included Papers[a]

Criterion	Amiridis et al[36] (2005)	Barbosa et al[45] (2020)	Bohrer et al[44] (2019)	Gajdosik et al[37] (2005)	Hartmann et al[40] (2009)	Kobayashi et al[33] (1999)	Kobayashi et al[42] (2016)	Mickle et al[43] (2016)	Schoen-felder[34] (2000)	Schoen-felder et al[35] (2004)	Simoneau et al[38] (2006)	Simoneau et al[39] (2007)	Wang et al[24] (2021)	Webber et al[41] (2010)	Yanaoka et al[22] (2020)	Zhao et al[23] (2021)
Eligibility criteria	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
Random allocation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Concealed allocation	0	0	0	1	0	0	0	1	0	0	0	0	1	1	1	0
Baseline comparability	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1
Participants who were blinded	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Therapists who were blinded	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Assessors who were blinded	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1
Adequate follow-up	0	1	0	1	0	0	0	0	1	0	0	1	1	0	0	1
Intention-to-treat analysis	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	1
Between-group comparisons	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
Point estimates and variability	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
Total	4	6	5	6	5	3	4	5	4	4	3	4	6	6	7	7

[a]The PEDro score of Barbosa[45] 2020, Simoneau[39] 2007, and Wang[24] 2021 were rated by the research team member.

Balance with eyes open: Eight studies[23,24,33–36,42,43] assessed static standing balance with the participants' eyes open. Five studies[23,24,33,36,42] measured postural sway with the total displacement or track length of the center of pressure (COP). Three studies[34,35,43] recorded the total time for the participants to perform the static balance tasks. Meta-analysis (6 studies, 7 comparisons, $n = 333$) illustrated with low-quality evidence that ankle and foot exercises with 3 to 4 sessions per week had a significant effect in improving balance under an eyes-open condition when compared with the control group with low heterogeneity (SMD = 0.44, 95% CI = 0.19 to 0.70, $P < .01$, $I^2 = 19\%$, Table 4, Figure 2D).

Furthermore, the most and second most effective studies in the meta-analysis have adopted a toe-grasping and bean bag transfer exercise, which consisted of mainly toe muscle training.[33,43] On the contrary, all studies with insignificant improvement did not include a toe muscle training component.[23,24,35]

Balance with eyes closed: Five studies[23,24,33,43,45] assessed balance performance under an eyes-closed condition. Four studies[23,24,33,45] measured the postural sway using the mean displacement of COP or the total distance traveled by the COP, while 1 study[43] recorded the time to maintain single-leg stance balance. Meta-analysis (5 studies, 6 comparisons, $n = 251$) showed with very low-quality evidence that ankle and foot exercises did not significantly improve eyes-closed balance ability when compared with the control group with moderate to high heterogeneity (SMD = 0.41, 95% CI = −0.10 to 0.92, $P = .11$, $I^2 = 71\%$, Table 4, Figure 2E).

A sensitivity analysis (4 studies, 5 comparisons, $n = 231$) was conducted to evaluate the effect of ankle and foot exercises with at least 3 sessions of training per week.[23,24,33,43] The improvement became significant with moderate heterogeneity (SMD = 0.56, 95% CI = 0.05 to 1.07, $P = .03$, $I^2 = 69\%$). In addition, similar to the result of balance performance in the eyes-open condition, the study that yielded the greatest effect on eyes-closed balance adopted toe muscle training.[33] This study was also the only study recruiting participants from residential care settings.[33]

Gait Speed

Five studies[22,34,35,40,44] measured the changes in normal gait speed[40,44] and the time[22,34,35] required to finish the 6 m walk test. Two studies[22,44] measured gait speed involving the acceleration period, 1 study[40] measured steady-state walking speed (without the acceleration and deceleration period), and 2 studies[34,35] did not specify whether the acceleration and deceleration periods were included in the walking speed measurement. One study[34] with an insignificant result on gait speed was not included in the meta-analysis as the standard deviation was not reported.

Meta-analysis (4 studies, $n = 205$) presented very low–quality evidence that ankle and foot exercises did not significantly increase gait speed when compared with the control group with high heterogeneity (SMD = 0.36, 95% CI = −0.24 to 0.96, $P = .24$, $I^2 = 76\%$, Table 4, Figure 2F).

Sensitivity analysis included only studies[22,44] that measured the speed with the acceleration period showed a significant improvement (SMD = 0.95, 95% CI = 0.44 to 1.45, $P < .001$, $I^2 = 0$). In addition, the studies[22,44] that showed improvement in gait speed have recruited participants with the ability to walk without the aid of an assistive device, while the study[35] that showed no effect on gait speed recruited a high

Table 4. Results of Meta-analyses of the Effects of Ankle-Foot Exercise on Targeted Outcomes[a]

Outcomes	Number of Studies (Comparison)[b]	Sample (n)		Pooled Effect Size			I^2
		Exp.	Con.	SMD	(95% CI)	*P*	
Strength:							
Plantarflexion	6 (7)	171	140	0.35	(0.04 to 0.65)	.03	40%
Dorsiflexion	4 (5)	91	70	0.29	(−0.24 to 0.82)	.28	60%
Flexibility	4	80	79	0.48	(−0.01 to 0.96)	.05	54%
Balance:							
Eyes-open condition	6 (7)	194	139	0.44	(0.19 to 0.70)	< .001	19%
Eyes-closed condition	5 (6)	152	99	0.41	(−0.10 to 0.92)	.11	71%
Gait speed	4	103	102	0.36	(−0.24 to 0.96)	.24	76%

[a]Abbreviations: Con. = control group; Exp. = experimental group; I^2 = heterogeneity index; SMD = standardized mean difference. [b]Three-arm randomized controlled trials[38,40] were separated into 2 comparisons in the meta-analyses.

proportion (82.5%) of older adults who needed an assistive device to walk. Furthermore, the most effective study is also the only study recruiting participants from residential care settings.[22]

Fear of Falling, Fall Incidence, and Risk of Falls

Two studies[34,35] ($n = 97$) assessed fear of falling. Both studies asked the participants to rate their fear of falling by the question "How concerned are you about falling?" with a 4-point system (ie, not at all concerned, somewhat concerned, fairly concerned, and very concerned). They reported that ankle and foot exercises have no significant effect on the fear of falling when compared with the control group. One study[34] ($n = 16$) performed an across-group comparison on fall incidence (number of falls) recorded from pre-test to post-test and from post-test to 3-month follow-up. It reported an insignificant result of ankle and foot exercises on fall incidence when compared with the control group. In addition, 1 study[35] ($n = 81$) assessed the risk of falls using the Risk Assessment for Falls Scale II. No significant effect in reducing the risk of falls was found in the exercise group when compared with the control group.

Associations Between the Improvements in Balance and Mobility Performance and the Improvements in Ankle Functions

For the studies that reported balance performance, 6 studies[23,24,34–36,42] also measured ankle and foot functions including strength and flexibility. In these 6 studies, 2 studies[23,36] that reported improvements in balance performance also reported significant improvement in either dorsiflexor strength or ankle flexibility (Suppl. Materials, Appendix S2). Among the 4 studies[24,34,35,42] that reported no effect of ankle and foot exercises on balance, 3[24,34,35] presented no significant findings in ankle and foot functions including strength and flexibility.

For gait speed, 4 studies[34,35,40,44] measured both gait speed and ankle functions. Three studies[34,35,40] identified no improvement in gait speed. All reported insignificant findings in plantarflexion, dorsiflexion strength, or ankle flexibility (Suppl. Materials, Appendix S2). In contrast, the only study[44] that identified the improvement in gait speed showed a significant effect of ankle and foot exercises on plantarflexion strength when compared with the control group.

Adverse Effects

Six studies[23,24,35,39,41,43] explicitly reported whether there were any adverse effects after the interventions. Four studies[23,24,35,39] reported no adverse effects during the intervention period. One study[43] reported that 1 participant withdrew from the study 1 week after joining the program due to the exacerbation of low back pain. Another study[41] also reported that 3 women dropped out due to the exacerbations of pre-existing musculoskeletal conditions. None of these 2 studies mentioned whether the exacerbations were caused by the exercises. Nevertheless, no serious adverse events were reported in all studies.

DISCUSSION

Our systematic review consolidated the latest evidence of the effects of ankle and foot exercises on ankle strength and flexibility (body function), balance and mobility (activity limitation), and falls in older adults.

Effect of Ankle and Foot Exercises on Ankle Strength and Flexibility

Our results showed, with very low to low quality of evidence, that the protocols used in the included studies could improve ankle plantarflexion strength and ankle flexibility but not ankle dorsiflexion strength.

A potential explanation for the lack of significant change in ankle dorsiflexion strength is that most studies[39–41] adopted a general ankle and foot strengthening program. The programs were not specifically targeted to improve dorsiflexion strength. This led to an insufficient dosage for improving dorsiflexion strength. Given that the only study focusing on training the ankle dorsiflexors demonstrated significant improvement, it suggests that with an adequate training regimen, it is possible to strengthen the ankle dorsiflexors.

This has demonstrated that ankle and foot exercises could largely improve outcomes at the body function level. This provides a solid foundation to evaluate whether the improvement in ankle functions can be translated to higher-level outcomes like balance and mobility performance.

Effect of Ankle and Foot Exercises on Balance and Gait Performance

The effects of ankle and foot exercises on activity-level outcomes were more inconsistent. A significant improvement was found in static balance in an eyes-open condition with low heterogeneity, but not in static balance in an eyes-closed condition. No significant effect was found in gait speed.

We observed that all studies included in the meta-analysis of the eyes-open condition conducted at least 3 training sessions per week. A sensitivity analysis of the eye-closed condition,

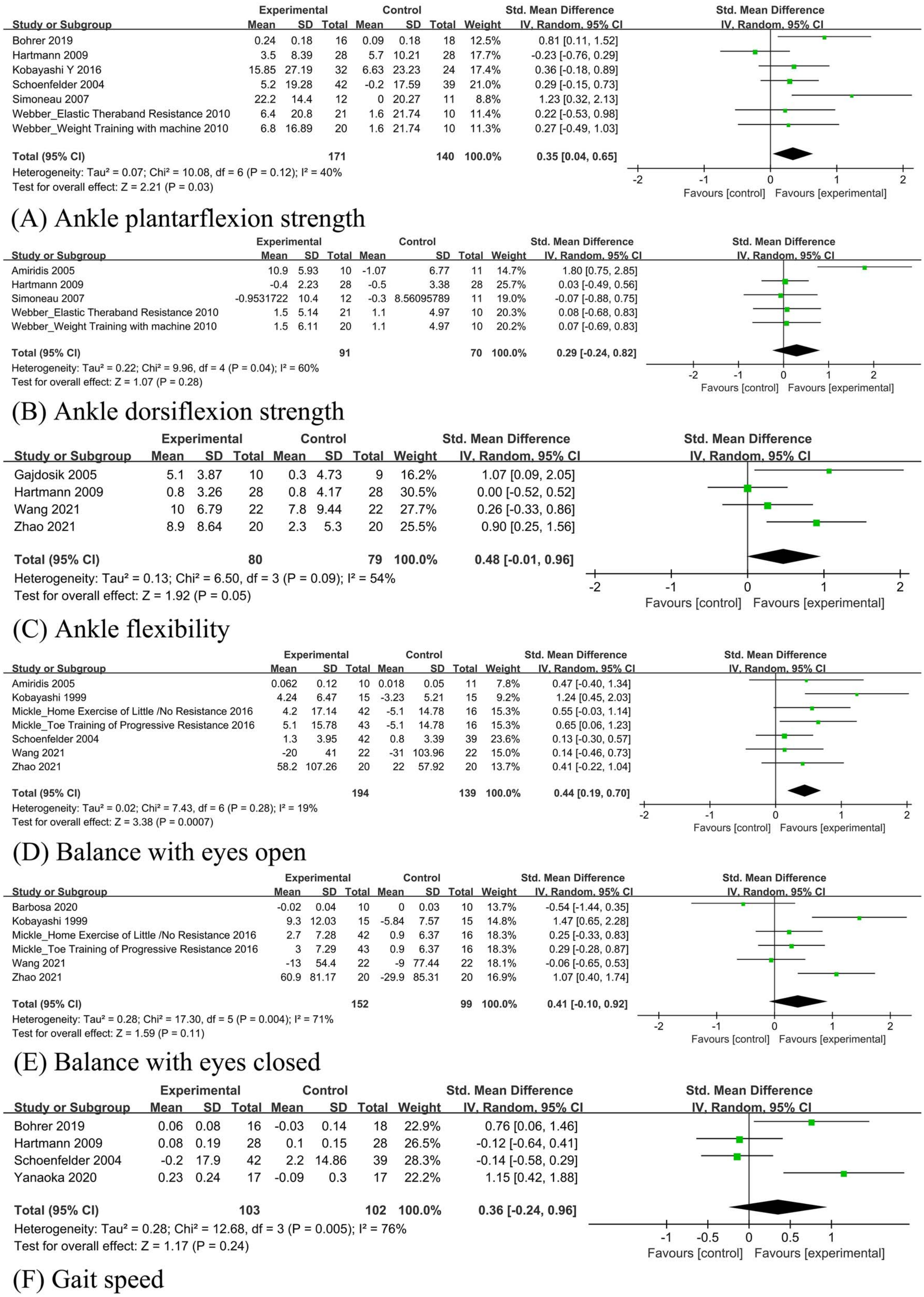

Figure 2. The Primary Meta-analyses of the Effect of Ankle and Foot Exercises Compared With the Control Group.

which kept only the studies with at least 3 training sessions per week, also yielded a significant improvement in the ankle and foot exercises group when compared with the control group. Therefore, training frequency might be a potential factor for the improvement of balance performance after ankle and foot exercises. In addition, the sensitivity analysis for gait speed revealed that studies[22,44] reporting significant improvements compared with the control group have incorporated measurements of gait speed during the acceleration phase. Future research should explore whether ankle and foot exercises are more effective in improving gait speed during the acceleration period.

Table 5. Grade of Recommendation, Assessment, Development and Evaluation (GRADE) Quality of Evidence[a]

Outcome	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Large Effect	Plausible Residual Confounding	Dose-Response Gradient	GRADE Quality
Plantarflexion strength	−1[a]	0	0	−1[b]	0	0	0	0	Low
Dorsiflexion strength	−1[a]	−1[c]	0	−2[d]	0	0	0	0	Very Low
Ankle flexibility	0	−1[c]	0	−1[b]	0	0	0	0	Low
Balance with eyes open	−1[a]	0	0	−1[b]	0	0	0	0	Low
Balance with eyes closed	−1[a]	−1[c]	0	−1[b]	0	0	0	0	Very Low
Gait speed	−1[a]	−1[c]	0	−2[d]	0	0	0	0	Very Low

[a]More than half of the participants included in the primary analysis from trials with a Physiotherapy Evidence Database (PEDro) score less than 6. [b]The number of participants included in the primary meta-analysis was less than 400 or the 95% CI spanned 0 and 0.2. [c]Heterogeneity I^2 larger than 50% in the meta-analysis. [d]The 95% CI spanned −0.2 and 0.2.

Effect of Ankle and Foot Exercises on Fall Incidence, Risk of Falls, and Fear of Falling

With only 2 studies reporting fall-specific outcomes,[34,35] current evidence does not support the ability of ankle and foot exercises to reduce fear of falling, fall incidence, and risk of falls in the older population. Considering the small sample sizes of these 2 studies, especially the study investigating the fall incidence ($n = 16$),[46] further studies with large sample sizes are required to study the effect of ankle and foot exercises on fall-specific outcomes.

Improvements of Body Functions of Ankle and Foot on Balance and Gait Performance

The improvements in ankle strength and flexibility appear to be associated with the improvement in balance and gait speed. Details were observed in 6 studies[23,24,34–36,42] that measured balance and ankle functions and 4 studies[34,35,40,44] that measured gait speed and ankle strength.

All studies reported improvement in balance performance also reported significant improvement in either dorsiflexor strength or ankle flexibility. This echoed the findings demonstrated by Bok et al,[47] where it has been identified that ankle muscle strength and ROM were significantly correlated with postural stability and balance performance in standing and gait in older people.[48]

In addition, all results in gait speed correlated well with the findings in ankle plantarflexion strength. A possible explanation is that the improvement in ankle plantarflexion strength could increase the efficiency in ambulation. It has been reported that the majority of the total leg mechanical output was contributed by the plantarflexors during the propulsion phase. Therefore, the increase in plantarflexion strength resulting from ankle and foot exercises could lead to a greater propulsive force, which subsequently improved the gait efficiency and gait speed.[49] It appears that an improvement in ankle strength and flexibility after ankle and foot exercise could be translated to improvements in balance performance and gait speed.

Determining Factors that Influence the Effectiveness of Ankle and Foot Exercises on Balance and Mobility

Participant Characteristics

Among the studies included in the meta-analyses of balance and gait speed, there was no observable trend indicating that mean age or sex proportion affected the effect.

Nevertheless, older people who stay in the residential care settings may gain more improvement in balance and gait after foot and ankle exercises since the studies recruiting in the residential care settings tended to show the largest effect sizes in the meta-analyses, including Kobayashi et al[33] for balance in both eyes-open and eyes-closed conditions, and Yanaoka et al[22] for gait speed. Further research is required to clarify this trend and its underlying reasons.

In addition, ankle and foot exercises appear to be more effective in improving gait speed in older adults who can walk without the aid of an assistive device. Considering that ankle and foot exercises could potentially improve gait speed indirectly through improving stability, those who carried an assistive device for external support might be less sensitive to show improvement in the assessment.[50]

Types of Exercise

Regarding the exercise type, our systematic review revealed that strengthening toe muscles significantly improved static balance. Toe-strengthening training might be more effective because it can activate intrinsic foot muscles efficiently. Intrinsic foot muscles, being a subtype of toe muscles, may have a significant role in balance performance. While extrinsic foot muscles originate in other parts of the lower limbs, intrinsic foot muscles have origins and insertions within the foot.[51] While the contribution of extrinsic muscles on balance control through ankle strategy is well established,[51] the role of intrinsic foot muscles on balance has been discussed much more in recent years. It was proposed that weak intrinsic foot muscles fail to provide a stable and well-aligned foot arch, potentially leading to abnormal ankle movements.[51] Consequently, intrinsic foot muscles might provide a stable foot arch with better ankle control, hence promoting balance and probably reducing the risk of falls. Despite the limited research, it has been proposed that intrinsic foot muscles might have sensor receptors that could be modulated through training to improve the somatosensory balance system.[52] More investigations about the effects of different types of intrinsic muscle training are needed.

Training Frequencies, Intensities, and Durations

Sufficient training frequency might be needed to gain significant improvement in balance performance. Our meta-analyses and sensitivity analysis indicated that at least 3 sessions of ankle and foot exercises per week might be required to improve balance performance significantly. This aligns with the guideline and empirical evidence for fall prevention in older people, which advocated for a regimen of balance training conducted 3 times a week.[46,53] This frequency of training has been shown to be effective in mitigating the risk of falls in this demographic.[46,53] In addition, no other specific dosages and program durations were found to be associated with improvement due to the large heterogeneity in study design.

Clinical Recommendation

Despite the supportive evidence being of very low to low quality, ankle and foot exercises were found to be safe and easy to administer. Therefore, we recommend therapists prescribe ankle and foot exercises that involve toe muscle strengthening and flexibility exercises for improving ankle and foot functions and balance in older people, particularly for those living in residential care settings or those with poor ankle and foot control. In addition, training for at least 3 sessions per week is recommended for improving static standing balance.

Limitations

There are several limitations in the reviewed studies. In terms of the outcome measures, most studies[23,24,33,36,42,45] measured the total length of the COP trajectory during static balance tasks, which is less indicative of functional balance. Also, only 1 study[37] included the FRT as the outcome measure, and therefore cannot be included in the meta-analysis. None of the studies assessed both static and dynamic balance with multi-item assessment tools, such as the BBS. Therefore, the meta-analysis can only reflect the effects of ankle and foot exercises on static standing balance.

Furthermore, only a few studies in our review measured both ankle functions and activity level outcomes. Among these studies, none explored the correlations between ankle functions and activity level outcomes. A strong conclusion on whether the improvements in balance or gait were caused by the improvements in ankle control cannot be made. Future studies are needed to explore the potential correlation between the improvements in ankle strength and balance following ankle and foot exercises.

In addition, the small number of participants included in the meta-analyses might lead to insignificant results in our meta-analyses. For example, balance with eyes open and balance with eyes closed yielded similar pooled effect sizes in the meta-analyses (SMD = 0.44 vs 0.41). However, only balance with eyes open showed a significant improvement compared with the control potentially due to the larger sample size involved ($n = 333$ vs $n = 251$). The same pattern was also found in the meta-analyses of strength (ankle plantarflexion and dorsiflexion).

For the systematic review, the components of ankle control and their effects on risk of falls were not fully explored. Ankle proprioception and reaction time were included in our search strategy. However, no study currently investigated the effects of specific ankle and foot exercises on ankle proprioception and reaction time. This limited the focus of our review on ankle strength and flexibility as the major outcomes representing ankle control. Additionally, only 1 study measured the number of falls, which was a direct indicator of the risk of falls. More RCTs investigating the effects of ankle and foot exercises on the risk of falls and fall incidence are required.

Finally, the quality of evidence for each meta-analysis was rated as very low to low by the GRADE tool due to the imprecision & inconsistency observed in the meta-analysis and the high risk of bias of the included studies. The findings presented in this review may be changed as new high-quality research papers with larger sample sizes are published.

CONCLUSION

This systematic review illustrated with very low to low-quality evidence that ankle and foot exercises are effective in improving ankle plantarflexion strength, ankle flexibility, and standing balance with eyes open. Furthermore, preliminary evidence showed that the improvements in balance and gait are correlated with the improvements in ankle strength and flexibility. Toe-strengthening exercise and a training frequency of at least 3 sessions per week appear to be important for improving static balance. However, ankle and foot exercises showed no significant effect on fear of falling, risk of falls, and fall incidence in older people as evidenced by 2 small studies. More research on the effect of ankle and foot exercise on the risk of falling and fall incidence is required.

CRediT – CONTRIBUTOR ROLES

Sam Guoshi Liang (Data curation, Formal analysis, Methodology, Software, Writing—original draft, Writing—review & editing [equal]), Chung Man Chow (Formal analysis, Investigation, Methodology, Writing—original draft [equal]), Nga Ming Leung (Formal analysis, Investigation, Methodology, Writing—original draft [equal]), Yee Nok Mo (Formal analysis, Investigation, Methodology, Writing—original draft [equal]), Ming Hin Ng (Formal analysis, Investigation, Methodology, Writing—original draft [equal]), Lok Ching Woo (Formal analysis, Investigation, Methodology, Writing—original draft [equal]), Freddy Man Hin Lam (Conceptualization, Methodology, Project administration, Resources, Supervision, Validation [Lead], Writing—review & editing [lead], Writing—original draft [equal]).

SUPPLEMENTARY MATERIAL

Supplementary material is available online.

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SYSTEMATIC REVIEW REGISTRATION

The protocol of this systematic review was pre-registered in PROSPERO (CRD42022287298).

DISCLOSURES

The authors completed the ICMJE Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest.

DATA AVAILABILITY

Data that support the results and analyses can be accessed by contacting the corresponding author.

REFERENCES

1. Ganz DA, Latham NK. Prevention of falls in community-dwelling older adults. *N Engl J Med*. 2020;382(8):734–743. https://doi.org/10.1056/NEJMcp1903252

2. Terroso M, Rosa N, Torres Marques A, Simoes R. Physical consequences of falls in the elderly: a literature review from 1995 to 2010. *Eur Rev Aging Phys Act*. 2014;11(1):51–59. https://doi.org/10.1007/s11556-013-0134-8
3. de Clercq H, Naude A, Bornman J. Older adults' perspectives on fall risk: linking results to the ICF. *J Appl Gerontol*. 2021;40(3): 328–338. https://doi.org/10.1177/0733464820929863
4. Ambrose AF, Paul G, Hausdorff JM. Risk factors for falls among older adults: a review of the literature. *Maturitas*. 2013;75(1): 51–61. https://doi.org/10.1016/j.maturitas.2013.02.009
5. Deandrea S, Lucenteforte E, Bravi F, Foschi R, La Vecchia C, Negri E. Risk factors for falls in community-dwelling older people: a systematic review and meta-analysis. *Epidemiology*. 2010;21(5): 658–668. https://doi.org/10.1097/EDE.0b013e3181e89905
6. Li Y, Hou L, Zhao H, Xie R, Yi Y, Ding X. Risk factors for falls among community-dwelling older adults: a systematic review and meta-analysis. *Front Med (Lausanne)*. 2022;9:1019094. https://doi.org/10.3389/fmed.2022.1019094
7. Papa EV, Dong X, Hassan M. Resistance training for activity limitations in older adults with skeletal muscle function deficits: a systematic review. *Clin Interv Aging*. 2017;12:955–961. https://doi.org/10.2147/CIA.S104674
8. Hsu WL, Chen CY, Tsauo JY, Yang RS. Balance control in elderly people with osteoporosis. *J Formos Med Assoc*. 2014;113(6): 334–339. https://doi.org/10.1016/j.jfma.2014.02.006
9. Pol F, Khajooei Z, Hosseini SM, Taheri A, Forghany S, Menz HB. Foot and ankle characteristics associated with fear of falling and mobility in community-dwelling older people: a cross-sectional study. *J Foot Ankle Res*. 2022;15(1):86. https://doi.org/10.1186/s13047-022-00593-w
10. Hernández-Guillén D, Roig-Casasús S, Tolsada-Velasco C, García-Gomáriz C, Blasco J-M. Talus mobilization-based manual therapy is effective for restoring range of motion and enhancing balance in older adults with limited ankle mobility: a randomized controlled trial. *Gait Posture*. 2022;93:14–19. https://doi.org/10.1016/j.gaitpost.2022.01.005
11. Lai Z, Wang R, Zhou B, Chen J, Wang L. Difference in the recruitment of intrinsic foot muscles in the elderly under static and dynamic postural conditions. *PeerJ*. 2023;11:e15719. https://doi.org/10.7717/peerj.15719
12. Pol F, Forghany S, Hosseini SM, Taheri A, Menz HB. Structural and functional foot and ankle characteristics associated with falls in older people. *Gait Posture*. 2021;88:78–83. https://doi.org/10.1016/j.gaitpost.2021.05.012
13. Menz HB, Auhl M, Spink MJ. Foot problems as a risk factor for falls in community-dwelling older people: a systematic review and meta-analysis. *Maturitas*. 2018;118:7–14. https://doi.org/10.1016/j.maturitas.2018.10.001
14. Dubin A. Gait: the role of the ankle and foot in walking. *Med Clin North Am*. 2014;98(2):205–211. https://doi.org/10.1016/j.mcna.2013.10.002
15. Kobayashi T, Tanaka M, Shida M. Intrinsic risk factors of lateral ankle sprain: a systematic review and meta-analysis. *Sports Med*. 2016;8(2):190–193. https://doi.org/10.1177/1941738115623775
16. Thompson C, Schabrun S, Romero R, Bialocerkowski A, van Dieen J, Marshall P. Factors contributing to chronic ankle instability: a systematic review and meta-analysis of systematic reviews. *Sports Med*. 2018;48(1):189–205. https://doi.org/10.1007/s40279-017-0781-4
17. Hirata K, Akagi R. Contribution of muscle stiffness of the triceps surae to passive ankle joint stiffness in young and older adults. Original research. *Front Physiol*. 2022;13:972755. https://doi.org/10.3389/fphys.2022.972755
18. Zhu RT-L, Lyu P-Z, Li S, Tong CY, Ling YT, Ma CZ-H. How does lower limb respond to unexpected balance perturbations? New insights from synchronized human kinetics, kinematics, muscle electromyography (EMG) and mechanomyography (MMG) data. *Biosensors (Basel)*. 2022;12(6):430.
19. Svoboda Z, Bizovska L, Gonosova Z, Linduska P, Kovacikova Z, Vuillerme N. Effect of aging on the association between ankle muscle strength and the control of bipedal stance. *PLoS One*. 2019;14(10):e0223434. https://doi.org/10.1371/journal.pone.0223434
20. Zhai M, Huang Y, Zhou S, et al. Effects of age-related changes in trunk and lower limb range of motion on gait. *BMC Musculoskelet Disord*. 2023;24(1):234. https://doi.org/10.1186/s12891-023-06301-4
21. Cattagni T, Scaglioni G, Laroche D, Van Hoecke J, Gremeaux V, Martin A. Ankle muscle strength discriminates fallers from non-fallers. *Front Aging Neurosci*. 2014;6:336. https://doi.org/10.3389/fnagi.2014.00336
22. Yanaoka T, Yamasaki Y, Ueda T, et al. The effect of foot functional training on gait ability in older adults with activities of daily living disability: a randomized controlled trial. *Int J Gerontol*. 2020;14(4):320–326.
23. Zhao Y, Cai K, Wang Q, Hu Y, Wei L, Gao H. Effect of tap dance on plantar pressure, postural stability and lower body function in older patients at risk of diabetic foot: a randomized controlled trial. *BMJ Open Diabetes Res Care*. 2021;9(1):e001909. https://doi.org/10.1136/bmjdrc-2020-001909
24. Wang Q, Zhao Y. Effects of a modified tap dance program on ankle function and postural control in older adults: a randomized controlled trial. *Int J Environ Res Public Health*. 2021;18(12):6379. https://doi.org/10.3390/ijerph18126379
25. Schwenk M, Jordan ED, Honarvararaghi B, Mohler J, Armstrong DG, Najafi B. Effectiveness of foot and ankle exercise programs on reducing the risk of falling in older adults: a systematic review and meta-analysis of randomized controlled trials. *J Am Podiatr Med Assoc*. 2013;103(6):534–547. https://doi.org/10.7547/1030534
26. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther*. 2003;83(8):713–721. https://doi.org/10.1093/ptj/83.8.713
27. Morton NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Aust J Physiother*. 2009;55(2):129–133. https://doi.org/10.1016/s0004-9514(09)70043-1
28. Goldet G, Howick J. Understanding GRADE: an introduction. *J Evid Based Med*. 2013;6(1):50–54. https://doi.org/10.1111/jebm.12018
29. Schünemann H, Brożek J, Guyatt G, Oxman A, editors. *GRADE Handbook*. The GRADE Working Group. Canada. 2013. Accessed November 22, 2024. https://gdt.gradepro.org/app/handbook/handbook.html
30. Granholm A, Alhazzani W, Møller MH. Use of the GRADE approach in systematic reviews and guidelines. *Br J Anaesth*. 2019;123(5):554–559. https://doi.org/10.1016/j.bja.2019.08.015
31. Mean AC. Standardized Mean difference (SMD), and their use in meta-analysis: as simple as it gets. *J Clin Psychiatry*. 2020;81(5):11349. https://doi.org/10.4088/JCP.20f13681
32. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327:557–560. https://doi.org/10.1136/bmj.327.7414.557
33. Kobayashi R, Hosoda M, Minematsu A, et al. Effects of toe grasp training for the aged on spontaneous postural sway. *J Phys Ther Sci*. 1999;11(1):31–34. https://doi.org/10.1589/jpts.11.31
34. Schoenfelder DP. A fall prevention program for elderly individuals. Exercise in long-term care settings. *J Gerontol Nurs*. 2000;26(3): 43–51. https://doi.org/10.3928/0098-9134-20000301-09
35. Schoenfelder DP, Rubenstein LM. An exercise program to improve fall-related outcomes in elderly nursing home residents. *Appl Nurs Res*. 2004;17(1):21–31. https://doi.org/10.1016/j.apnr.2003.10.008
36. Amiridis I, Arabatzi F, Violaris P, Stavropoulos E, Hatzitaki V. Static balance improvement in elderly after dorsiflexors

electrostimulation training. *Eur J Appl Physiol*. 2005;94(4): 424–433. https://doi.org/10.1007/s00421-005-1326-3

37. Gajdosik RL, Vander Linden DW, McNair PJ, Williams AK, Riggin TJ. Effects of an eight-week stretching program on the passive-elastic properties and function of the calf muscles of older women. *Clin Biomech (Bristol, Avon)* 2005;20(9):973–983. https://doi.org/10.1016/j.clinbiomech.2005.05.011
38. Simoneau E, Martin A, Porter MM, Van Hoecke J. Strength training in old age: adaptation of antagonist muscles at the ankle joint. *Muscle Nerve*. 2006;33(4):546–555. https://doi.org/10.1002/mus.20492
39. Simoneau E, Martin A, Van Hoecke J. Adaptations to long-term strength training of ankle joint muscles in old age. *Eur J Appl Physiol*. 2007;100(5):507–514. https://doi.org/10.1007/s00421-006-0254-1
40. Hartmann A, Murer K, de Bie RA, de Bruin ED. The effect of a foot gymnastic exercise programme on gait performance in older adults: a randomised controlled trial. *Disabil Rehabil*. 2009;31(25):2101–2110. https://doi.org/10.3109/09638280902927010a
41. Webber SC, Porter MM. Effects of ankle power training on movement time in mobility-impaired older women. *Med Sci Sports Exerc*. 2010;42(7):1233–1240. https://doi.org/10.1249/MSS.0b013e3181cdd4e9
42. Kobayashi Y, Ueyasu Y, Yamashita Y, Akagi R. Effects of 4 weeks of explosive-type strength training for the plantar flexors on the rate of torque development and postural stability in elderly individuals. *Int J Sports Med*. 2016;37(6):470–475. https://doi.org/10.1055/s-0035-1569367
43. Mickle KJ, Caputi P, Potter JM, Steele JR. Efficacy of a progressive resistance exercise program to increase toe flexor strength in older people. *Clin Biomech (Bristol, Avon)*. 2016;40:14–19. https://doi.org/10.1016/j.clinbiomech.2016.10.005
44. Bohrer RCD, Pereira G, Beck JK, Lodovico A, Rodacki ALF. Multicomponent training program with high-speed movement execution of ankle muscles reduces risk of falls in older adults. *Rejuvenation Res*. 2019;22(1):43–50. https://doi.org/10.1089/rej.2018.2063
45. Barbosa RN, Silva NRS, Santos DPR, Moraes R, Gomes MM. Force stability training decreased force variability of plantar flexor muscles without reducing postural sway in female older adults. *Gait Posture*. 2020;77:288–292. https://doi.org/10.1016/j.gaitpost.2020.02.015
46. Sherrington C, Michaleff ZA, Fairhall N, et al. Exercise to prevent falls in older adults: an updated systematic review and meta-analysis. *Br J Sports Med*. 2017;51(24):1750–1758. https://doi.org/10.1136/bjsports-2016-096547
47. Bok SK, Lee TH, Lee SS. The effects of changes of ankle strength and range of motion according to aging on balance. *Ann Rehabil Med*. 2013;37(1):10–16. https://doi.org/10.5535/arm.2013.37.1.10
48. Beijersbergen CM, Granacher U, Vandervoort AA, DeVita P, Hortobagyi T. The biomechanical mechanism of how strength and power training improves walking speed in old adults remains unknown. *Ageing Res Rev*. 2013;12(2):618–627. https://doi.org/10.1016/j.arr.2013.03.001
49. Browne MG, Franz JR. The independent effects of speed and propulsive force on joint power generation in walking. *J Biomech*. 2017;55:48–55. https://doi.org/10.1016/j.jbiomech.2017.02.011
50. Härdi I, Bridenbaugh SA, Gschwind YJ, Kressig RW. The effect of three different types of walking aids on spatio-temporal gait parameters in community-dwelling older adults. *Aging Clin Exp Res*. 2014;26(2):221–228. https://doi.org/10.1007/s40520-014-0204-4
51. Nashner LM, McCollum G. The organization of human postural movements: a formal basis and experimental synthesis. *Behav Brain Sci*. 2010;8(1):135–150. https://doi.org/10.1017/s0140525x00020008
52. Liebenson C. *Rehabilitation of the Spine: A Practitioner's Manual*. 2nd ed. Philadelphia, PA, USA: Lippincott Williams & Wilkins; 2007.
53. Panel on Prevention of Falls in Older Persons AGS, Society BG. Summary of the Updated American Geriatrics Society/British Geriatrics Society Clinical Practice Guideline for Prevention of Falls in Older Persons. *J Am Geriatr Soc*. 2011;59(1):148–157. https://doi.org/10.1111/j.1532-5415.2010.03234.x

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https://doi.org/10.1093/ptj/pzae157
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