Cognitive motor interference for preventing falls in older adults: a systematic review and meta-analysis of randomised controlled trials

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Abstract

Objective: we conducted a systematic review to determine the effect of cognitive motor interference (CMI) for the prevention of falls in older adults.

Methods: we searched studies through Medline, Embase, the Cochrane Library, Web of Science, CINAHL, PEDro and the China Biology Medicine disc. Only randomised controlled trials examining the effects of CMI for older people were included. The primary outcome measure was falls; the secondary outcome measures included gait, balance function and reaction time.

Results: a total of 30 studies of 1,206 participants met the inclusion criteria, and 27 studies of 1,165 participants were used as data sources for the meta-analyses. The pooling revealed that CMI was superior to control group for fall rate \( \text{SMD} (95\% \text{ CI}) = -3.03 (-4.33, -1.73), P < 0.0001 \), gait speed \( \text{SMD} (95\% \text{ CI}) = 0.36 (0.07, 0.66), P = 0.01 \), step length \( \text{SMD} (95\% \text{ CI}) = 0.48 (0.16, 0.80), P = 0.003 \), cadence \( \text{SMD} (95\% \text{ CI}) = 0.19 (0.01, 0.36), P = 0.03 \), timed up and go test \( \text{SMD} (95\% \text{ CI}) = -0.22 (-0.38, -0.06), P = 0.007 \), centre of pressure displacement \( \text{SMD} (95\% \text{ CI}) = -0.32 (-1.06, 0.43), P = 0.04 \) and reaction time \( \text{SMD} (95\% \text{ CI}) = -0.47 (-0.86, -0.08), P = 0.02 \).

Conclusion: the systematic review demonstrates that CMI is effective for preventing falls in older adults in the short term. However, there is, as yet, little evidence to support claims regarding long-term benefits. Hence, future studies should investigate the long-term effectiveness of CMI in terms of fall prevention in older adults.

Keywords: cognitive motor interference, falls, gait, balance, older people, systematic review

Introduction

Falls are a major cause of injury in older people (aged over 65) [1, 2]. More than one in three older people fall at least once a year, and 5–10% of older people with a history of falls will have a head injury, fracture or serious laceration [3, 4]. The severity of fall-related complications also increases with age [5]. Falls are the result of an interaction between physiological risk factors and environmental factors. For example, muscle weakness, impaired vision and slow reaction time are common symptoms among individuals who are likely to fall [6, 7]. Moreover, older adults are more likely to fall when performing concurrent tasks, such as walking while performing other cognitive or motor tasks [8].

A cognitive motor task is, in effect, two tasks—a cognitive task and a motor task—that are carried out simultaneously [9, 10, 11]. Cognitive motor interference (CMI) may lead to a decline in the performance of one or both tasks when these are performed simultaneously. Most daily activities require the ability to maintain balance while performing various tasks simultaneously [10, 11]. Therefore, training for the performance of two tasks simultaneously may help to prevent falls [11]. Although a few studies [12, 13] have

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†X.W. and Y.P. contributed equally to this study.
suggested that CMI could be more effective than single-task exercise for improving balance function in older people, no consensus currently exists regarding the matter.

A systematic review [14] that included 28 articles has concluded that the effectiveness of CMI in improving physical functioning in older adults is limited. However, this review only focused on a description of the studies and on qualitative synthesis rather than on meta-analysis. Another systematic review [15] reported that the gait speed of healthy participants was slower under dual-task conditions than single-task ones. However, the systematic review was not conducted to determine the effect of CMI comparing with single-task exercise or no intervention.

At present, it remains unclear whether CMI is more beneficial in terms of preventing falls in older people than single-task exercise or no intervention. In preventing falls among the elderly, designing the most effective exercise plan based on scientific evidence is crucial. Doing so ensures that valuable staff time and resources are not wasted. Thus, we performed a systematic review and meta-analysis of all available randomised controlled trials (RCTs) to estimate the effectiveness of CMI for preventing falls in older adults compared with single-task exercise or no intervention.

Methods
Search strategy
Relevant studies were identified by electronically searching the following data sources (January 1974–August 2013): Medline, Embase, the Cochrane Library, Web of Science, CINAHL, PEDro and China Biology Medicine disc. The search was limited to RCTs but had no language restrictions. We also supplemented the electronic searches by manual searches. The full electronic search strategies for all databases are provided in Supplementary data, Appendix e-1 available in Age and Ageing online. We registered the Systematic review in PROSPERO (Registration number: CRD42012002606, http://www.crd.york.ac.uk/PROSPERO).

Inclusion criteria
- Types of studies: we included published articles with completed RCTs. No restrictions were made regarding language or the date of the trial.
- Types of participants: we only selected trials with both male and female participants aged over 60. Any articles that included participants with any pathology affecting the balance function, such as Parkinson’s disease, stroke or serious arthritis, were excluded.
- Types of interventions: we only considered those trials that compared a treatment group, which performed CMI, and a control group, which performed single-task exercise (e.g. walking or strength and balance exercises) or no intervention. In a typical CMI, subjects needed to answer a series of simple addition/subtraction questions (e.g. 5 + 3 = 8, 100–7 = 93) while they were performing a motor task [16].
- Types of outcome measures: these included the following: (i) gait variables such as gait speed, stride length, step length and cadence; (ii) balance function, gauged via the timed up and go test, activities-specific balance confidence scale, functional reach test, one leg test, chair stand test, berg balance scale, Tinetti test and centre of pressure displacement; (iii) measures related to falls, including the falls efficacy scale, the number of falls and the number of people who fall; and (iv) reaction time.

Selection of studies
Two authors independently used the same selection criteria to screen titles, abstracts and full papers of the relevant articles. Studies were excluded if they did not meet the selection criteria. Any disagreement was resolved through discussion; if disagreement persisted, then a third author was asked to make final selection decisions regarding inclusion or exclusion.

Data extraction and management
The following data were extracted: study characteristics (e.g. author and year), participant characteristics (e.g. age and number of subjects), description of interventions, duration of trial period, types of outcomes assessed and time point/s. The two authors who performed the selection of studies extracted the data from the included articles. Any disagreement was resolved through discussion, and if disagreement persisted, a third author was consulted.

Assessment of risk of bias in the included studies
The Physiotherapy Evidence Database scale [17, 18] was used to evaluate the risk of bias for inclusion in the systematic review. The following information were assessed: random allocation, blind subjects, blind therapists, blind assessors, concealed allocation, baseline comparability, intention-to-treat analysis, adequate follow-up, between-group comparisons, point estimates and variability. Two review authors independently used a pre-determined 10-item scoring system to assess the methodological quality of each study. Review authors did not evaluate their own studies. Again, a third author was consulted if there was any disagreement.

Statistical analysis
For the meta-analysis, we required means and standard deviations (SD) for outcome measures. If continuous data were reported as median and inter-quartile range (IQR), the median would be assumed to be equivalent to the mean, and the relationship of IQR and the standard deviation is roughly as follows [19]: SD = IQR/1.35. It was necessary to contact the author if standard deviations were not shown or derivable in the original publication.

The data were combined when similar contrasts were used in those studies with multiple comparisons. Three
studies [12, 20, 21] reported different subgroups of CMI (such as dual-task fixed exercise, dual-task variable exercise), and in these cases, the means and standard deviations of these subgroups were pooled using the following formulas [19]:

We used Review Manager Software (RevMan5.2) to conduct the meta-analysis. We used the χ² test and the I² statistic to evaluate heterogeneity among the studies. When the heterogeneity test showed no significant difference (I² < 50%; P > 0.1), we used the fixed-effects model; otherwise, the random-effects model was used. We considered P < 0.05 to be statistically significant. Funnel plot asymmetry was used to assess possible publication bias by Egger’s regression test.

### Results

#### Search results

Among 3,571 identified records from Medline, Embase, the Cochrane Library, Web of Science, CINAHL, PEDro, the China Biology Medicine disc and manual search, according to their titles and abstracts, we identified 60 potentially eligible studies. After reviewing the full papers of the 60 potential articles, 30 articles [8, 10, 12, 13, 20, 21, 22, 23, 24, 25, 26, 27, 28–32, 33, 34, 35, 36, 37–45] fulfilled the inclusion criteria. The remaining 30 articles were excluded, because their studies included participants with neurological illness (e.g. stroke, Parkinson’s disease and cognitive impairment) or participants were younger than 60 years. Other studies were excluded either because original data was no longer available from the authors or because they did not compare CMI with a control group. Supplementary data, Appendix 1 available in *Age and Ageing* online summarise the characteristics of each included study. The process of identifying eligible studies is outlined in Supplementary data, Appendix 1 available in *Age and Ageing* online.

#### Description of studies

The Physiotherapy Evidence Database scale (with scores from 1 to 10) was used for the methodological quality assessment and yielded a mean score of 5.43 (SD = 1.38). Briefly, every study was reported as using random allocation, but 22 of the included trials failed to adopt allocation concealment. A total of 16 studies tried to blind the assessors to the allocated treatment, and 7 trials performed intention-to-treat analysis. According to the total PEDro score, studies were classified as high-, moderate- and low-quality RCTs. Only one article was low quality, other included articles were of moderate-to-high quality and 26.7% (8 out of 30) were high quality. Full details of the methodological quality of these trials are presented in Supplementary data, Appendix 2 available in *Age and Ageing* online.

### Effects of CMI on gait variables

Effects of CMI on gait speed: the results showed that CMI for gait speed was better than the control group in a random-effects model [SMD (95% CI) = 0.36 (0.07, 0.66), P = 0.01] (Figure 1; Table 1).

Effects of CMI on stride length: the results showed that CMI improved stride length compared with controls in a fixed-effects model [SMD (95% CI) = 0.26 (0.03, 0.48), P = 0.03] (Supplementary data, Appendix 2 available in *Age and Ageing* online; Table 1).

Effects of CMI on step length: CMI was better than controls in terms of improving step length in a fixed-effects model [SMD (95% CI) = 0.48 (0.16, 0.80), P = 0.003] (Supplementary data, Appendix 3 available in *Age and Ageing* online; Table 1).

Effects of CMI on cadence: CMI was better than the control group for improving cadence in a fixed-effects model [SMD (95% CI) = 0.19 (0.01, 0.36), P = 0.03] (Supplementary data, Appendix 4 available in *Age and Ageing* online; Table 1).

### Effects of CMI on balance function

Effects of dual-task exercise on the timed up and go test: CMI was better than controls for improving the timed up and go test performance in a fixed-effects model [SMD (95% CI) = −0.22 (−0.38, −0.06), P = 0.007] (Figure 2; Table 1).

Effects of CMI on the functional reach test: the data did not reveal any difference between CMI and controls in a random-effects model [MD (95% CI) = 0.57 (−1.20, 2.33), P = 0.53] (Table 1).

Effects of CMI on performance in the activities-specific balance confidence scale: the data did not reveal any difference between CMI and control group in a fixed-effects model [MD (95% CI) = 2.34 (−2.02, 6.70), P = 0.29] (Table 1).

Effects of CMI on the one leg test: the data did not reveal any difference between CMI and control group in a fixed-effects model [MD (95% CI) = 3.04 (−0.33, 6.40), P = 0.08] (Table 1).
Effects of CMI on the berg balance scale: the data did not reveal differences between CMI and control group in a random-effects model [MD (95% CI) = 1.39 (−1.18, 3.96), P = 0.290] (Table 1).

Effects of CMI on the chair stand test: the data did not reveal any difference between CMI and control group in a fixed-effects model [MD (95% CI) = 1.0 (−0.32, 2.31), P = 0.14] (Table 1).

Effects of CMI on Tinetti test: the results showed that CMI was better than control group in a random-effects model [SMD (95% CI) = −0.64 (−1.24, −0.05), P = 0.03] (Table 1).

Effects of CMI on centre of pressure displacement: the results showed that CMI was better than control group for centre of pressure displacement in a fixed-effects model [SMD (95% CI) = −0.4 (−0.77, −0.02), P = 0.04] (Supplementary data, Appendix 5 available in Age and Ageing online; Table 1).

Effects of CMI on fall rate: the results showed that CMI was better than control group in terms of reaction time [SMD (95% CI) = −0.47 (−0.86, −0.08), P = 0.02] (Supplementary data, Appendix 6 available in Age and Ageing online; Table 1).

Publication bias
Egger’s regression test did not show any publication bias for gait speed (asymmetry test, P = 0.879) and time up and go test (asymmetry test, P = 0.971) (Figure 3).

Discussion
Many different types of physical activity interventions are used to try to prevent falls among older adults. Previous systematic reviews have concentrated on single-task exercise (e.g. strength training and balance exercise), but this current review and meta-analysis brings together evidence from relevant articles evaluating CMI (i.e. simultaneous cognitive and motor tasks) in the context of preventing falls in older adults.

Our systematic review and meta-analysis of trials from 30 RCTs comprising 1,206 subjects provided evidence supporting the efficacy of CMI for improving gait and balance, and preventing falls in older adults. The results of our systematic
## Table 1. Summary of results

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Trials</th>
<th>Participants</th>
<th>Statistical method</th>
<th>Effect estimate</th>
<th>Heterogeneity</th>
<th>P value</th>
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<td><strong>Gait</strong></td>
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<td>Gait speed</td>
<td>12</td>
<td>760</td>
<td>Standard mean difference</td>
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<td>Stride length</td>
<td>8</td>
<td>310</td>
<td>Standard mean difference</td>
<td>0.26 [0.03, 0.48]</td>
<td>0.23</td>
<td>0.03</td>
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<td>(IV, fixed, 95% CI)</td>
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<td>Step length</td>
<td>3</td>
<td>165</td>
<td>Standard mean difference</td>
<td>0.48 [0.16, 0.80]</td>
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<td>Cadence</td>
<td>5</td>
<td>533</td>
<td>Standard mean difference</td>
<td>0.19 [0.01, 0.36]</td>
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<td><strong>Balance function</strong></td>
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<td>Timed up and go test</td>
<td>12</td>
<td>629</td>
<td>Standard mean difference</td>
<td>−0.22 [−0.38, −0.06]</td>
<td>0.11</td>
<td>0.0007</td>
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<td>(IV, fixed, 95% CI)</td>
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<tr>
<td>Functional reach test</td>
<td>4</td>
<td>140</td>
<td>Mean difference</td>
<td>0.57 [−1.20, 2.33]</td>
<td>0.98</td>
<td>0.53</td>
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<td>(IV, fixed, 95% CI)</td>
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<tr>
<td>Activities-specific balance confidence</td>
<td>3</td>
<td>76</td>
<td>Mean difference</td>
<td>0.26 [−7.11, 7.63]</td>
<td>0.31</td>
<td>0.94</td>
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<tr>
<td>One leg balance</td>
<td>2</td>
<td>162</td>
<td>Mean difference</td>
<td>3.04 [−0.33, 6.40]</td>
<td>0.3</td>
<td>0.08</td>
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<td>(IV, fixed, 95% CI)</td>
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<tr>
<td>Berg balance scale</td>
<td>2</td>
<td>59</td>
<td>Mean difference</td>
<td>0.18 [−2.73, 3.10]</td>
<td>0.1</td>
<td>0.9</td>
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<td>(IV, fixed, 95% CI)</td>
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<tr>
<td>Chair Stand Test</td>
<td>2</td>
<td>120</td>
<td>Mean difference</td>
<td>0.59 [−1.67, 2.86]</td>
<td>0.48</td>
<td>0.61</td>
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<tr>
<td>Centre of pressure displacement</td>
<td>7</td>
<td>371</td>
<td>Standard mean difference</td>
<td>−0.32 [−0.80, 0.15]</td>
<td>0.01</td>
<td>0.04</td>
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<td><strong>Falls</strong></td>
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<tr>
<td>Falls rate</td>
<td>2</td>
<td>204</td>
<td>Standard mean difference</td>
<td>−3.03 [−4.33, −1.73]</td>
<td>0.004</td>
<td>&lt;0.0001</td>
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<td>(IV, random, 95% CI)</td>
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<tr>
<td>Falls efficacy scale</td>
<td>5</td>
<td>168</td>
<td>Mean difference</td>
<td>−0.66 [−3.23, 1.91]</td>
<td>0.04</td>
<td>0.61</td>
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<tr>
<td><strong>Reaction time</strong></td>
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<tr>
<td>Reaction time</td>
<td>3</td>
<td>107</td>
<td>Standard mean difference</td>
<td>−0.47 [−0.86, −0.08]</td>
<td>0.44</td>
<td>0.02</td>
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**Figure 2.** Meta-analyses of cognitive motor interference on time up and go test. TUG, time up and go; SD, standard deviation; 95% CI, 95% confidence intervals; IV, inverse variance.
review showed significant differences in comparing CMI with single-task exercise or no intervention for eight outcomes, including gait speed, stride length, step length, cadence, the timed up and go test, centre of pressure displacement, fall rates and reaction time. Most of the observed differences among the groups were not large, but the improvements seen for gait speed, the timed up and go test, Tinetti test, centre of pressure displacement, fall rates and reaction time were at levels that may signify clinical importance. Moreover, no serious adverse events were reported in the 30 RCTs included in our meta-analysis.

In contrast to the above-mentioned outcome measures, there were no significant difference in other balance function and fall outcome measures (e.g. activities-specific balance confidence scale, functional reach test, one leg test, berg balance scale, chair stand test and falls efficacy scale) when comparing CMI with single-task exercise or no intervention. However, it is possible that the number of included participants and studies were not sufficient to detect the effects of CMI.

Strengths and limitations
This is the first systematic review and meta-analysis to evaluate the effects of CMI in terms of balance, gait and falls in older people by comparing with single-task exercise or no intervention. Previous systematic reviews [14, 15, 46, 47, 48] either focused on qualitative synthesis rather than meta-analysis or did not compare CMI with single-task exercise or no intervention. Compared with prior systematic reviews, most of the included studies were new in the current study, and we only considered older people (aged over 60) for all of the articles in the current analysis.

Furthermore, a wide range of electronic databases were searched in our systematic review covering all relevant articles [49]. In addition, there were no restrictions on the basis of publication date or language, and most of the articles were published within the last 5 years. To decrease bias and transcription errors, two reviewers independently selected studies, extracted the data and evaluated the quality of the article. The results of our systematic review are considered to be very robust due to these characteristics.

However, there are some limitations in our systematic review. First, high-quality articles were still deficient in our systematic review. Based on PEDro score, only 26.7% (8 out of 30) RCTs were high quality in the systematic review. Most studies had inadequate reporting or poor methodological quality. Only 8 of the 30 studies showed how allocation of participants was concealed, and 23 of 30 studies did not perform intention-to-treat analyses. None of the 30 studies blinded participants and therapists, and only 16 studies blinded assessors.

Second, 22% of older people aged over 75 have mild cognitive impairment [50] and cognitive impairment in the elderly increases risk of falls, and hence, the improvement of cognitive function may be a reduction in fall risk [51]. Thus, we would have liked to have looked for differences in cognitive function measures between subjects undergoing CMI and single-task exercise or no intervention in our review, but few studies reported these cognitive function outcome measures.

Third, the follow-up durations were <1 year in all of the studies, and hence, the long-term effect of CMI could not be estimated.

Fourth, the incidence and prevalence of chronic diseases increase with age stroke and serious arthritis. However, due to heterogeneity, older people with pathological causes of poor balance are excluded in this article. Hence, it is necessary to perform a meta-analysis to determine the effect of CMI on falls for different patients with pathological causes of poor balance.

Implications for research
In brief, articles should adhere to generally accepted standards of reporting clinical trials (e.g. the Consolidated
Standards of Reporting Trials (CONSORT) statement) [52]. As previously mentioned, most of the studies in our systematic review had short follow-up periods, and the sample sizes in individual studies were modest. Consequently, there is a need for large-scale RCTs for CMI. At present, there are many types of CMI that could have different results in older adults. Therefore, it is necessary to perform a systematic review of different CMI for determining the optimal intervention programme in older people. Eventually, theories regarding the mechanisms by which CMI may prevent the likelihood of falls in older people should be explored further.

Conclusions and implications for practice
In our systematic review, we found that CMI is more effective than single-task exercise or no intervention in older adults for reducing falls and improving gait and balance. This provides useful information for older people (not include older people with any pathology affecting the balance function) as well as for medical staff and health-care decision-makers in coming up with effective exercise regimes for this age group.

Key points
• This is the first systematic review to objectively estimate the effects of CMI for older people.
• A wide range of electronic databases were searched in our systematic review covering all relevant articles.
• There were no restrictions on the basis of publication date or language.

Acknowledgements
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Conflicts of interest
None declared.

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Supplementary data
Supplementary data mentioned in the text are available to subscribers in Age and Ageing online.

Cognitive motor interference for older adults

References
The very long list of references supporting this review has meant that only the most important are listed here and are represented by bold type throughout the text. The full list of references is available on Supplementary data, Appendix e-2 available in Age and Ageing online.
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