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Step training improves reaction time, gait and balance and reduces falls in older people: a systematic review and meta-analysis

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ABSTRACT

Objective To examine the effects of stepping interventions on fall risk factors and fall incidence in older people.

Data source Electronic databases (PubMed, EMBASE, CINAHL, Cochrane, CENTRAL) and reference lists of included articles from inception to March 2015.

Study selection Randomised (RCT) or clinical controlled trials (CCT) of volitional and reactive stepping interventions that included older (minimum age 60) people providing data on falls or fall risk factors.

Results Meta-analyses of seven RCTs (n=660) showed that the stepping interventions significantly reduced the rate of falls (rate ratio=0.48, 95% CI 0.36 to 0.65, $p<0.0001$, $I^2=0\%$) and the proportion of fallers (risk ratio=0.51, 95% CI 0.38 to 0.68, $p<0.0001$, $I^2=0\%$). Subgroup analyses stratified by reactive and volitional stepping interventions revealed a similar efficacy for rate of falls and proportion of fallers. A meta-analysis of two RCTs (n=62) showed that stepping interventions significantly reduced laboratory-induced falls, and meta-analysis findings of up to five RCTs and CCTs (n=36–416) revealed that stepping interventions significantly improved simple and choice stepping reaction time, single leg stance, timed up and go performance ($p<0.05$), but not measures of strength.

Conclusions The findings indicate that both reactive and volitional stepping interventions reduce falls among older adults by approximately 50%. This clinically significant reduction may be due to improvements in reaction time, gait, balance and balance recovery but not in strength. Further high-quality studies aimed at maximising the effectiveness and feasibility of stepping interventions are required.

Systematic reviews registration number CRD42015017357.

INTRODUCTION

Falls among older people are the leading cause of bone fractures,[1] fear of falling[2] and restricted activity[3] and, as such, constitute a substantial economic burden.[4] Studies undertaken over the past three decades have shown that exercise interventions among older adults living in the community can reduce falls by 17–30%[5–7] and that balance training is the most important component of efficacious exercise programmes.[6]

In many previous exercise interventions for fall prevention, balance training has often been directed to controlling the centre of mass within a reduced base of support.[6] Balance control, however, also requires adaptive increases and reductions in the base of support associated with stepping; a change-in-support strategy that is frequently used by older adults to maintain balance at the critical moment of slipping or tripping.[8 9] Such appropriately timed and directed steps may be initiated voluntarily to adapt gait and proactively avoid falling, or induced reactively in response to sudden external perturbations to balance.[10]

Training interventions focusing on the execution of correct, rapid and well-directed steps may have a very valuable role in preventing falls in older adults. It is likely that many previous intervention trials have included stepping components, but the effect of stepping on fall risk factors and falls is unclear as it is not possible to isolate the effect of stepping from the many trials that have included multimodal interventions. Recently, a mix of pilot and more definitive studies have been conducted that have specifically evaluated stepping programmes, both volitional and reactive, in relation to fall risk in older people. Some of these have been included in a systematic review on the role of perturbation training in preventing falls,[11] but this review included pooled data from disease-specific (eg, Parkinson's disease) and younger populations, limiting its generalisability for older adults. The purpose of the current study was to systematically examine and summarise the effects of volitional and reactive stepping interventions on fall risk factors pertaining to strength, balance and gait and the incidence of falls among older people both in the community and institutional settings.

METHODS

Registry of this systematic review protocol

This review complied with the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) guidelines.[12] A protocol was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO) (registration number CRD42015017357).

Literature search strategy

Four electronic databases (PubMed, EMBASE, CINAHL, Cochrane, CENTRAL) were searched for articles published from their inceptions to March 2015. Medical Subject Headings (MeSH) terms and key words were chosen on the basis of study design (controlled trials), exposure (stepping interventions), outcomes (falls and fall risk factors) and participants (older adults). The full search strategy for PubMed can be found in online supplementary appendix A. No language or other restrictions were applied to the initial search. Reference lists of included studies were also searched for relevant articles.

Inclusion criteria

Randomised (RCTs) and clinical controlled trials (CCTs) conducted in all settings (community, hospitals and institutions) were included. The target population was older adults with a minimum age of 60 years. Studies investigating disease-specific samples (eg, Parkinson's disease, stroke) were excluded. Interventions with stepping training as the main component (excluding warm-up and cool-down) in at least one treatment arm were included. Stepping intervention was defined as 'training of single or multiple volitional or reactive steps in an upright (standing or walking) position in response to an environmental challenge (eg, stepping onto a target, avoiding an obstacle, or responding to a perturbation)'. Regular locomotive (eg, walking), rhythmic (eg, dancing) and multimodal (eg, Tai Chi) exercises that do not exclusively train stepping in response to an environmental challenge were excluded. Controlled studies with non-intervention or other training control groups were included. Primary outcomes were number of falls during follow-up and the proportion of fallers. Secondary outcomes included physical (eg, reaction time, gait, balance and strength), psychological (eg, fear of falling, depression) and cognitive (eg, processing speed, executive functioning) risk factors for falls. Study protocols, abstracts and articles published in languages other than English were excluded.

Screening process and data extraction

Titles and abstracts of studies were screened independently by two reviewers to identify studies that potentially met the inclusion criteria. The full texts of these studies were retrieved and independently assessed for eligibility by the two reviewers. Any disagreement was solved through discussion with a third reviewer. A standardised, pre-piloted form was used to extract data from the included studies for assessment of study quality and evidence synthesis. Extracted information included: study population, participant demographics, study setting; details of the intervention and control conditions; study design; fall outcomes with follow-up periods; fall risk factors at preintervention and postintervention; information about the risk of bias. One reviewer extracted the data, and any ambiguity identified was discussed with another reviewer. Missing data related to study outcomes and eligibility were requested from study authors.

Risk of bias assessment

Using the Physiotherapy Evidence Database (PEDro) scale, two reviewers independently assessed the risk of bias of the included studies. This instrument consists of 11 items related to internal and external validity as well as to statistical information necessary for the interpretation of data (online supplementary appendix C). One point is given for each fulfilled criterion (maximum 11 points). Disagreements were solved by discussion and with the involvement of a third reviewer.

Statistical analyses

Analyses were conducted using Review Manager (RevMan, V.5.3.; The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark). Studies that used the same outcome measures were pooled using random-effects meta-analyses. The pooled mean differences (MD) for continuous outcomes with the same measurement units and standardised MDs (SMD) for continuous outcomes with different measurement units were calculated. Risk ratios (RR) for the proportion of fallers and rate ratios (RaR) for the rate of falls were calculated with 95% CIs and two-sided p values. For these fall-related analyses, the generic inverse variance method was used, with the natural logarithm and SE of the RR and RaR entered into the analysis. Preplanned and post hoc subgroup analyses were conducted to examine possible differential intervention effects relating to intervention type (volitional vs reactive stepping), intervention periods (<4 vs ≥4 weeks), follow-up periods (<12 vs ≥12 months) and setting (community vs institution). Samples were also categorised as 'healthy' or 'high-risk' if frailty, muscle weakness or a balance and gait impairment was a study inclusion criterion. Preplanned sensitivity analysis based on study quality was also conducted and publication bias was assessed by examining funnel plots and excluding asymmetric studies. p Values <0.05 were considered statistically significant.

RESULTS

Studies included

Figure 1 shows the flow chart of the selection process. The initial search yielded 633 articles. Of these, 41 were obtained as full text and 16 were identified as eligible after applying the selection criteria. Twelve of the 13 authors contacted provided the necessary details and/or unpublished data.

Description of included studies

The summarised methodology of the included studies is presented in online supplementary appendix B. Eleven studies

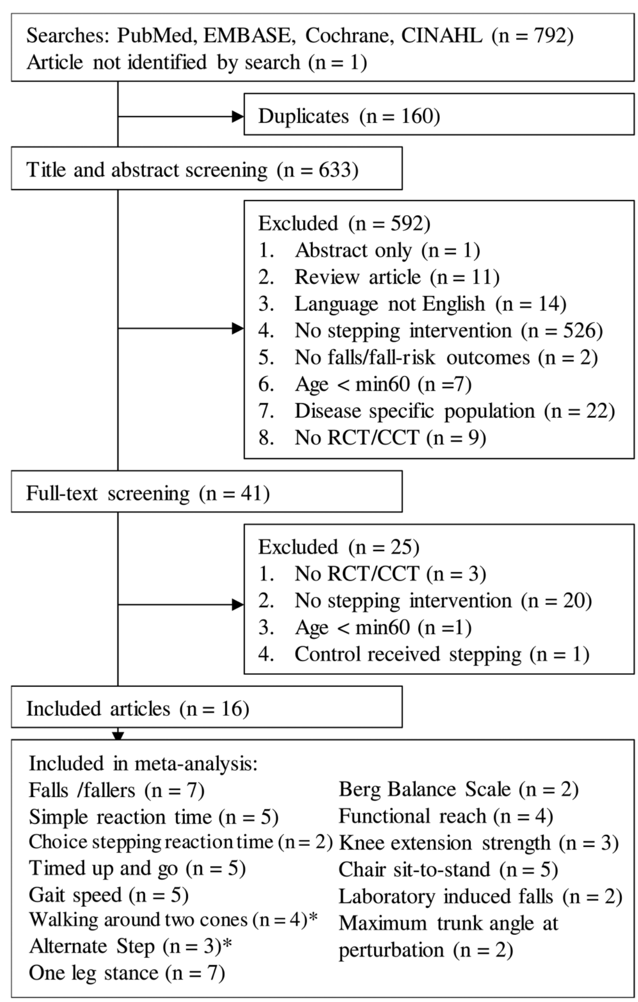

Figure 1 Flow chart of the study selection process (RCT, randomised controlled trial; CCT, clinical controlled trial). *Results are presented in online supplementary appendix J.

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targeted healthy older adults,[13–23] four studies targeted high-risk older adults with balance impairments or frail individuals,[24–27] and one study included healthy and high-risk older adults.[28] Intervention periods varied considerably, with five studies ranging between 1 day and 1 week,[20–23 25] and the remaining 11 studies ranging between 6 and 24 weeks.[13–19 24 26–28] The interventions for nine studies comprised volitional step training,[14–19 24 27 28] and the remaining seven studies provided reactive step training.[20–23 25–27] All volitional step interventions used stepping targets, such as mats partitioned into squares,[15–19] exergame dance mats/pads[13 14] or coloured squares.[24 28] The reactive step interventions used surface perturbations with movable platforms,[20 22 23 26] treadmills with tripping obstacles[21] or sudden speed changes.[25 27] The volitional step interventions had significantly longer durations (105.9±43.4 days) than the reactive step interventions (34.7±62.6 days, p<0.0001). Eight volitional step interventions included cognitive training such as memorising step patterns[15–19] and distinguishing step targets from distracters.[13 14 24] Seven studies reported falls as an outcome,[16 17 22 24–27] five of which used monthly fall diaries supplemented by follow-up telephone calls or face-to-face interviews.[16 17 22 24 26] One study used falls monitoring by staff members and monthly self-report,[27] and one study used phone interviews only (at 3 months).[25] One reactive[26] and two volitional[14 15] step training studies reported on adverse events and all three reported no falls or injuries related to their interventions.

Methodological quality

Results of the methodological quality assessment are presented in online supplementary appendix B. The PEDro quality scores of the included studies ranged from 2 to 8 of a maximum of 11 points; median (IQR)=5 (3.75 to 7) points. Seven studies did not fulfil criterion 1 (reporting source of participant recruitment and eligibility criteria) which relates to the external validity. Twelve studies were RCTs[13 14 16 17 20–27] and four studies were CCTs.[15 18 19 28] Outcome assessments were administered by blinded assessors in five studies,[14 16 21 24 26] and no studies blinded therapists or participants to treatment allocation.

Effects of step interventions on falls

Seven studies (n=660)[16 17 22 24–27] included data on falls and were included in the meta-analyses (figure 2). The step interventions significantly reduced the number of falls (RaR 0.48, 95% CI 0.36 to 0.65, p<0.0001, I^2=0%), as well as the proportion of fallers (RR 0.51, 95% CI 0.38 to 0.68, p<0.0001, I^2=0%).

Effects of step interventions on fall risk factors

Reaction time: Five studies (n=175)[14 16 23 26 27] that included simple reaction time, and two studies (n=95)[14 16] that included choice stepping reaction time as outcomes were included in the meta-analyses (figure 3). The step interventions significantly reduced both simple reaction time (MD (ms): −35.32, 95% CI −53.69 to −16.95, p=0.0002, I^2=60%) and choice stepping reaction time (MD (ms): −80.11, 95% CI −112.50 to −47.71, p<0.0001, I^2=0%).

Gait: Five studies (n=377)[14 18 24 25 28] reporting timed up and go (TUG) performance and five studies (n=345)[17 20 21 24 27] reporting gait speed were included in the meta-analyses (figure 4, online supplementary appendix J). The step interventions significantly reduced TUG times (MD (s): −1.61, 95% CI −2.81 to −0.41, p=0.009, I^2=71%) and showed a trend for increasing

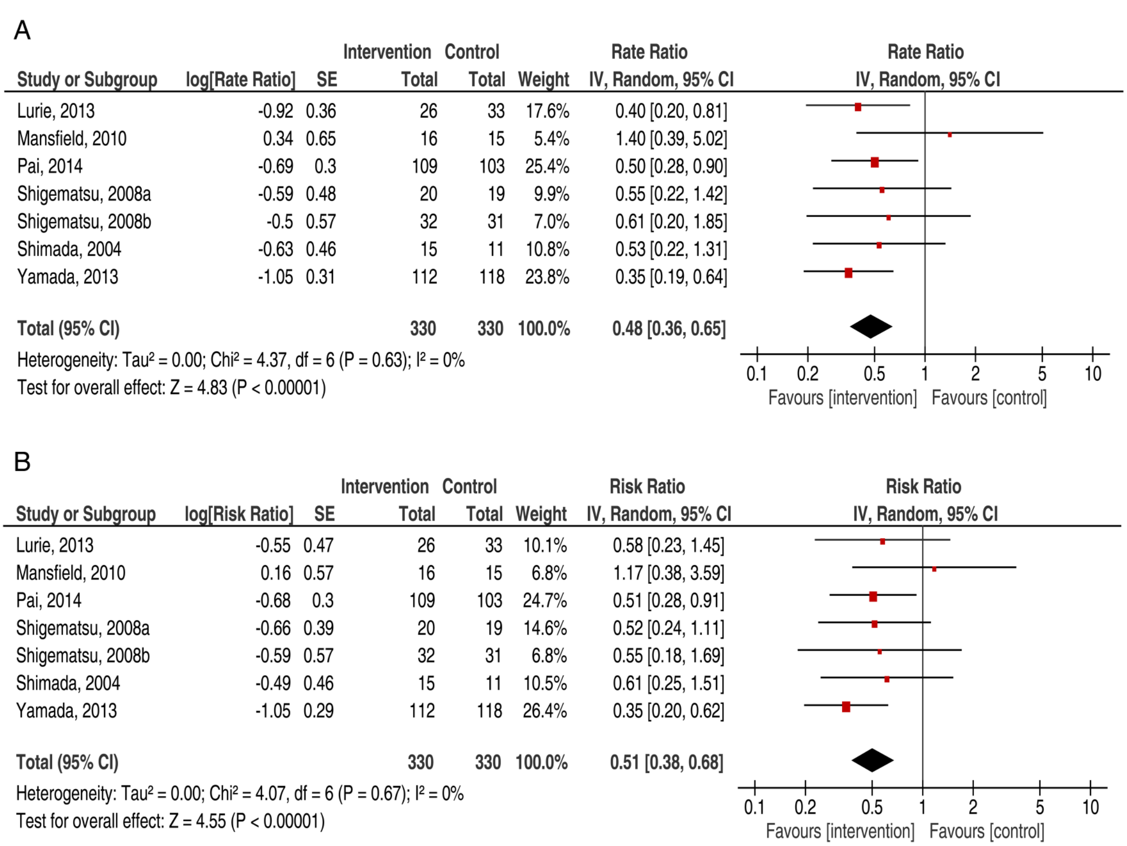

Figure 2 Result of meta-analyses for falls. (A) Rate of falls and (B) proportion of fallers. *Shigematsu *et al*[17] only reported trip-related falls and trip-related fallers.

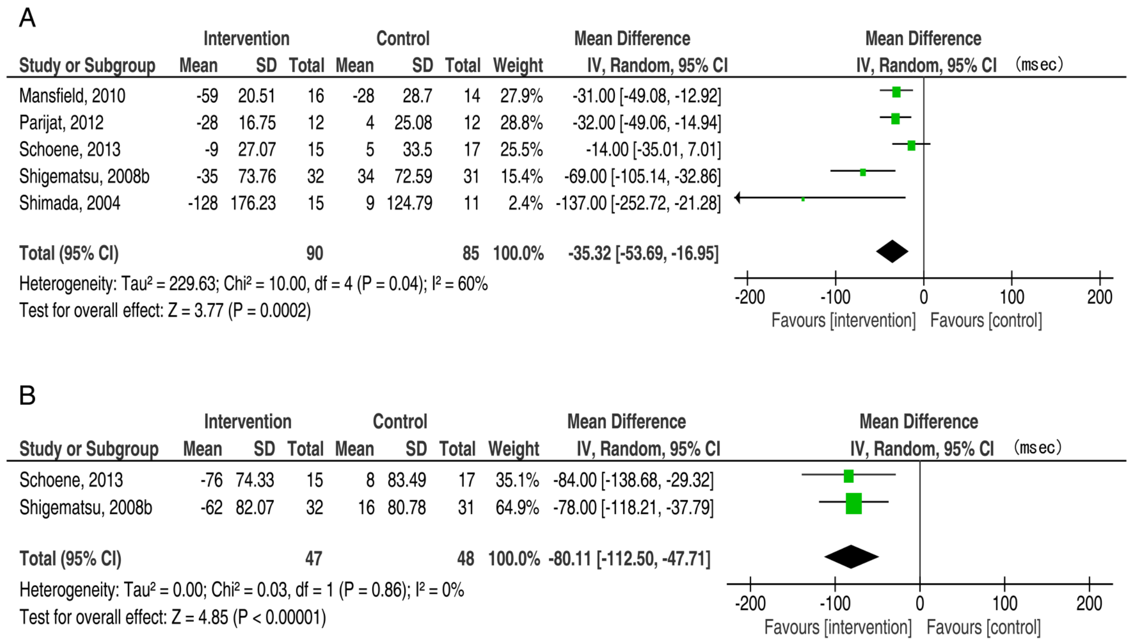

Figure 3 Result of meta-analyses for reaction. (A) Simple reaction time and (B) choice stepping reaction time.

gait speed (MD (m/s): 0.11, 95% CI −0.02 to 0.25, p=0.09, I^2=71%).

Balance: Five studies[15–17 27 28] (n=161) reported intervention effects on single leg stance time, two studies[18 25] (n=87) reported intervention effects on the Berg Balance Scale (BBS), and four studies[16 17 24 27] (n=358) provided results for the functional reach test (figure 5). Meta-analyses demonstrated significantly increased time of single leg stance times following intervention (MD (s): 2.46, 95% CI 0.11 to 4.80, p=0.04, I^2=21%), a trend in favour of the intervention for BBS (MD (score): 2.71, 95% CI −0.37 to 5.79, p=0.08, I^2=48%) but no intervention effects for functional reach distance (MD (cm): 1.17, 95% CI −1.18 to 4.14, p=0.44, I^2=78%).

Strength: Three studies[14 16 17] (n=134) reported results for knee extension strength and five studies[14–17 24] (n=416) reported results for sit-to-stand transfer times (figure 6). There were no between-group differences for these measures; knee extension strength (SMD: 0.22, 95% CI −0.12 to 0.56, p=0.21, I^2=0%) and sit-to-stand times (MD: −0.71, 95% CI −0.71 to 0.24, p=0.14, I^2=67%).

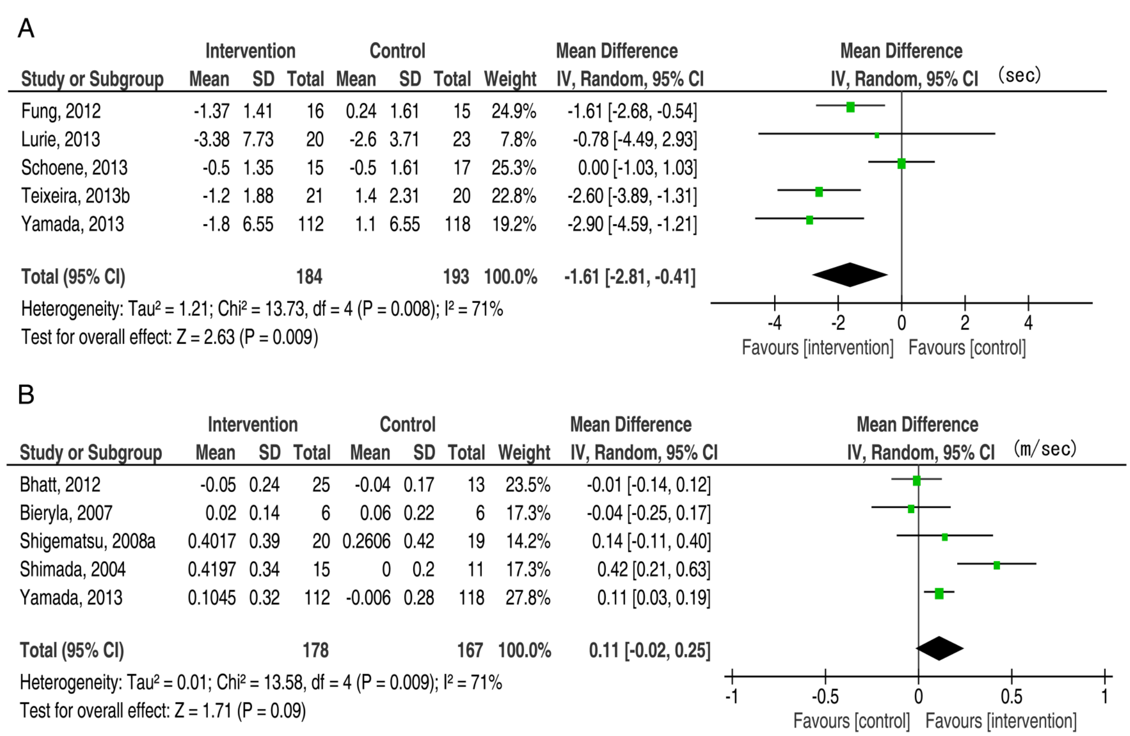

Figure 4 Result of meta-analyses for gait. (A) Timed up and go and (B) gait speed. Walking times[16 27 24] were converted to gait speed. Gait speed in Pichierri[13] was not included due to lack of mean and SD values.

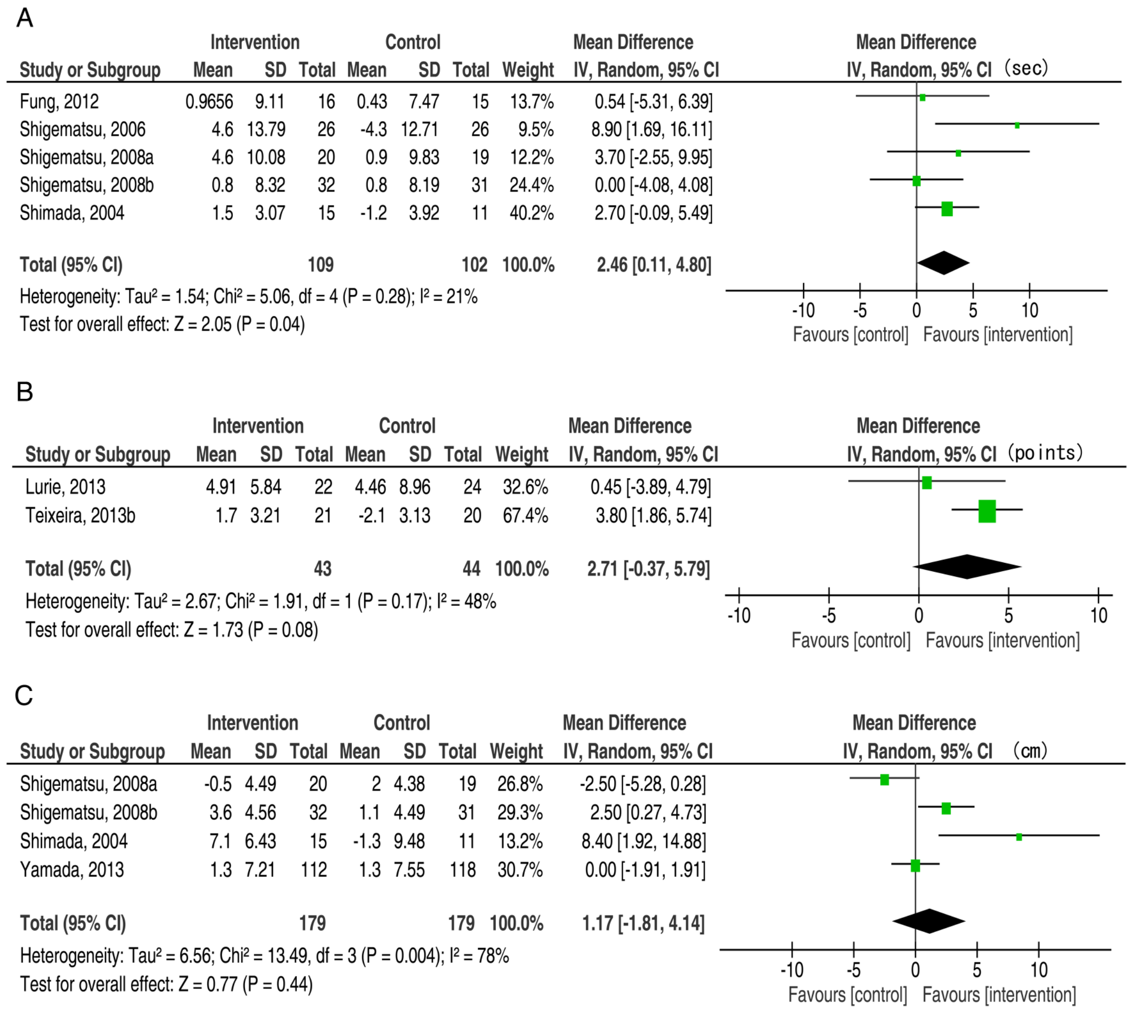

Figure 5 Result of meta-analyses for balance. (A) Single leg stance, (B) Borg Balance Scale and (C) functional reach. Single leg stance was measured with eyes opened for Fung[28] and Shimada.[27] Others were measured with eyes closed.

Balance recovery: Two studies[20 23] (n=62) reported on laboratory-induced falls and two studies[21 23] (n=36) reported on the maximum trunk angle at perturbation (figure 7). Reactive stepping interventions significantly reduced the proportion of laboratory-induced fallers (RR 0.09, 95% CI 0.01 to 0.73, p=0.02, I^2=0%) but not maximum trunk angle (MD (°): −9.17, 95% CI −22.34 to 4.01, p=0.17, I^2=69%) at perturbation.

Cognitive and psychological factors: Meta-analyses were not conducted for cognitive and psychological outcomes due to the diversity of outcome measures across studies. Yamada *et al*[24] reported a significant reduction of prevalence of fear of falling. However, five other studies found no significant change in either fear/concern of falling[13 14 16 17] or balance confidence[25] following stepping interventions. The effects of step training on cognitive measures are also inconsistent. Significant between-group differences in favour of stepping interventions have been reported for the Mini-Mental State Examination, Toulouse-Pierón speed and quality and the Modified Card Sorting Test,[19] but non-significant between-group differences have been reported for δ Trail-making performance (B-A)[14] and Digit Span (forward and backward).[19] Dual task gait performance improved postintervention in two studies in which participants counted backwards while walking[13] or named animals (verbal fluency) during the TUG test.[14]

Subgroup analyses

The subgroup analyses separating volitional and reactive step interventions are presented in online supplementary appendices D–G. The number of falls was significantly reduced by both volitional (RaR 0.43, 95% CI 0.27 to 0.68, p<0.0001, I^2=0%, n=332) and reactive (RaR 0.52, 95% CI 0.35 to 0.76, p<0.0001, I^2=0%, n=328) step interventions. Similarly, the number of fallers was significantly reduced by both volitional (RR 0.42, 95% CI 0.28 to 0.64, p<0.0001, I^2=0%, n=332) and reactive (RR 0.60, 95% CI 0.40 to 0.90, p<0.0001, I^2=0%, n=328) step interventions.

Subgroup analyses stratified by participant's living status (community vs institution), characteristics (healthy vs high-risk), intervention periods (<4 weeks vs ≥4 weeks) and follow-up periods (<12 months vs ≥12 months) did not influence the results in relation to intervention effects on fall rates or proportion of fallers. Although the reduction in simple reaction time was non-significant in the volitional (MD (ms): −39.45, 95% CI −93.20 to 14.30, p=0.15, I^2=85%, n=95) but significant in the reactive (MD (ms): −33.97, 95% CI −51.86 to −16.08, p=0.0002, I^2=37%, n=80) step interventions, this subgroup difference was statistically not significant (p=0.85). Gait speed was significantly improved by volitional (MD (m/s): 0.11, 95% CI 0.04 to 0.19, p=0.003, I^2=0%, n=269) but not by reactive (MD (m/s): 0.12, 95% CI −0.15 to 0.39, p=0.39, I^2=85%,

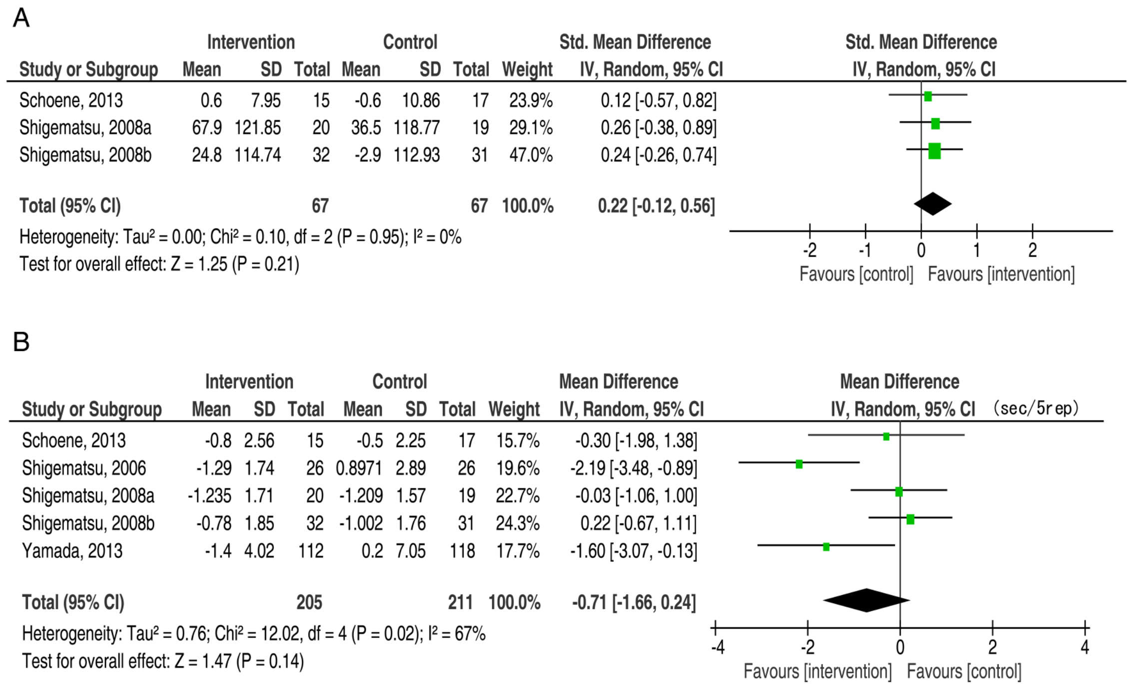

Figure 6 Result of meta-analyses for strength. (A) Knee extension strength and (B) chair sit-to-stand. Repetition values for chair sit-to-stand were converted to time values.[15 17]

n=76) stepping interventions, but this subgroup difference was statistically not significant (p=0.97).

Sensitivity analyses

A sensitivity analysis was conducted for studies with falls as an outcome to explore the possible impact of bias. Excluding one study[27] with low methodological quality (PEDro score=4; remaining 7) did not change the results with respect to fall rate (RaR 0.48, 95% CI 0.35 to 0.65, p<0.0001, I^2=0%, n=634) or proportion of fallers (RR 0.50, 95% CI 0.36 to 0.68, p<0.0001, I^2=0%, n=634). Excluding one study[17] which only reported trip-related falls did not change the results of fall rate (RaR 0.47, 95% CI 0.35 to 0.65, p<0.0001, I^2=0%, n=621) or proportion of fallers (RR 0.51, 95% CI 0.37 to 0.69, p<0.0001, I^2=0%, n=621).

The exclusion of one study comprising step training on a computerised dance mat without walking[14] reduced heterogeneity of the TUG test results (MD (ms): −2.13, 95% CI −2.85 to −1.40, p<0.0001, I^2=0%, n=345). Similarly, the exclusion of one reactive stepping intervention with a long duration (24 weeks) and a large effect[27] reduced heterogeneity of the gait speed results (MD (m/s): 0.06, 95% CI −0.02 to 0.14, p=0.12, I^2=21%, n=319). Finally, the stepping intervention effect on gait speed became significant when excluding two studies with short durations (1–2 days)[20 21] (MD (m/s): 0.11, 95% CI 0.04 to 0.19, p=0.003, I^2=0%, n=269).

Publication bias

The funnel plot for rate of falls (see online supplementary appendix H) revealed no indication of publication bias (with the

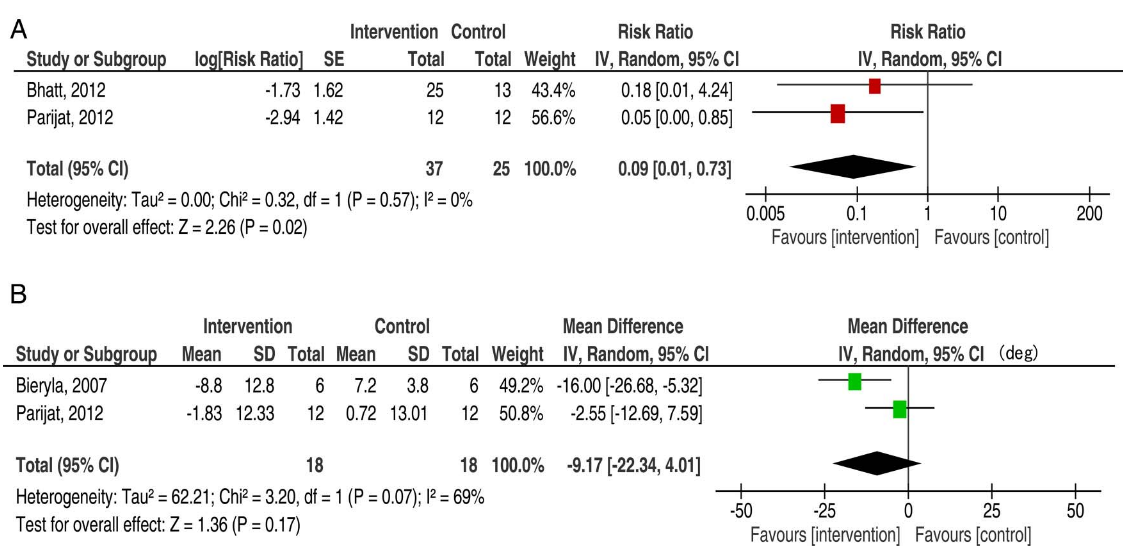

Figure 7 Result of meta-analyses for balance recovery. (A) Proportion of laboratory-induced fallers and (B) maximum trunk angle at perturbation.

inclusion of the unpublished and negative data from a small study). Exclusion of asymmetrical studies[16 26] did not change the result of rate of falls either (see online supplementary appendix I).

DISCUSSION

To the best of our knowledge, this is the first study to synthesise the evidence with regard to volitional and reactive stepping interventions on the risk of falling in older people. The results indicate that both reactive and volitional stepping programmes can prevent falls by approximately 50% in older adults both in the community and institutional settings, most likely through improvements in reaction time, gait, balance and balance recovery, but not in strength.

Effects of the stepping interventions on falls

Our meta-analysis showed that the stepping interventions were effective in reducing the rate of falls by 52% and the proportion of fallers by 49%. These effects were consistent across studies with no indication of heterogeneity ($I^2=0\%$), and similar among healthy and high-risk as well as in community-dwelling and institutionalised older adults. A recent systematic review and meta-analysis,[11] which pooled the results from eight reactive step training RCTs, reported significant reductions of 46% for falls ($I^2=73\%$) and 29% for fallers ($I^2=31\%$). Our subgroup analysis found reductions of 48% falls ($I^2=0\%$) and 40% fallers ($I^2=0\%$) for reactive step training interventions. The notable difference for fallers could be attributed to the inclusion of more homogeneous older and non-disease-specific samples in our review.

The magnitude of fall reduction for the step training interventions included in the systematic review was larger than that reported for general exercise interventions. For example, the Cochrane collaboration[5] reported that multiple-component group exercise, multiple-component home-based exercise and multifactorial interventions followed by individual risk assessments significantly reduced the number of falls by 29%, 32% and 24%, respectively. The complementary review by Sherrington *et al*,[7] which pooled results of 54 RCTs, reported similar findings, that is, exercise interventions overall significantly reduced falls by 16% and the best combination of exercise components (challenging balance training, no walking training, and 50+ h of total dose) significantly reduced falls by 38%. The approximate 50% fall reduction by step training is even more encouraging considering that most of the included RCTs had active control arms such as strength and balance training,[17 24 27] physiotherapy[25] and lower exposure to perturbations.[22]

The greater fall reduction effect of step training compared to general training may be explained by greater task specificity, that is, more directly training or shaping the neuropsychological and sensorimotor skills required for avoiding falls. During trips, slips and lateral falling, quick stepping in forward, backward and sideways directions are required.[29] The repetitive task-relevant exercises (included in all the stepping interventions in this review) may generate stored motor programmes that can be accessed when anticipatory or reactive postural threats are detected. In contrast, significantly increased lower extremity muscle strength resulting from 16 weeks of resistance training has been shown to not transfer to better responses to laboratory-induced trips,[30] suggesting a lack of necessary functional muscle coordination.

Effects of step training on fall risk factors

In synthesising the evidence regarding fall risk factors, this review revealed that stepping interventions were effective in improving balance recovery, reaction time, balance and gait but not strength.

Considering its task specificity, improved balance recovery may be a major contributor to the reduced fall rates seen with perturbation step training. The 0% prevalence of laboratory-induced falls at the completion of reactive stepping interventions[20 22 23] suggests that older people have the capacity to learn motor skills necessary to recover balance after trips and slips.[31] The significant reductions in simple reaction time observed following both voluntary and reactive step training indicate improvements in central processing speed, initiation and velocity of movement execution, major components of the motor skill required for successful balance recovery.[32] Volitional step training also significantly improved choice stepping reaction time,[14 17] a good composite measure of cognitive and physical fall risk which resembles fall avoiding situations.[33] Three of the volitional step training programmes[13 14 24] specifically trained a cognitive fall risk factor of inhibition[34] by distinguishing step targets from distracters, and these interventions brought about improvements in stepping accuracy,[24] executive function[14] and choice stepping reaction time.[14] These findings suggest quick and appropriate decision-making and step execution acquired by step training may generalise to proactive avoidance of falls in everyday situations.

Most of the volitional and reactive step training exercises involved quick, multidirectional stepping movements and weight transfers with subsequent improvements in gait and balance. Of note, the largest effect on gait was obtained in the RCT using a walking treadmill[27] and no effect was obtained in the RCT using a stepping mat without walking.[14] These may indicate that gait was improved by the walking components and not necessarily by step training itself.

Our meta-analysis indicates that fall reduction can be achieved in the absence of improved lower extremity muscle strength. This finding is consistent with meta-analyses[6 7] that have reported that the presence of moderate-intensity or high-intensity strength training was not associated with a greater effect of exercise on falls. However, it should be noted that muscle weakness is a strong fall risk factor among frail institutionalised older adults,[35] in whom most falls occur in the absence of overt external hazards.[36]

Findings from individual studies included in this review indicate that volitional step training improves global cognition,[19] executive function,[14] short-term memory[19] and dual-task ability.[13 14 19] Although these findings are not based on meta-analysis, improved gait under a cognitive load could be an important protective factor for falls when older people undertake activities requiring heightened attention and planning. The effects of step training, however, on fear of falling have been inconsistent with most studies reporting no changes following intervention.[13 14 16 17]

Volitional versus reactive step training

Rogers *et al*[10] have reported that reactive step training results in greater improvement in step initiation time than does volitional step training. However, our findings do not indicate that reactive step training is superior to volitional step training with respect to simple reaction time (MD −33.97 and −39.45, respectively). Improved choice stepping reaction time, cognition and gait speed were only apparent for volitional step training.

With regard to fall reduction effects, while there was no significant difference observed between reactive and volitional step training, the effect sizes indicate that volitional step training had greater effects (−58%) on the risk of falling than reactive step training (−40%). This greater fall reduction effect of volitional step training may have been due to the longer training periods, higher doses and additional cognitive stimulation.

It appears, however, that reactive step training, which involves large perturbations (ie, laboratory-induced falls or near-falls), induces large adaptations protective for falling even after very brief periods of training.[20–23] This may be because reactive step training accurately simulates many real world falls (such as slips and trips) in terms of the type, speed and stability range of the movement. It also provides a greater threat to balance and hence a greater stimulus for learning how to avoid a fall via feed-forward control mechanisms. Even so, it is surprising that a single session of reactive step training (24 slips in 37 trials) demonstrated a significant 50% fall reduction in the following year.[22] Further studies are required to confirm these initial, encouraging findings and to explore other potential underlying factors.

It is tempting to speculate that reactive step training prevents falls induced by slips or trips while volitional training prevents falls requiring preplanned altered step patterns and gait adaptability. However, since circumstances of falls were not ascertained in most studies, it cannot be determined whether reactive and volitional step training prevents different types of falls that require different adaptations.

Quality of the included studies

The overall quality of the included studies was acceptable to good with a median PEDro score of 5. Most studies used monthly fall calendars and telephone/interviews or staff monitoring,[27] which are recommended methods to ascertain falls.[37] Although our meta-analysis has sufficient power to draw firm conclusions, samples of the studies were relatively small (n<100) except for two recent RCTs with over 200 participants,[22 24] suggesting that step training research has come through its piloting phase. High-quality RCTs (ie, with sufficient sample sizes, allocation concealment, blinded assessors and intention-to-treat analysis) are now required to substantiate our review findings. Further subgroup/sensitivity analyses should also be undertaken to examine dose–response relationships (eg, frequency and period), type of perturbation (eg, movable platform or perturbation treadmill) and to determine the most efficacious volitional step tasks for fall prevention.

Generalisability, safety and feasibility of step training

Our findings apply mostly to healthy and high-risk older adults with balance and gait impairments or frailty living in the community and institutional settings. However, owing to study exclusion criteria, they cannot be generalised to older people with disease-specific pathologies such as Parkinson's disease, stroke, dementia and other cognitive impairments.

Reactive step training can be conducted safely with the use of a full body harness and individual supervision.[26] This training modality has potential for centre-based fall prevention, but currently the large and expensive equipment required is restricting its application to clinical settings. In contrast, volitional step training can be readily applied to community exercise classes[15–17 24] or undertaken unsupervised by an individual at home.[14]

Clinical implications

Our findings demonstrate that step training can significantly prevent falls in older people. It is therefore recommended that step training should be a major component of exercise fall prevention interventions. This training could be either volitional or reactive but should be performed in an upright position and undertaken in response to environmental challenges which mimic common fall situations such as stepping onto a target, avoiding an obstacle or responding to a perturbation.

Limitations of this review

Although our systematic review and meta-analysis was conducted following the PRISMA guidelines including the acquisition of unpublished data, we acknowledge several limitations. First, we may have omitted relevant articles not described as 'stepping' or not published in English. Second, heterogeneity of the methods within the volitional and reactive step training programmes was substantial but subgroup analyses based on programme components could not be carried out.

CONCLUSION

The findings indicate that both reactive and volitional stepping interventions reduce falls among older adults by approximately 50%. This clinically significant reduction may be due to improvements in balance recovery, reaction time, gait and balance but not strength. Further studies are needed to investigate common and differing mechanisms of volitional and reactive step training, such as motor learning, reflex behaviour, brain function and cognitive and physical factors as well as the most effective methodology of stepping interventions, dose–response relationships and subpopulations that benefit most.

What are the findings

- This systematic review and meta-analysis has demonstrated that step training can prevent falls by approximately 50% in older adults in both community and institutional settings.
- Subgroup analyses stratified by reactive and volitional stepping interventions revealed a similar efficacy for rate of falls and proportion of fallers.
- This clinically significant reduction may be due to improvements in reaction time, gait, balance and balance recovery, but not in strength.

How might it impact on clinical practice in the future?

- Our findings suggest that step training should be a major component of exercise fall prevention interventions.
- This training could be either volitional or reactive but should be performed in an upright position and undertaken in response to environmental challenges which mimic common fall situations such as stepping onto a target, avoiding an obstacle or responding to a perturbation.
- Reactive step training which requires a perturbation module and full body harness is not readily available but volitional step training can be applied to various settings including community exercise classes or an individual's home.

Correction notice This paper has been amended since it was published Online First. The affiliation for Stephen R Lord was incorrectly attributed to number 3 when it should be affiliation 4.

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