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Effects of Physical Exercise Interventions on Gait-Related Dual-Task Interference in Older Adults: A Systematic Review and Meta-Analysis

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Key Words
Gait · Rehabilitation · Attention · Aging · Cognitive-motor interference · Mobility

Abstract
Dual-task interference during walking can substantially limit mobility and increase the risk of falls among community-dwelling older adults. Previous systematic reviews examining intervention effects on dual-task gait and mobility have not assessed relative dual-task costs (DTC) or investigated whether there are differences in treatment-related changes based on the type of dual task or the type of control group. The purpose of this systematic review was to examine the effects of physical exercise interventions on dual-task performance during walking in older adults. A meta-analysis of randomized controlled trials (RCTs) compared treatment effects between physical exercise intervention and control groups on single- and dual-task gait speed and relative DTC on gait speed. A systematic search of the literature was conducted using the electronic databases PubMed, CINAHL, EMBASE, Web of Science, and PsycINFO searched up to September 19, 2014. Randomized, nonrandomized, and uncontrolled studies published in English and involving older adults were selected. Studies had to include a physical exercise intervention protocol and measure gait parameters during continuous, unobstructed walking in single- and dual-task conditions before and after the intervention. Of 614 abstracts, 21 studies met the inclusion criteria and were included in the systematic review. Fourteen RCTs were included in the meta-analysis. The mean difference between the intervention and control groups significantly favored the intervention for single-task gait speed (mean difference: 0.06 m/s, 95% CI: 0.03, 0.10, $p < 0.001$), dual-task gait speed (mean difference: 0.11 m/s, 95% CI 0.07, 0.15, $p < 0.001$), and DTC on gait speed (mean difference: 5.23%, 95% CI 1.40, 9.05, $p = 0.007$). Evidence from subgroup comparisons showed no difference in treatment-related changes between cognitive-motor and motor-motor dual tasks, or when interventions were compared to active or inactive controls. In summary, physical exercise interventions can improve dual-task walking in older adults primarily by increasing the speed at which individuals walk in dual-task conditions. Currently, evidence concerning whether physical exercise interventions reduce DTC or alter the self-selected dual-task strategy during unobstructed walking is greatly lacking, mainly due to the failure of studies to measure and report reciprocal dual-task effects on the non-gait task.

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Introduction

Dual-task interference during walking is widely recognized as a functional mobility concern among older adults and is an important public health problem due to its association with the risk of falls [1]. Dual-task interference occurs when there are competing demands for attentional resources [2]. Specifically, when the attentional demands of the two tasks exceed the total attentional capacity, performance in one or both of the tasks declines relative to single-task performance. Theoretically then, dual-task interference may be minimized by reducing the attentional demands of one of the tasks (i.e., increasing automaticity) [3]. Task automaticity can be increased by repetitive practice [4, 5]. Alternatively, dual-task interference may be improved through the repeated practice of dual-tasking (i.e., dual-task interventions) in accordance with the principles of task-specific training.

The importance of dual-task interference in older adults is evidenced by the growing number of systematic reviews addressing the topic [1, 6–15], with 5 of these focusing specifically on treatment effects for dual-task gait and mobility [7–9, 13, 14]. The earliest of these reviews [9] examined the effects of cognitive and cognitive-motor interventions on physical functioning in older adults and adults with stroke or traumatic brain injury; however, the authors did not explicitly examine intervention effects on dual-task walking or dual-task interference. Gobbo et al. [7] examined the effects of interventions on the dual-task ability in static or dynamic balance; however, due to very stringent inclusion criteria regarding outcome measures [required direct measures from stabilometric balance or force platforms or scores on clinical tests such as the Timed Up and Go (TUG)], their review excluded several studies that evaluated exercise interventions on dual-task walking. Recently, Agmon et al. [6] examined intervention effects on dual-task postural control from 22 studies in which dual-task performance was assessed during standing balance tasks, step execution, or a range of walking tasks (e.g., obstacle negotiation, TUG, or steady-state unobstructed walking). The heterogeneity of gait-related outcome measures in Agmon et al.'s [6] systematic review limited the quantitative synthesis of the intervention effects on dual-task walking in older adults.

Only one of the prior systematic reviews of intervention effects on dual-task walking included a meta-analysis. Wang et al. [13] found a small (nonsignificant) treatment effect on dual-task gait speed in favor of 'dual-task training' over 'single-task training'. Importantly, however, of the 8 randomized controlled trials (RCTs) they pooled for a meta-analysis of treatment effects on dual-task gait speed, dual-task exercises comprised only a component of the experimental exercise regime in most of the studies; therefore, the 'dual-task' interventions were often not very different from the 'single-task' exercise control groups. Indeed, the authors included one study in which both the experimental and control groups practiced walking while performing cognitive tasks [16], and another in which the experimental group received cognitive and motor interventions performed separately, not as a dual-task [17]. They also included a study with non-normally distributed data [18].

Given that there are very few clear-cut dual-task intervention studies in older adults and that, theoretically, both single- and dual-task exercise activities may improve dual-task gait performance, the purpose of this systematic review and meta-analysis was to compare any physical exercise intervention to a control group on dual-task interference during walking in older adults. Secondary aims were to examine differences in treatment effects based on the type of dual-task assessment (e.g., cognitive-motor or motor-motor) and the type of control group (i.e., active or inactive). Our meta-analysis is further unique in that we examined interventions on relative dual-task costs (DTC) as well as average gait parameters to better evaluate intervention effects on dual-task interference. While we included only RCTs in the meta-analysis, in order to be as inclusive as possible in our synthesis of the evidence for physical exercise interventions on dual-task walking, we also included non-RCTs and uncontrolled trials in the systematic review.

Methods

Search Strategy

A systematic search was conducted using the following electronic databases: PubMed, CINAHL, EMBASE, Web of Science, and PsycINFO. Key words and MeSH terms were developed for population, intervention, and outcome according to the PICO model. The search strategy and results for each database are presented in Appendix 1. Two investigators (P.P., L.A.Z.) independently screened the titles, abstracts, and full texts (where necessary) to determine eligibility for inclusion in the review. Discrepancies regarding study eligibility were resolved by discussion with a third reader (C.G.). We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement in reporting this review [19].

Inclusion and Exclusion Criteria

The following inclusion criteria were used: primary studies that were RCTs, controlled trials, or uncontrolled trials; published up to September 19, 2014 (including those published electronically ahead of print); studied a population of typical older adults who were at least 60 years old; a protocol that included a physical exercise intervention; measured gait parameters during unobstructed walking in single- and dual-task conditions before and after the intervention, and published in English. Typical older adults were considered those functionally independent, walking with or without an assistive device, and free of neurological disorders, dementia, and any other comorbidity that restricted gait performance. Studies that included older adults with a history of stroke, heart disease, and pain were considered eligible for inclusion only if it was specified that the participants had no symptoms that might affect their participation. Studies with fallers, balance-impaired older adults, and older adults at risk of frailty were included. However, studies that measured dual-task performance during TUG, dual-task obstacle negotiation task, or dual-task step execution task, but did not assess straight, unobstructed dual-task walking were excluded because direct comparison of gait performance during mobility tasks of different complexities could not be made. Abstracts, conference proceedings, letters to the editor, dissertations, and review articles were not considered for this review.

Study Quality Assessment

Study quality was assessed independently by 2 reviewers (P.P., L.A.Z.) using the checklist for randomized and nonrandomized studies of health care interventions of Downs and Black [20]. Since this review focused on pre- and post-assessment of older adults that were primarily community-dwelling, items relating to follow-up (items 9, 17, and 26) and representativeness of treatment facilities (item 13) were not relevant and not included in the scoring. Item 27 concerning the power analysis was modified to a 2-point (a priori power analysis reported and based on a clinically meaningful effect size), 1-point (a priori power analysis reported but effect size/importance of effect size unclear), or 0-point (no power analysis reported) scale [9]. The maximum score, therefore, was 25, with higher values indicating better quality. The 2 reviewers met to reconcile differences in scoring after all included studies were evaluated.

Data Extraction

One reviewer (P.P.) performed data extraction independently, and another reviewer (L.A.Z.) checked the accuracy of the extracted data. Information on the study participants, randomization and blinding, intervention duration, frequency, intensity, and type, outcome measures for dual-task gait assessment for both the gait and non-gait (secondary) tasks as well as results related to the dual-task outcomes were extracted from each included article using an electronic, standardized data extraction form. We requested single- and dual-task gait speed data from the authors of two of the RCTs [17, 21], and both provided the data.

Data Analysis and Synthesis

Gait speed was chosen as the outcome of interest for the meta-analysis, since it was the only parameter available for all RCTs and is an established predictor of adverse outcomes in older adults [22]. To estimate the overall effect of physical exercise interventions on single- and dual-task gait speed and of DTC on gait speed, we conducted a random-effects model of the generic inverse variance on the RCTs retrieved from the search. This model assigned the weight of the studies dependent upon their standard error to give less weight to studies with more variance. The study by Pichierri et al. [18] was excluded from the meta-analysis, because the authors reported medians and interquartile ranges due to non-normally distributed data.

Where DTC were not reported, these were calculated from the group means for single- and dual-task gait speed as follows: (dual-task gait speed – single-task gait speed)/single-task gait speed × 100% (negative values indicating a decline in gait speed relative to single-task gait), and standard deviations for the DTC were computed using propagation of uncertainty.

The raw mean difference (and standard deviation) in gait speed and DTC on gait speed from pre- to post-intervention was calculated for each intervention and control group. The standard deviation for the raw mean difference was calculated according to the following formula [23]: $SD_{diff} = \sqrt{(SD_{pre}^2 + SD_{post}^2 - 2 \times r \times SD_{pre} \times SD_{post})}$, where SD_{diff} is the standard deviation of the change score, SD_{pre} is the standard deviation of the pre-intervention gait speed, SD_{post} is the standard deviation of the post-intervention gait speed, and r is the estimated Pearson correlation between the pre- and post-intervention gait speeds. An r value of 0.5 was used for the calculations, which conservatively assumes a moderate correlation [24]. From the pre- versus post-intervention mean change scores and standard deviations, the mean difference and standard deviation between the intervention and comparison groups for each trial could be calculated.

Effect sizes were pooled from each individual study to assess the impact of physical exercise interventions on the three dependent variables: single-task gait speed (m/s), dual-task gait speed (m/s), and DTC on gait speed (%). For RCTs with two intervention arms and one control arm, we included each intervention arm as an intervention group, which meant that some trials were included in the analysis more than once, and the control arms were counted twice. Similarly, for studies in which gait was assessed in more than one dual-task condition, the same group was included more than once in the analysis.

The primary analysis was a comparison of intervention versus control. For dual-task gait speed and DTC on gait speed, a subgroup analysis was conducted for the type of dual-task assessment: cognitive-motor (arithmetic), cognitive-motor (verbal fluency), motor-motor, and triple task. An additional subgroup analysis was conducted for the type of control group: active (physical exercise) or inactive (no physical exercise) control groups for all three dependent variables. A single true effect size could not be assumed since the interventions differed among the RCTs. Therefore, analyses were performed using a random-effects model.

Results for the meta-analysis are presented as effect sizes (mean differences) with a 95% confidence interval (CI). Q and I^2 were calculated to assess the true heterogeneity between studies. Q was used to assess the presence of heterogeneity, while I^2 was used to ascertain the percentage of the total variation. Furthermore, τ^2 was used to evaluate the between-studies variance. p values were reported to evaluate statistical significance; with a two-tailed p value <0.05 considered statistically significant [25].

Results

Search Results

The search yielded 804 articles, of which 190 were found to be duplicates and were removed, leaving 614 articles for screening (fig. 1). Of the 614 papers, 576 were discarded because they were not published in English

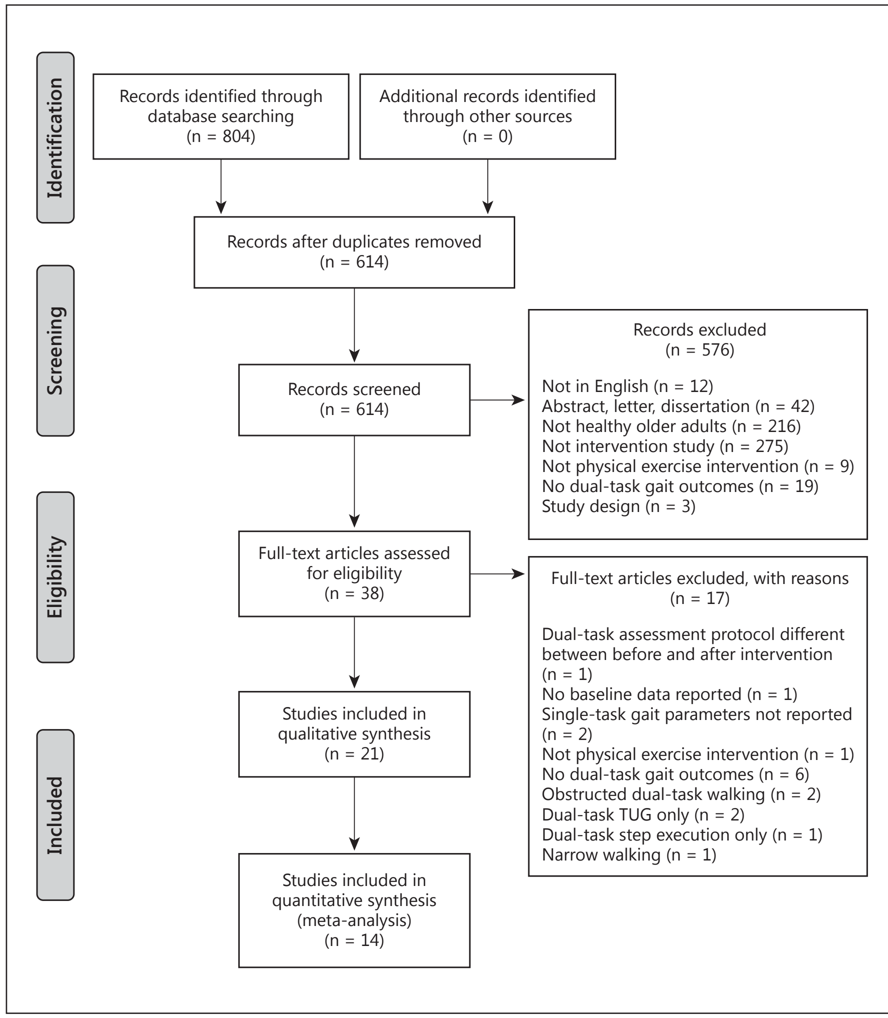

Fig. 1. Flow diagram of article selection.

(n = 12); were abstracts, letters, or dissertation theses (n = 42); were not studies of healthy older adults (n = 216); were not intervention studies (n = 275); were not physical exercise interventions (n = 9); did not include a dual-task gait outcome measure (n = 19), or were not primary RCTs, controlled trials, or uncontrolled trials (n = 3). After full reading of the remaining 38 articles, an additional 17 were excluded for the following reasons: the dual-task assessment conditions differed between pre- and post-assessments (n = 1) [26], no baseline data were reported (n = 1) [27], single-task gait parameters were not reported for pre- and/or post-assessments (n = 2) [28, 29], the intervention was not a physical exercise intervention (n = 1) [30], dual-task gait outcomes were not measured (n = 6) [31–36], or the study reported dual-task performance only during TUG (n = 2) [37, 38], obstacle negotiation tasks (n = 2) [39, 40], or a step execution task (n = 1) [41]. A further study was excluded because the walking task (narrow walking with the path width set at 50% of the individual pelvic width) was considered more challenging than usual unobstructed walking and, therefore, too dissimilar for inclusion [5].

Thus, 21 articles remained that met the inclusion criteria and were included in this review [16–18, 21, 42–58], of which 15 were RCTs (table 1). The publication dates ranged from 2006 to 2014.

Methodological Quality of the Studies

Table 1 summarizes the type of design and quality assessment of the 21 studies included. Of these, 15 were RCTs [16–18, 21, 44, 46–50, 53, 55–58], 2 were controlled trials [51, 54], and 4 were uncontrolled trials [42, 43, 45, 52]. The quality scores ranged from 12 to 21 out of a maximum of 25. The mean quality score was 16.8, the median

Table 1. Study designs and quality assessment

First author [Ref], year	Design	Quality assessment*	% max. score	Rating
Agmon [42], 2012	UT	16	64	good
Beauchet [43], 2013	UT	14	56	fair
Cadore [44], 2014	RCT	16	64	good
de Bruin [17], 2013	RCT	15	60	good
Dorfman [45], 20140	UT	16	64	good
Granacher [21], 2010	RCT	15	60	good
Halvarsson [47], 2011	RCT	19	76	good
Halvarsson [46], 2014	RCT	18	72	good
Hiyama [48], 2012	RCT	16	64	good
Manor [49], 2014	RCT	19	76	good
Pichierri [18], 2012	RCT	16	64	good
Silsupadol [50], 2009	RCT	21	84	excellent
Theill [51], 2013	CT	13	52	fair
Toulotte [52], 2006	UT	12	48	fair
Trombetti [53], 2011	RCT	20	80	excellent
Uemura [16], 2012	RCT	18	72	good
van Het Reve [54], 2014	CT	12	48	fair
Yamada [57], 2010	RCT	17	68	good
Yamada [55], 2011	RCT	20	80	excellent
Yamada [56], 2011	RCT	20	80	excellent
Yamada [58], 2011	RCT	19	76	good

UT = Uncontrolled study; CT = controlled study.
* Quality assessment is based on the modified checklist of Downs and Black [20]. The maximum score is 25. Higher scores indicate better quality.

score was 16, and the mode was 16. Among the 15 RCTs, the average quality score was 17.9 (range 15–21), whereas the mean quality score for the non-RCTs was 13.8 (range 12–16). We expressed the quality score as a percentage of the maximum score; studies with scores ≥80% of the maximum were considered to be of excellent quality, 60–80% was considered good quality, 40–60% was fair, and <40% was poor. Four studies were of excellent quality, 13 were good, and 4 were fair (table 1). All studies lacked external validity.

Sample Characteristics

Characteristics of the samples in the included studies are summarized in table 2. All studies involved older adults who could walk independently (with or without an assistive device). The mean age of the participants ranged from 71.1 years [52] to 91.1 years [44]. Gender distribution was not specified in 1 study [57]; women comprised ≥70% of the sample in all other studies, except in 2 [17, 54]. The sample size ranged from a 10-subject single-group design [45] to a RCT of 134 participants [53]. The smallest RCT had a sample size of 13 [17]. Of the 21 studies, 14 included individuals with a fear of falling and/or a history of falls in the last 6 or 12 months [18, 42–47, 50, 52–54, 56–58]; only 2 studies specifically recruited individuals without a fear or history of falling [17, 21]. Fall history was not specified in the other 5 studies [16, 48, 49, 51, 55], although several studies reported values on the TUG or Berg Balance Scale that suggested a moderate-to-high fall risk (table 2). Cognitive ability was screened using the Montreal Cognitive Assessment, the Mini-Mental State Examination (MMSE), the short MMSE, or the Rapid Dementia Screening Test (RDST). Only 2 studies included participants who scored below the normal cutoff on these items: Trombetti et al. [53] included 25 participants (of 134) who scored less than 24 on the MMSE, and Uemera et al. [16] reported standard deviations for the mean values on the RDST suggesting that 1 or more of the participants had scores below the cutoff for dementia (≤4 points) [59]. Since the meta-analysis was based on group data and the group means on the cognitive screening tools of these 2 studies were within normal limits, they were retained for the analysis. The living situation was predominantly community-dwelling (table 2).

Table 2. Sample characteristics of included studies

First author [Ref], year	Sample size, n (% female)	Age, years	Health and mobility characteristics	Falls (fear, frequency, risk factors)	Cognitive characteristics	Living environment
Agmon [42], 2012	28 (89%)	74.5 (7.9)	Older adults who had not started any new exercise in the last 2 months, able to walk 10 m independently, no experience with the intervention	Falls in the last 12 months: n = 5 (18%)	MoCA: 27.0 (1.5)	Community-dwelling
Beauchet [43], 2013	48 (75%)	72.2 (8)	Healthy older adults, regular participation in physical activity (n = 24)	Falls in the last 12 months: n = 20 (42%) Fear of falling: n = 20 (42%)	Short MMSE ≥5 Not taking anti-dementia medication	Community-dwelling
Cadore [44], 2014	32 Analyzed: 24 (70%)	Control: 93.4 (3.2) Experimental: 90.1 (1.1)	Met Fried's criteria for frailty, not disabled (Barthel Index >60), able to walk independently without physical assistance from another person	*Baseline fall incidence:* Control: 0.93 (0.3) Experimental: 0.77 (0.4)	No dementia	Institution (nursing home)
de Bruin [17], 2013	16 (69%) Analyzed: 13 (62%)	Control: 75 (8.3) Experimental: 79.8 (6.8)	Healthy older adults not involved in structured physical or cognitive training, able to walk 20 m without an assistive device	*No fear of falling on FES-I:* Control: 18.6 (17–20) Experimental: 26.3 (17–43)	*MMSE:* Control: 29.3 (5) Experimental: 28.7 (8)	Senior citizens Hostel residents
Dorfman [45], 2014	10 (70%)	78.1 (5.8)	Able to ambulate independently for at least 10 min	Required a history of at least 2 falls in the last 6 months to be included Mean number of falls in the last 6 months: 4.2 (2.6, range 2–10)	MoCA: 25 (1.75) Frontal assessment battery (max. 24): 15.1 (2.1) No severe depression	Community-dwelling
Granacher [21], 2010	20 (70%)	Control: 75 (6) Experimental: 72 (5)	Healthy older adults able to walk independently without an assistive device, no serious concerns about falling	No; excluded if had a fear of falling (FES-I >70) *FES-I:* Control:19.7 (2.0) Experimental: 19.2 (2.4)	*MMSE:* Control: 27.0 (3.1) Experimental: 28.3 (1.6)	Community-dwelling
Halvarsson [47], 2011	59 (71%) Analyzed: 55 (75%)	Control: 78 (69–91) Experimental: 76 (67-93)	Older adults with a fear of falling and/or an experience of a fall in the last 12 months	*Fall in the last 12 months:* Control: 90% Experimental: 89% *Fear of falling:* Control: 84% Experimental: 86%	MMSE: 29 (24–30)	Community-dwelling
Halvarsson [46], 2014	96 (98%) Analyzed: 69 (99%)	Control: 76 (68–85) Experimental: 76 (68–87), 77 (69–87)	Older adults with osteoporosis and a fear of falling and/or a fall in the last 12 months, independent ambulators, without fractures in the last year	*Falls in the last 12 months:* Control: 89% Experimental: 72%, 72%	*MMSE:* Control: 28 (25–30) Experimental: 29 (24–30), 28 (25–29)	Community-dwelling
Hiyama [48], 2012	40 (100%)	Control: 73.8 (5.7) Experimental: 71.9 (5.2)	Older adults with knee osteoarthritis, no resting pain or difficulty increasing walking activity	Not specified *TUG:* Control: 13.0 s (2.1) Experimental: 12.9 s (2.0)	MMSE ≥24	Community-dwelling
Manor [49], 2014	66 Analyzed: 57 (79%)	Control: 87 (75–95) Experimental: 86 (71–98)	Older adults at risk of developing frailty, able to ambulate unassisted	Not specified *BBS, TUG:* Control: 44.4 (6.5), 13.9 s (5.6) Experimental: 45.6 (6.8), 12.0 s (4.2)	Not specified	Supported housing facilities

Table 2 (continued)

First author [Ref], year	Sample size, n (% female)	Age, years	Health and mobility characteristics	Falls (fear, frequency, risk factors)	Cognitive characteristics	Living environment
Pichierri [18], 2012	31 Analyzed: 22 (82%)	Control: 85.6 (4.2) Experimental: 86.9 (5.1)	Older adults able to walk at least 8 m with or without assistive device	*Categorized as 'faller':* Control: 55% Experimental: 45% *Falls in the last 6 months:* Control: 27% Experimental: 9%	*MMSE:* Control: 27.0 (2.6) Experimental: 27.2 (2.0)	Hostels for the aged
Silsupadol [50], 2009	23 (74%) Analyzed: 21 (81%)	Control: 74.7 (7.8) Experimental: 74.4 (6.2), 76.0 (4.7)	Older adults with balance impairment, able to walk 10 m without assistance of another person, balance impairment (BBS <52) and/or gait speed <1.1 m/s	*Number of falls in the last 12 months:* Control: 1.43 (1.15) Experimental: 1.13 (1.64), 1.0 (0.89)	*MMSE:* Control: 8.9 (1.7) Experimental: 27.5 (1.8), 29.0 (0.9)	Recruited from community, living environment not specified
Theill [51], 2013	63 (73%) Analyzed: 51	Control: 70.9 (4.8) Simultaneous training: 72.4 (4.2) Single cognitive training: 73.3 (6.1)	Healthy older adults (no other physical characteristics specified)	Not specified	*MMSE:* Control: 29.2 (0.9) Simultaneous training: 28.9 (1.0) Single cognitive training: 29.3 (0.9)	Recruited from community, living environment not specified
Toulotte [52], 2006	16 (100%)	Fallers: 71.1 (5.0) Nonfallers 68.4 (4.5)	Adults aged ≥60 years who had fallen (n = 8) or not (n = 8) in the last 2 years, walking without an assistive device or foot orthoses	Fallers (50%) had 3.4 (1.7) falls in the last 2 years	All had maximum score on MMSE	Recruited from community, living environment not specified
Trombetti [53], 2011	134 (96%)	Control: 76 (6) Experimental: 75 (8)	Older adults able to walk independently but not fully dependent on an assistive device, no previous experience with Jaques-Dalcroze eurhythmics (except childhood), at increased risk of falling	*Falls in the last 12 months:* Control: 54% Experimental: 56% *History of falls:* Control: 85% Experimental: 91%	MMSE: 26 (3) MMSE <24: n = 25 (19%)	Community-dwelling
Uemura [16], 2012	18 Analyzed: 15 (80%)	Control: 82.4 (6.8) Experimental: 82.4 (5.9)	Older adults able to walk independently with or without a cane, no regular exercise in the last 12 months	Not specified	Able to execute arithmetic tasks and follow multiple commands *RDST:* Control: 3.3 (3.1) Experimental: 4.6 (3.0)	Community-dwelling
van Het Reve [54], 2014	44 (64%)	Brochure: 76 (15) Social: 74 (5) Individual: 75 (6)	Older adults able to walk 20 m with or without assistive devices	*Falls in the last 6 months:* Brochure: 24% Social: 38% Individual: 14%	Not specified	Recruited from co-op housing services, autonomously living
Yamada [57], 2010	60 (gender not specified) Analyzed: 58	Control: 81.4 (4.9) Experimental: 79.5 (6.2)	Older adults able to walk independently with or without a cane, no regular exercise in the last 12 months	*Fall in the last 12 months:* Control: 34.5% Experimental: 37.9%	*MMSE:* Control: 28.0 (1.7) Experimental: 27.8 (2.1)	Community-dwelling

Table 2 (continued)

First author [Ref], year	Sample size, n (% female)	Age, years	Health and mobility characteristics	Falls (fear, frequency, risk factors)	Cognitive characteristics	Living environment
Yamada [55], 2011	93 Analyzed: 84 (77%)	Control: 82.9 (5.5) Experimental: 83.0 (6.7)	Older adults able to walk independently with or without a cane, no regular exercise in the last 12 months	Not specified	No severe cognitive impairment *RDST:* Control: 8.9 (1.5) Experimental: 8.5 (1.2)	Community-dwelling
Yamada [56], 2011	53 Analyzed: 50 (76%)	Control: 81.2 (7.6) Experimental: 80.3 (5.4)	Older adults able to walk independently with or without a cane, no regular exercise in the last 12 months	*Fall in the last 12 months:* Control: 23% Experimental: 29.1%	*MMSE:* Single task: 27.8 (1.8) Dual task: 28.0 (2.1)	Community-dwelling
Yamada [58], 2011	57 Analyzed: 52 (77%)	Control: 72.8 (27) Experimental: 70.8 (4.6)	Able to walk independently (none used a gait aid), no regular exercise in the last 12 months	*Fall in the last 12 months:* Control: 30% Experimental: 28% *Fear of falling:* Control: 37% Experimental: 44%	*RDST* Control: 9.6 (2.0) Experimental: 9.8 (1.7)	Community-dwelling

Values represent mean (SD or range). BBS = Berg Balance Scale (max. 56, <45 indicates fall risk); FES-I = Falls Efficacy Scale International; MoCA = Montreal Cognitive Assessment (max. 30). The maximum score on the MMSE is 30.

Description of Interventions

The nature of the physical exercise interventions varied across the studies (table 3). The interventions in 10 of the 21 studies involved a dual-task component, either by performing cognitive activities [16, 45–47, 50–52, 55, 56] or other motor activities [21, 46, 47, 52] during exercises. Of these 10 studies, 7 included dual-task walking activities [16, 45–47, 50–52], 1 involved standing balance activities [21], and 2 studies involved seated exercises [55, 56]. Cognitive activities used in the dual-task interventions included counting forwards [16, 47] or backwards [5, 47, 50], reciting letters of the alphabet [16], naming words in a particular category [5, 16, 50, 55, 56], spelling backwards [5, 50], and n-back and serial position working memory tasks [51]. Motor-motor dual-tasks as part of the interventions were not always specified but included walking while buttoning and unbuttoning or carrying a tray with glasses of water [47] and balancing while catching and throwing a ball [21]. For most of these studies, the dual-task activities were only part of the intervention; therefore, the intensity of the dual-task training varied across the studies and was not possible to define. Silsupadol et al. [50] incorporated two different types of dual-task interventions: one in which participants were instructed to pay attention to both cognitive and motor tasks at all times (fixed-priority dual-task training) and one in which attention was focused on motor (gait and balance) components of dual-task activities for half of each session and on cognitive tasks for the other half (variable-priority dual-task training). de Bruin et al. [17] incorporated a cognitive training component in their intervention, but it was performed separately from the balance and gait training program.

Three studies involved a dance or rhythm-based intervention [18, 53, 58]. In two of these, the dance intervention was combined with a program involving more traditional strengthening and aerobic exercises [18, 58]. Pichierri et al. [18] referred to their dance game intervention as a ‘cognitive-motor intervention’; however, the cognitive component was related to the execution of the motor task (i.e., stepping in the direction indicated by arrows) rather than being a discrete cognitive task independent of the motor task. Thus, for the purposes of this review, this dance intervention was not considered a dual-task intervention. Dual-task interventions were defined as those involving a discrete cognitive task (or a discrete secondary motor task) performed simultaneously with physical exercise activities (e.g., counting backwards while performing balance exercises).

Fourteen of the 21 studies involved group training [16, 18, 21, 42, 43, 45, 47, 49, 52, 53, 55–58]. Interventions ranged from 20 to 90 min in duration, with a frequency of 1–3 times per week, for 4–25 weeks, although some

Table 3. Description of study interventions

First author [Ref], year	Setting	Intervention protocol			Content	
		time, min	frequency	duration	intervention	control/comparison
Agmon [42], 2012	Group training	60	3×/week	6 weeks (18 sessions)	EnhanceFitness: cardiovascular and strength training plus balance-challenging gait activities, such as walking with head turns, quick stops, obstacle negotiation, and tandem walking	None
Beauchet [43], 2013	Group training	90	1×/week	12 weeks (12 sessions)	Intervention: standing and gait exercises focusing on awareness of body motion, balance stability, gait regularity, coordination, and stretching	None
Cadore [44], 2014	Individual	40	2×/week	12 weeks (24 sessions)	Exercise intervention: multicomponent exercise program involving upper and lower body progressive resistance training, balance, and gait training	Control group: mobility exercises (active and passive movements, stretches) 30 min/day, 4×/week
de Bruin [17], 2013	Individual	45 (exercise) + 10 (cognitive training)	2×/week exercise, 3–5×/week cognitive training	12 weeks (24 sessions)	Motor-cognition group: same as motor group plus 10 min of progressive computerized training for attention, starting in week 3	Motor group: machine-driven progressive strength training and balance and gait exercises
Dorfman [45], 2014	Individual	progressive 17–47 (average 30)	3×/week	6 weeks (18 sessions)	Intervention: treadmill walking at progressively faster speeds (up to 110% of usual overground gait speed) and reduced hand support (to none in week 6); cognitive tasks (listening comprehension, simple arithmetic operations, verbal fluency) performed during walking (except first 5 min of each session)	None
Granacher [21], 2010	Group training	60	3×/week	6 weeks (18 sessions)	Balance training: postural stabilization involving bilateral and unilateral stance activities on various surfaces; additional motor tasks added to intensify training (e.g., catching or throwing a ball)	Control group: maintained normal activities (no intervention)
Halvarsson [47], 2011	Group training	45	3×/week	12 weeks (36 sessions)	Exercise group: progressive, task-specific balance training comprising 5 levels of difficulty, including cognitive-motor dual tasks and motor-motor dual tasks (level 5 only)	Control group: no prescribed intervention; encouraged to live their regular life
Halvarsson [46], 2014	Group training + individual	45 (group) + 30 (individual)	3×/week	12 weeks (36 sessions)	Balance training: exercises targeting stability limits, sensory orientation, gait with or without cognitive or motor dual tasks or multiple tasks, and reactive postural control Balance training + physical activity: as above plus instructed to walk at least 30 min 3×/week	Control group: maintained regular lifestyle activity (no intervention)
Hiyama [48], 2012	Individual	Not specified	1×/week physical therapy + daily home exercise and daily walking	4 weeks	Walking group: attended physical therapy 1×/week plus ice therapy, ROM, and daily strengthening exercises at home; asked to increase number of daily steps by 3,000 from baseline (using pedometer)	Control group: same as walking group except no request to increase daily steps
Manor [49], 2014	Group training + individual	60 (group) + 20 (home)	2×/week (group) + 3×/week (home)	12 weeks (24 sessions)	Tai Chi: traditional Tai Chi warm-up exercises and five core movements; instructed to practice at home 20 min 3×/week with instructional DVD	Educational control: time-matched attention control; group sessions comprising lectures, discussions, and patient education handouts
Pichierri [18], 2012	Group training	40 (exercise) + 10–15 (dance games)	2×/week	12 weeks (24 sessions)	Dance intervention group: progressive resistance training, static and dynamic functional balance training, and dance video gaming	Control group: same exercise program excluding the dance component

Table 3 (continued)

First author [Ref], year	Setting	Intervention protocol			Content	
		time, min	frequency	duration	intervention	control/comparison
Silsupadol [50], 2009	Individual	45	3×/week	4 weeks (12 sessions)	Dual-task fixed priority: same as single-task but with cognitive tasks simultaneously; attention on both tasks at all times Dual-task variable priority: same as fixed priority, but attention focused on balance tasks for one half of each session and on cognitive tasks for the other half)	Single-task: balance training (stability, stability plus manipulation, transport, and transport plus manipulation)
Theill [51], 2013	Individual	30	2×/week	10 weeks (20 sessions)	Simultaneous working memory and treadmill training: performed working memory training while walking quickly on a treadmill at a 60–80% age-adjusted heart rate maximum	Passive control group: no intervention Single working memory training: computer-based n-back and serial position training
Toulotte [52], 2006	Group training	60	2×/week	12 weeks (24 sessions)	Intervention: exercises to develop muscular strength, flexibility, static balance, and walking with simultaneous cognitive or motor tasks	None
Trombetti [53], 2011	Group training	60	1×/week	25 weeks (25 sessions)	Intervention group: Jaques-Dalcroze eurhythmics: walking in time to music, responding to changes in rhythmic patterns, various movements to challenge balance while walking and standing	Control group: instructed to maintain their usual activities
Uemura [16], 2012	Group training	30	1×/week	24 weeks (24 sessions)	Dual-task switch group: seated exercise for stretching and lower extremity strengthening, standing and walking exercises with cognitive task (standing weight shift, start-and-stop walking, switching direction of movement without turning) Cognitive tasks added in both groups at weeks 7–12 (simple) and weeks 13–24 (more difficult)	Control group: seated exercise as in the intervention group, steady-state walking with cognitive task (no stopping and turning)
van Het Reve [54], 2014	Individual	Not specified	2×/week (strength and flexibility) + 5×/week (balance)	12 weeks (24 sessions strength and flexibility + 60 sessions balance)	Active lifestyle app (social): tablet-based software with progressive strength, flexibility, and balance training plan, includes social network of training partners and caregivers for motivation Active lifestyle app (individual): same as social group except for the network; individual motivation strategies only	Brochure: brochure-based progressive training program (same motor intervention as active lifestyle app groups)
Yamada [57], 2010	Group training	90	1×/week	16 weeks (16 sessions)	Trail-walking exercise: moderate-intensity aerobic exercise, progressive strength training, flexibility and balance plus 'trail walking': 30 min walking passed sequentially numbered flags (1–15) in random locations within a 5 × 5 m area	Walking exercise: same exercise program plus instructed to walk comfortably for as long as possible (up to 30 min)
Yamada [55], 2011	Group training	20	2×/week	24 weeks (48 sessions)	DVD group: seated exercise (stretching, strength, agility) and dual-task stepping exercise (verbal fluency task while alternately stepping up and down with each leg whilst sitting)	Control group: no exercise program
Yamada [56], 2011	Group training	50	1×/week	24 weeks (24 sessions)	Dual-task group: moderate-intensity aerobic exercise, progressive strength, flexibility and balance training, and seated stepping exercise with concurrent verbal fluency (category naming)	Single-task group: same seated stepping exercise without concurrent verbal fluency task
Yamada [58], 2011	Group training	60	1×/week	24 weeks (24 sessions)	Rhythmic stepping exercise: moderate-intensity aerobic exercise, progressive strength training, flexibility and balance, plus standing and stepping at 60–120 beats/min according to accompanying rhythm with the direction of each step indicated verbally by an instructor	Nonrhythmic stepping exercise: same exercise program plus standing and stepping as quickly as possible into the indicated square by an instructor's verbal command

ROM = Range of motion.

Table 4. Description of study dual-task outcome measures and pre- and post-intervention results

First author [Ref], year	Blinded assessor	Gait task and measures	Secondary task(s) and measures	Prioritization instruction	Pre- and post-intervention results by outcome measure
Agmon [42], 2012	Not specified	Walking at self-selected speed for 1 min Measures: distance walked, relative DTC	Verbal fluency (naming words beginning with a particular letter) Measures: number of words, relative DTC	Not specified	Gait: significant increase in distance walked in 1 min in DT and ST; no significant change in DTC Verbal fluency: no significant change in DT or ST; significant increase (worsening) in DTC
Beauchet [43], 2013	Not specified	Walking at self-selected speed for 10 m Measures: stride duration variability (CV)	Counting backwards; verbal fluency (enumerating animal names) Measures: not measured	Instructed to combine both tasks to the best of their ability	Stride duration variability: no change in either DT, significant reduction in ST in the participants who had the highest gait variability at baseline
Cadore [44], 2014	Yes	Walking at self-selected speed for 5 m Measures: gait speed	Verbal fluency (enumerating animal names), counting backward from 100 by 1 s Measures: verbal score, arithmetic score	Not specified	Gait: no changes in ST or DT gait speed in intervention group in either verbal or arithmetic task; decreased ST gait speed and DT gait speed after the intervention in the arithmetic task and a nonsignificant decrease in DT gait speed in the verbal task in control group Verbal: no change in DT verbal score in either group, ST not assessed Arithmetic score: no change in DT arithmetic score in either group, ST not assessed
de Bruin [17], 2013	Yes	Walking at self-selected speed for 24 m on floor surface and on foam surface Measures: relative DTC of gait speed, cadence, step duration, step length	Counting backwards by 7 s (or by 3 s or naming words, if too difficult)[†] Measures: not measured	Not specified	Gait (floor surface): significant reduction in DTC on gait speed in experimental group Gait (foam surface): significant reduction in DTC on gait speed in control group, significant reduction in DTC on cadence and step duration in experimental group
Dorfman [45], 2014	Not specified	Walking at self-selected speed for 1 min Measures: gait speed, step length, stride duration variability (CV)	Counting backwards by 3 s from a 3-digit number Measures: number of correct subtractions during ST (sitting) and DT (walking)	Not specified	Gait: significant increase in ST and DT gait speed, step length; significant improvement in stride duration variability in ST walking but not DT walking Subtraction: significant increase in the number of subtractions performed during ST (sitting) and DT walking
Granacher [21], 2010	Not specified	Walking at self-selected speed for 10 m Measures: gait speed[†], stride duration variability (CV)	Counting backwards by 3 s (cognitive); holding interlocking rings on the end of long sticks steady in front of the body (motor); combination of cognitive and motor (triple task) Measures: total number of correct subtractions; total contact time of interconnected rings	Instructed to give equal priority to all tasks	Stride duration variability: significantly reduced in ST in intervention group but not in control group; no changes in DT and triple-task conditions Gait speed[†]: see meta-analysis results Subtraction task: no changes in ST or DT in either group Contact time of rings: significantly reduced (better) in intervention group compared to control group during DT but not triple task
Halvarsson [47], 2011	Yes	Walking at self-selected speed for 8 m Measures: gait speed, cadence, step length, double support duration	Reciting alternate letters of the alphabet Measures: not measured	Not specified	Gait: significant improvement in DT gait parameters in both groups (no difference between groups); intervention group also significantly increased ST cadence

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Table 4 (continued)

First author [Ref], year	Blinded assessor	Gait task and measures	Secondary task(s) and measures	Prioritization instruction	Pre- and post-intervention results by outcome measure
Halvarsson [46], 2014	Only at baseline	Walking at self-selected speed (distance not specified) Measures: gait speed	Reciting alternate letters of the alphabet Measures: errors (percent)	Not specified	Gait: significant increase in ST gait speed in both intervention groups but not in control group; significant increase in DT gait speed in training + physical activity group only Cognitive-task errors: significant decrease during DT in training group and control group, ST not assessed
Hiyama [48], 2012	Yes	Walking at self-selected speed over 16 m Measures: automaticity index (dual-task gait speed expressed as percentage of single-task gait speed)	Counting backward by 3 s from 100 or 50 Measures: number of responses	Instructed to walk at a comfortable pace and to perform the subtraction task	Gait: significant improvement in the automaticity index for intervention but not control group Subtraction: no change in the number of responses during DT for either group, ST not assessed
Manor [49], 2014	Yes	Walking at self-selected speed along 30 m-course for 90 s measures: gait speed, DTC on gait speed	Counting backward by 5 s from a 3-digit number Measures: not measured	Not specified	Gait: significant increase in ST and DT gait speed in intervention but not control group; no change in DTC in either group
Pichierri [18], 2012	No	Walking at self-selected speed for 8 m Measures: gait speed, cadence, step duration, stride duration, stance duration, single limb support duration, double support duration, step length, and relative DTC on each	Counting backwards by 7 s from a 3-digit number Measures: not measured	Not specified	Gait: dance group significantly improved all DT gait parameters except for step length; control group significantly improved DT gait speed only; no significant between-group differences; dance and control groups significantly improved all ST gait parameters except for gait speed and step length
Silsupadol [50], 2009	Yes	Walking at self-selected gait speed over 6 m Measures: gait speed	Addition or subtraction questions Measures: number of responses, error rate	Not specified	Gait speed: equivalent increases in ST gait speed in all 3 groups, only DT training groups had significantly greater improvements in DT gait speed Number of responses, error rate: no differences in DT performance between groups before and after intervention, small effect sizes, ST not assessed
Theill [51], 2013	Not specified	Walking at self-selected speed for 20 m with a turn at 10 m Measures: gait speed, step duration variability (CV)	Counting backwards by 7 s from a 3-digit number Measures: number of correct calculations and errors	Not instructed to prioritize either task	Gait speed: no significant change in ST or DT gait speed in any group Gait variability: significant reduction in DT gait variability in DT group Subtraction accuracy: no significant change in DT performance in any group, ST not assessed
Toulotte [52], 2006	Not specified	Walking at self-selected speed for 10 m Measures: gait speed, stride length, cadence, stride duration, single support duration	Carrying a glass of water in the dominant hand (instructed to look straight ahead) Measures: not measured	Not specified	Gait: significant improvement in ST and DT conditions in fallers and nonfallers for all gait measures

Table 4 (continued)

First author [Ref], year	Blinded assessor	Gait task and measures	Secondary task(s) and measures	Prioritization instruction	Pre- and post-intervention results by outcome measure
Trombetti [53], 2011	Yes	Walking at self-selected speed (distance not specified) Measures: variability (CV) of stride duration and stride length, gait speed, cadence, stride length, double support duration, support base	Counting backward by 1 s from 50 Measures: not measured	Not instructed to prioritize either task	Gait speed: significant increase in ST in intervention group Stride length: significant increase in ST and DT in intervention group Gait variability: significant reduction in ST stride duration variability and DT stride length variability in intervention group Cadence, double support, support base: no significant changes in either group
Uemura [16], 2012	Not specified	Steady-state walking for 10 m Measures: time taken to walk 10 m	Counting backward Measures: not measured	Not specified	Steady-state gait speed: intervention group had larger reduction in time taken to walk 10 m in DT condition than control group, but group × time interaction was not statistically significant (large effect size, possibly underpowered)
van Het Reve [54], 2014	Not specified	Walking at self-selected speed (distance not specified) Measures: gait speed, cadence, step duration, step length, double support duration, variability (SD) of step duration and length; DTC on gait speed	Counting backwards by 7 or 3 s; verbal fluency task (enumerating animal names or flowers) if unable to perform subtraction task Measures: not measured	Instructed to try to perform both tasks equally well	Gait: significant improvements in all gait parameters during ST and DT walking in both intervention groups but not in control group; significant improvement in DTC on gait speed, cadence, step duration, and double support duration in individual tablet group only
Yamada [57], 2010	Yes	Walking at self-selected speed for 10 m Measures: time taken to walk 10 m, number of steps	Counting backwards by 1 s from 50 Measures: not measured	Specifically instructed not to prioritize either task	Gait: significant reduction in the number of steps and time taken to walk 10 m in DT condition in trail-walking group; no change in ST condition for either group
Yamada [55], 2011	Yes	Walking at self-selected speed for 10 m Measures: time taken to walk 10 m, DTC	Carrying a ball on a tray Measures: not measured	Not specified	Gait: significant improvement in DT walking time and DTC on walking time in DVD but not control group; no changes in ST walking time
Yamada [56], 2011	Yes	Walking at self-selected speed for 10 m Measures: gait speed, number of steps, cadence, DTC on gait speed (unconventional DTC calculation)	Counting backwards by 1 s from 50; carrying a ball on a tray in one hand Measures: numbers counted, pass/fail in tray carrying task	Specifically instructed not to prioritize either task	Gait: significant improvements in DT (counting, carrying) gait speed, cadence, DTC in DT group; no changes in ST gait Counting: significant improvement in numbers enumerated during DT in DT group, ST not assessed Carrying: not reported
Yamada [58], 2011	Yes	Walking at self-selected speed for 10 m Measures: time to walk 10 m, DTC on gait speed	Counting backwards; carrying a ball on a tray in one hand Measures: not measured	Not specified	Gait: significant improvements in time to walk in ST, DT (counting), and DTC (counting) in rhythmic stepping group; significantly greater improvements in DT (carrying) time to walk in rhythmic stepping than nonrhythmic stepping group

CV = Coefficient of variation; ST = single-task; DT = dual-task.
† Additional information provided by authors.

studies required additional home practice more regularly (table 3). The randomized and nonrandomized controlled studies had control groups that involved an active exercise intervention [16–18, 44, 48, 50, 54, 56–58], a cognitive exercise intervention [51], an education control [49], or were inactive (no treatment/delayed treatment) [21, 46, 47, 51, 53, 55]. The control interventions are described in table 3.

Dual-Task Outcome Measures

The studies were selected specifically for their inclusion of straight-line walking in single- and dual-task conditions, so the gait tasks used as outcome measures were comparable across studies (table 4). Gait parameters were evaluated during walking at a self-selected speed over at least 5 m, and up to 90 s of continuous walking. Theill et al. [51] required a single turn in walking after 10 m. Gait speed was the most frequently reported measure of dual-task walking performance. Indeed, of the 21 studies, 17 assessed gait performance using walking speed [16, 18, 44–58]. Other measures of gait performance included gait variability (e.g., variability in stride/step duration or stride length) [21, 43, 45, 51, 53, 54], cadence [17, 18, 47, 52–54], step duration [17, 18, 54], stride duration [18, 52], step length [17, 18, 45, 47], stride length [18, 52], single support duration [18, 52], double support duration [18, 47, 53, 54], support base [53], distance walked in 1 min [42], and number of steps over 10 m [56, 57]. Seven studies also measured the relative DTC on gait parameters, computed as a percentage change in performance in dual-task walking relative to single-task walking [17, 18, 42, 49, 54, 55, 58]. Two studies used a variation of the traditional DTC formula [48, 56].

The secondary tasks used in the dual-task conditions varied across the studies (table 4). The most frequent dual task was walking while counting backwards, either by 1 s [16, 43, 44, 53, 56–58], by 3 s [21, 45, 48, 49], or by 7 s [17, 18, 51]. Other secondary tasks included verbal fluency (e.g., enumerating animal names or naming words beginning with a particular letter) [42–44, 54], saying alternate letters of the alphabet [46, 47], adding and subtracting [50], carrying a glass with water [52], carrying a ball on a tray [55, 56, 58], and holding steady interlocking rings on the end of long sticks held in front of the body [21].

Effects of Interventions on Gait

Table 4 summarizes the outcomes of all 21 studies included.

Gait Speed

Data on single-task gait speed were available from 14 RCTs for 16 comparisons; the analysis involved 647 participants. Overall, there was a significantly greater increase in single-task gait speed with physical exercise intervention than with control intervention (mean difference: 0.06 m/s, 95% CI: 0.03, 0.10, $p = 0.0002$; fig. 2). There was no evidence of heterogeneity of the treatment effects between the trials ($p = 0.10$, $I^2 = 33\%$). The mean difference in single-task gait speed in favor of the intervention was not significantly greater than in active controls (0.06 m/s, 95% CI: –0.01, 0.12, $p = 0.08$; fig. 3), but was significantly greater than in inactive controls (0.06 m/s, 95% CI: 0.02, 0.09, $p = 0.0008$). There was no evidence that the treatment effects differed across the two types of control groups ($p = 0.99$, $I^2 = 0\%$).

Data on dual-task gait speed were available from 14 RCTs for 21 comparisons; the analysis involved 897 participants. Overall, there was a significant improvement in dual-task gait speed in favor of the intervention (mean difference: 0.11 m/s, 95% CI: 0.07, 0.15, $p < 0.00001$; fig. 4). There was evidence of heterogeneity of the treatment effects between the trials ($p = 0.01$, $I^2 = 47\%$). The mean difference was largest for the motor-motor dual tasks (0.15 m/s, 95% CI: 0.02, 0.27, $p = 0.02$) and smallest for the triple task (0.03 m/s, 95% CI: –0.23, 0.29, $p = 0.82$), which was evaluated in only 1 study. The mean difference for the cognitive-motor arithmetic tasks (0.11 m/s, 95% CI: 0.06, 0.16, $p < 0.00001$) was greater than that for the verbal fluency tasks (0.09 m/s, 95% CI: 0.05, 0.14, $p < 0.00001$), but the difference in the treatment effect on dual-task gait speed between the types of dual tasks was not significant ($p = 0.81$, $I^2 = 0\%$). Additionally, there was no difference in the treatment effect relative to active versus inactive control (fig. 5).

Among the 7 studies not included in the meta-analysis, 4 reported significant increases in single- and dual-task gait speed following the intervention [18, 45, 52, 54], and 1 reported no change in single- or dual-task gait speed [51]. The other 2 studies did not report gait speed [42, 43].

DTC on Gait Speed

Data on DTC on gait speed were available from 14 RCTs for 21 comparisons; the analysis involved 897 participants. Overall, there was a significant decrease in DTC on gait speed in favor of the intervention (mean difference: 5.23, 95% CI: 1.40, 9.05, $p = 0.007$; fig. 6). There was evidence of heterogeneity of the treatment effects between the trials ($p = 0.04$, $I^2 = 38\%$). The treatment effect on DTC did not differ between the types of dual tasks

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Study or subgroup	Mean difference	SE	Weight, %	Mean difference IV, random (95% CI)
Cadore [44], 2014	0.12	0.031	13.1	0.12 (0.06, 0.18)
de Bruin [17], 2013	0.02	0.136	1.5	0.02 (–0.25, 0.29)
Granacher [21], 2010	0.1	0.094	3.0	0.10 (–0.08, 0.28)
Halvarsson [47], 2011	0.08	0.059	6.3	0.08 (–0.04, 0.20)
Halvarsson [46], 2014 (training + physical activity)	0.1	0.063	5.7	0.10 (–0.02, 0.22)
Halvarsson [46], 2014 (training group)	0.08	0.06	6.1	0.08 (–0.04, 0.20)
Hiyama [48], 2012	0.02	0.042	9.8	0.02 (–0.06, 0.10)
Manor [49], 2014	0.1	0.064	5.6	0.10 (–0.03, 0.23)
Silsupadol [50], 2009 (dual FP group)	0.13	0.1	2.7	0.13 (–0.07, 0.33)
Silsupadol [50], 2009 (dual VP group)	0.06	0.094	3.0	0.06 (–0.12, 0.24)
Trombetti [53], 2011	0.05	0.022	16.5	0.05 (0.01, 0.09)
Uemura [16], 2012	0.01	0.108	2.3	0.01 (–0.20, 0.22)
Yamada [57], 2010	0.02	0.065	5.5	0.02 (–0.11, 0.15)
Yamada [55], 2011	–0.04	0.062	5.9	–0.04 (–0.16, 0.08)
Yamada, [58], 2011	0.16	0.043	9.5	0.16 (0.08, 0.24)
Yamada [56], 2011	–0.17	0.085	3.5	–0.17 (–0.34, –0.00)
Total (95% CI)			100.0	0.06 (0.03, 0.10)

Heterogeneity: $\tau^2 = 0.00$, $\chi^2 = 22.28$, d.f. = 15 ($p = 0.10$), $I^2 = 33\%$

Test for overall effect: Z = 3.66 ($p = 0.0002$)

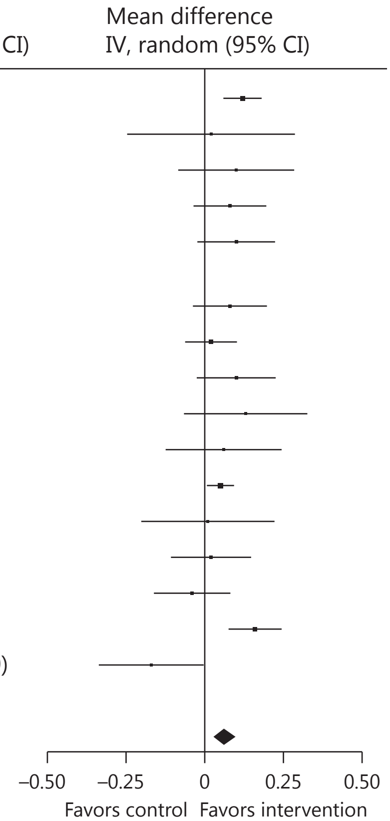

Fig. 2. Meta-analysis of single-task gait speed (m/s). SE = Standard error; IV = inverse variance.

($p = 0.25$, $I^2 = 26\%$), but was largest for the motor-motor dual task (mean difference: 11.82, 95% CI: 2.77, 20.87, $p = 0.01$) and smallest for the verbal fluency tasks (mean difference: 0.06, 95% CI: –7.13, 7.25, $p = 0.99$; fig. 6). There was no difference in the treatment effect on DTC relative to active versus inactive control (fig. 7).

Other Gait Parameters

Of the 6 studies that measured treatment effects on gait variability during dual-task walking [21, 43, 45, 51, 53, 54], van Het Reve et al. [54] found significant improvements in the variability of both stride duration and stride length, Trombetti et al. [53] found improvements in the variability of stride length but not stride duration, and Theill et al. [51] found significant improvements in the step duration variability. There were too few studies focusing on other gait parameters to effectively summarize intervention effects on other aspects of dual-task walking (see table 4 for study-specific results).

Effects of Interventions on Non-Gait Tasks

Only 9 of the 21 studies measured the performance of the non-gait (secondary) task during dual-task walking [21, 42, 44–46, 48, 50, 51, 56]. Of these, 6 reported no significant change in dual-task performance of cognitive non-gait tasks [21, 42, 44, 48, 50, 51], while 3 studies reported significant improvements in cognitive dual-task performance [45, 46, 56] (table 4). Performance on the manual non-gait tasks (e.g., carrying a glass of water or carrying a ball on a tray) was rarely quantified [52, 55, 56, 58]. Granacher et al. [21] were the only investigators to objectively measure the manual secondary task. They found that the contact time between two interlocking rings on the end of sticks held in front of the body was reduced (more) after training in the intervention group compared to the control group.

Importantly, DTC on the non-gait tasks could rarely be quantified: of the 9 studies that measured dual-task performance on the non-gait task, only 3 assessed single- as

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Study or subgroup	Mean difference	SE	Weight, %	Mean difference IV, random (95% CI)
Intervention vs. active (exercise) control				
Cadore [44], 2014	0.12	0.031	13.1	0.12 (0.06, 0.18)
de Bruin [17], 2013	0.02	0.136	1.5	0.02 (–0.25, 0.29)
Hiyama [48], 2012	0.02	0.042	9.8	0.02 (–0.06, 0.10)
Silsupadol [50], 2009 (dual FP group)	0.13	0.1	2.7	0.13 (–0.07, 0.33)
Silsupadol [50], 2009 (dual VP group)	0.06	0.094	3.0	0.06 (–0.12, 0.24)
Uemura [16], 2012	0.01	0.108	2.3	0.01 (–0.20, 0.22)
Yamada [57], 2010	0.02	0.065	5.5	0.02 (–0.11, 0.15)
Yamada [58], 2011	0.16	0.043	9.5	0.16 (0.08, 0.24)
Yamada [56], 2011	–0.17	0.085	3.5	–0.17 (–0.34, –0.00)
Subtotal (95% CI)			50.9	0.06 (–0.01, 0.12)
Heterogeneity: $\tau^2 = 0.00$, $\chi^2 = 17.57$, d.f. = 8 ($p = 0.02$), $I^2 = 54\%$				
Test for overall effect: Z = 1.77 ($p = 0.08$)				
Intervention vs. inactive (no exercise) control				
Granacher [21], 2010	0.1	0.094	3.0	0.10 (–0.08, 0.28)
Halvarsson [47], 2011	0.08	0.059	6.3	0.08 (–0.04, 0.20)
Halvarsson [46], 2014 (training + physical activity)	0.1	0.063	5.7	0.10 (–0.02, 022)
Halvarsson [46], 2014 (training group)	0.08	0.06	6.1	0.08 (–0.04, 0.20)
Manor [49], 2014	0.1	0.064	5.6	0.10 (–0.03, 0.23)
Trombetti [53], 2011	0.05	0.022	16.5	0.05 (0.01, 0.09)
Yamada [55], 2011	–0.04	0.062	5.9	–0.04 (–0.16, 0.08)
Subtotal (95% CI)			49.1	0.06 (0.02, 0.09)
Heterogeneity: $\tau^2 = 0.00$, $\chi^2 = 3.97$, d.f. = 6 ($p = 0.68$), $I^2 = 0\%$				
Test for overall effect: Z = 3.36 ($p = 0.0008$)				
Total (95% CI)			100.0	0.06 (0.03, 0.10)
Heterogeneity: $\tau^2 = 0.00$, $\chi^2 = 22.28$, d.f. = 15 ($p = 0.10$), $I^2 = 33\%$				
Test for overall effect: Z = 3.66 ($p = 0.0002$)				
Test for subgroup differences: $\chi^2 = 0.00$, d.f. = 1 ($p = 0.99$), $I^2 = 0\%$				

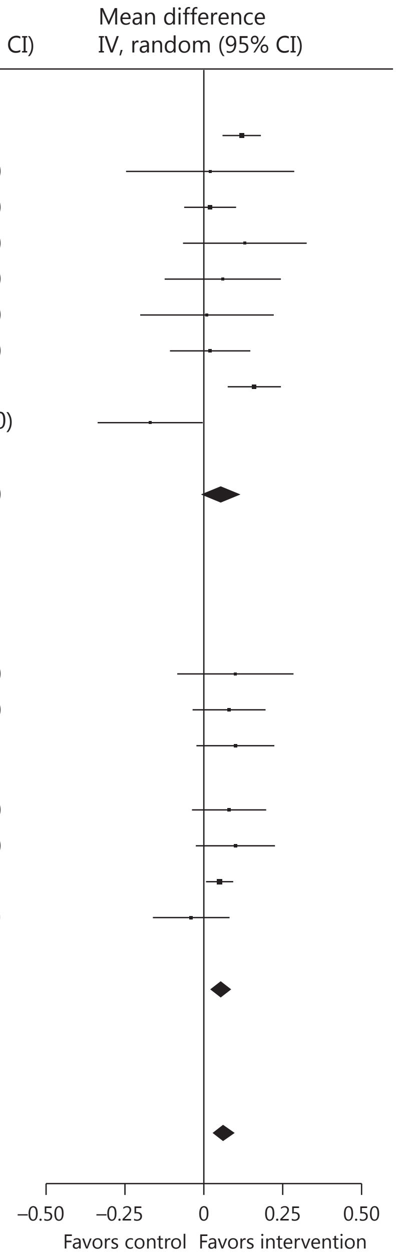

Fig. 3. Subgroup meta-analysis of single-task gait speed (m/s). SE = Standard error; IV = inverse variance.

well as dual-task performance [21, 42, 45]. In 1 of these [42], it was found that the DTC of the verbal fluency task after the intervention significantly worsened (while the DTC on gait was unchanged). Dorfman et al. [45] found significant improvements in single- and dual-task performance of both gait and non-gait tasks, thus the DTC for each task (data not reported) showed little to no change after the intervention. DTC on the non-gait tasks in the study by Granacher et al. [21] could not be computed because data were presented in figure form only.

Publication Bias

Funnel plots were created for each of the analyses and assessed visually for asymmetry to indicate the possibility

Study or subgroup	Mean difference	SE	Weight, %	Mean difference IV, random (95% CI)
Cognitive-motor (arithmetic) dual-task gait speed				
Cadore [44], 2014	0.08	0.029	9.9	0.08 (0.02, 0.14)
de Bruin [17], 2013	0.04	0.147	1.4	0.04 (–0.25, 0.33)
Granacher [21], 2010	–0.11	0.145	1.4	–0.11 (–0.39, 0.17)
Hiyama [48], 2012	0.13	0.035	8.9	0.13 (0.06, 0.20)
Manor [49], 2014	0.11	0.061	5.3	0.11 (–0.01, 0.23)
Silsupadol [50], 2009 (dual FP group)	0.15	0.09	3.1	0.15 (–0.03, 0.33)
Silsupadol [50], 2009 (dual VP group)	0.14	0.087	3.3	0.14 (–0.03, 0.31
Trombetti [53], 2011	0.03	0.027	10.2	0.03 (–0.02, 0.08)
Uemura [16], 2012	0.14	0.14	1.5	0.14 (–0.13, 0.41
Yamada, 2010	0.1	0.045	7.3	0.10 (0.01, 0.19)
Yamada [58], 2011	0.36	0.076	4.0	0.36 (0.21, 0.51)
Yamada [56], 2011	0.11	0.085	3.4	0.11 (–0.06, 0.28)
Subtotal (95% CI)			59.8	0.11 (0.06, 0.16)
Heterogeneity: $\tau^2 = 0.00$, $\chi^2 = 22.12$, d.f. = 11 ($p = 0.02$), $I^2 = 50\%$				
Test for overall effect: Z = 4.46 ($p < 0.00001$)				
Cognitive-motor (verbal fluency) dual-task gait speed				
Cadore [44], 2014	0.1	0.025	10.5	0.10 (0.05, 0.15)
Halvarsson [47], 2011	–0.01	0.08	3.7	–0.01 (–0.17, 0.15)
Halvarsson [46], 2014 (training + physical activity)	0.17	0.092	3.0	0.17 (–0.01, 0.35)
Halvarsson [46], 2014 (training group)	0.07	0.072	4.3	0.07 (–0.07, 0.21)
Subtotal (95% CI)			21.6	0.09 (0.05, 0.14)
Heterogeneity: $\tau^2 = 0.00$, $\chi^2 = 2.54$, d.f. = 3 ($p = 0.47$), $I^2 = 0\%$				
Test for overall effect: Z = 4.22 ($p = 0.0001$)				
Motor-motor dual-task gait speed				
Granacher [21], 2010	0	0.109	2.3	0.00 (–0.21, 0.21)
Yamada [55], 2011	0.08	0.058	5.7	0.08 (–0.03, 0.19)
Yamada [58], 2011	0.29	0.058	5.7	0.29 (0.18, 0.40)
Yamada [56], 2011	0.16	0.088	3.3	0.16 (–0.01, 0.33)
Subtotal (95% CI)			16.9	0.15 (0.02, 0.27)
Heterogeneity: $\tau^2 = 0.01$, $\chi^2 = 9.08$, d.f. = 3 ($p = 0.03$), $I^2 = 67\%$				
Test for overall effect: Z = 2.24 ($p = 0.02$)				
Triple-task gait speed				
Granacher [21], 2010	0.03	0.132	1.7	0.03 (–0.23, 0.29)
Subtotal (95% CI)			1.7	0.03 (–0.23, 0.29)
Heterogeneity: not applicable				
Test for overall effect: Z = 0.23 ($p = 0.82$)				
Total (95% CI)			100.0	0.11 (0.07, 0.15)
Heterogeneity: $\tau^2 = 0.00$, $\chi^2 = 37.60$, d.f. = 20 ($p = 0.010$), $I^2 = 47\%$				
Test for overall effect: Z = 5.97 ($p < 0.00001$)				
Test for subgroup differences: $\chi^2 = 0.98$, d.f. = 3 ($p = 0.81$), $I^2 = 0\%$				

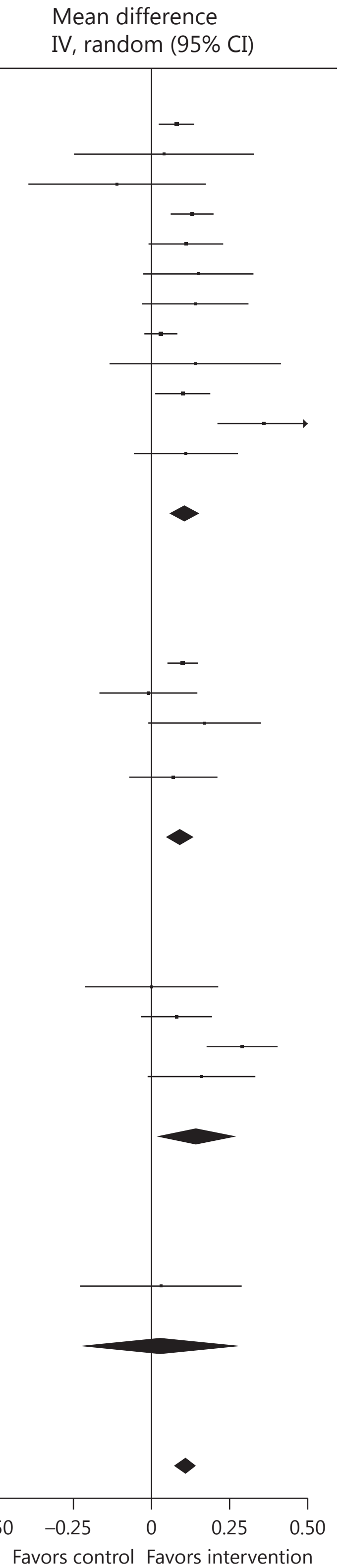

Fig. 4. Meta-analysis of dual-task gait speed (m/s). SE = Standard error; IV = inverse variance.

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Study or subgroup	Mean difference	SE	Weight, %	Mean difference IV, random (95% CI)
Intervention vs. active (exercise) control				
Cadore [44], 2014 (arithmetic task)	0.08	0.029	8.5	0.08 (0.02, 0.14)
Cadore [44], 2014 (verbal fluency task)	0.1	0.025	8.9	0.10 (0.05, 0.15)
de Bruin [17], 2013	0.04	0.147	1.8	0.04 (–0.25, 0.33)
Hiyama [48], 2012	0.13	0.035	8.0	0.13 (0.06, 0.20)
Silsupadol [50], 2009 (dual FP group)	0.15	0.092	3.6	0.15 (–0.03, 0.33)
Silsupadol [50], 2009 (dual VP group)	0.14	0.087	3.8	0.14 (–0.03, 0.31)
Uemura [16], 2012	0.14	0.14	1.9	0.14 (–0.13, 0.41)
Yamada [57], 2010	0.1	0.045	7.0	0.10 (0.01, 0.19)
Yamada [58], 2011 (cognitive task)	0.36	0.078	4.4	0.36 (0.21, 0.51)
Yamada [58], 2011 (motor task)	0.29	0.059	5.8	0.29 (0.17, 0.41)
Yamada [56], 2011	0.11	0.085	3.9	0.11 (–0.06, 0.28)
Subtotal (95% CI)			57.5	0.14 (0.09, 0.19)
Heterogeneity: $\tau^2 = 0.00$, $\chi^2 = 21.06$, d.f. = 10 (p = 0.02), $I^2 = 53\%$				
Test for overall effect: Z = 5.83 (p < 0.00001)				
Intervention vs. inactive (no exercise) control				
Granacher [21], 2010 (cognitive task)	–0.11	0.144	1.8	–0.11 (–0.39, 0.17)
Granacher [21], 2010 (motor task)	0	0.112	2.7	0.00 (–0.22, 0.22)
Grenacher [21], 2010 (triple task)	0.03	0.133	2.1	0.03 (–0.23, 0.29)
Halvarsson [47], 2011	–0.01	0.094	3.5	–0.01 (–0.19, 0.17)
Halvarsson [46], 2014 (training + physical activity)	–0.01	0.094	3.5	–0.01 (–0.19, 0.17)
Halvarsson [46], 2014 (training group)	0.07	0.075	4.5	0.07 (–0.08, 0.22)
Manor [49], 2014	0.11	0.061	5.6	0.11 (–0.01, 0.23)
Trombetti [53], 2011	0.03	0.027	8.7	0.03 (–0.02, 0.08)
Yamada [55], 2011 (cognitive task)	0.36	0.082	4.1	0.36 (0.20, 0.52)
Yamada [55], 2011 (motor task)	0.23	0.057	5.9	0.23 (0.12, 0.34)
Subtotal (95% CI)			42.5	0.09 (0.01, 0.17)
Heterogeneity: $\tau^2 = 0.01$, $\chi^2 = 26.43$, d.f. = 9 (p = 0.002), $I^2 = 66\%$				
Test for overall effect: Z = 2.16 (p = 0.03)				
Total (95% CI)			100.0	0.12 (0.08, 0.16)
Heterogeneity: $\tau^2 = 0.00$, $\chi^2 = 51.33$, d.f. = 20 (p = 0.0001), $I^2 = 61\%$				
Test for overall effect: Z = 5.66 (p < 0.00001)				
Test for subgroup differences: $\chi^2 = 1.36$, d.f. = 1 (p = 0.24), $I^2 = 26.2\%$				

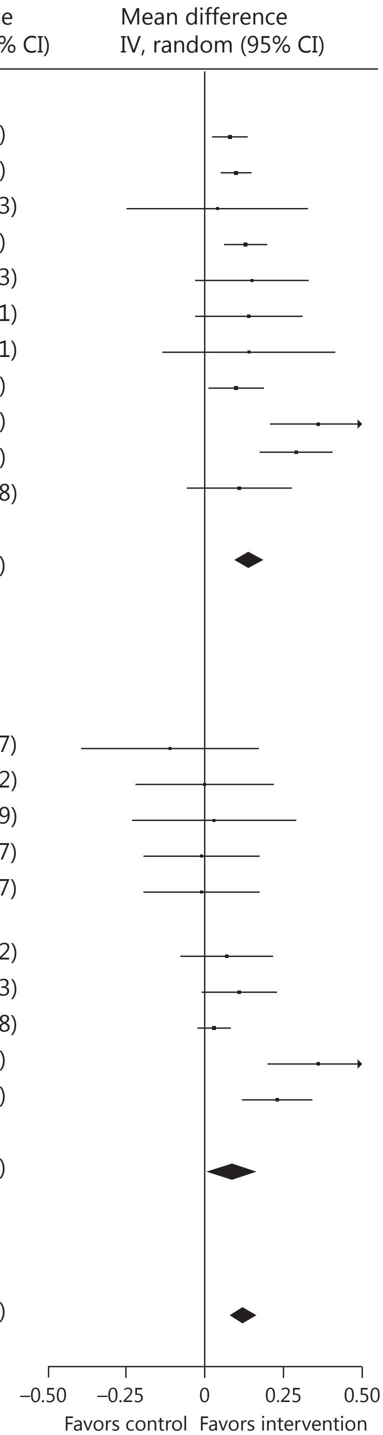

Fig. 5. Subgroup meta-analysis of dual-task gait speed (m/s). SE = Standard error; IV = inverse variance.

Study or subgroup	Mean difference	SE	Weight, %	Mean difference IV, random (95% CI)
Cognitive-motor (arithmetic) dual-task gait speed				
Cadore [44], 2014	–2.01	5.678	6.6	–2.01 (–13.14, 9.12)
de Bruin [17], 2013	2.3	5.347	7.1	2.30 (–8.18, 12.78)
Granacher [21], 2010	–14.61	13.095	1.9	–14.61 (–40.28, 11.06)
Hiyama [48], 2012	11.89	5.55	6.8	11.89 (1.01, 22.77)
Manor [49], 2014	–1.2	2.299	12.5	–1.20 (–5.71, 3.31)
Silsupadol [50], 2009 (dual FP group)	2.97	11.201	2.5	2.97 (–18.98, 24.92)
Silsupadol [50], 2009 (dual VP group)	7.05	10.764	2.7	7.05 (–14.05, 28.15)
Trombetti [53], 2011	1.08	5.473	6.9	1.08 (–9.65, 11.81)
Uemura [16], 2012	17	21.048	0.8	17.00 (–24.25, 58.25)
Yamada [57], 2010	9.8	9.232	3.5	9.80 (–8.29, 27.89)
Yamada [58], 2011	17.99	6.281	5.9	17.99 (5.68, 30.30)
Yamada [56], 2011	22.11	11.695	2.4	22.11 (–0.81, 45.03)
Subtotal (95% CI)			59.6	4.69 (–0.24, 9.62)
Heterogeneity: $\tau^2 = 24.71$, $\chi^2 = 18.03$, d.f. = 11 ($p = 0.08$), $I^2 = 39\%$				
Test for overall effect: $Z = 1.86$ ($p = 0.06$)				
Cognitive-motor (verbal fluency) dual-task gait speed				
Cadore [44], 2014	0.87	5.433	7.0	0.87 (–9.78, 11.52)
Halvarsson [47], 2011	–7.05	8.795	3.7	–7.05 (–24.29, 10.19)
Halvarsson [46], 2014 (training + physical activity)	6.65	9.672	3.2	6.65 (–12.31, 25.61)
Halvarsson [46], 2014 (training group)	–0.29	7.728	4.5	–0.29 (–15.44, 14.86)
Subtotal (95% CI)			18.4	0.06 (–7.13, 7.25)
Heterogeneity: $\tau^2 = 0.00$, $\chi^2 = 1.14$, d.f. = 3 ($p = 0.77$), $I^2 = 0\%$				
Test for overall effect: $Z = 0.02$ ($p = 0.99$)				
Motor-motor dual-task gait speed				
Granacher [21], 2010	–3.96	11.567	2.4	–3.96 (–26.63, 18.71)
Yamada [55], 2011	15.5	4.958	7.7	15.50 (5.78, 25.22)
Yamada [58], 2011	8.05	4.604	8.2	8.05 (–0.97, 17.07)
Yamada [56], 2011	28.74	11.674	2.4	28.74 (5.86, 51.62)
Subtotal (95% CI)			20.6	11.82 (2.77, 20.87)
Heterogeneity: $\tau^2 = 34.14$, $\chi^2 = 5.18$, d.f. = 3 ($p = 0.16$), $I^2 = 42\%$				
Test for overall effect: $Z = 2.56$ ($p = 0.01$)				
Triple-task gait speed				
Granacher [21], 2010	–0.41	15.664	1.4	–0.41 (–31.11, 30.29)
Subtotal (95% CI)			1.4	–0.41 (–31.11, 30.29)
Heterogeneity: not applicable				
Test for overall effect: $Z = 0.03$ ($p = 0.98$)				
Total (95% CI)			100.0	5.23 (1.40, 9.05)
Heterogeneity: $\tau^2 = 25.27$, $\chi^2 = 32.36$, d.f. = 20 ($p = 0.04$), $I^2 = 38\%$				
Test for overall effect: $Z = 2.68$ ($p = 0.007$)				
Test for subgroup differences: $\chi^2 = 4.08$, d.f. = 3 ($p = 0.25$), $I^2 = 26.4\%$				

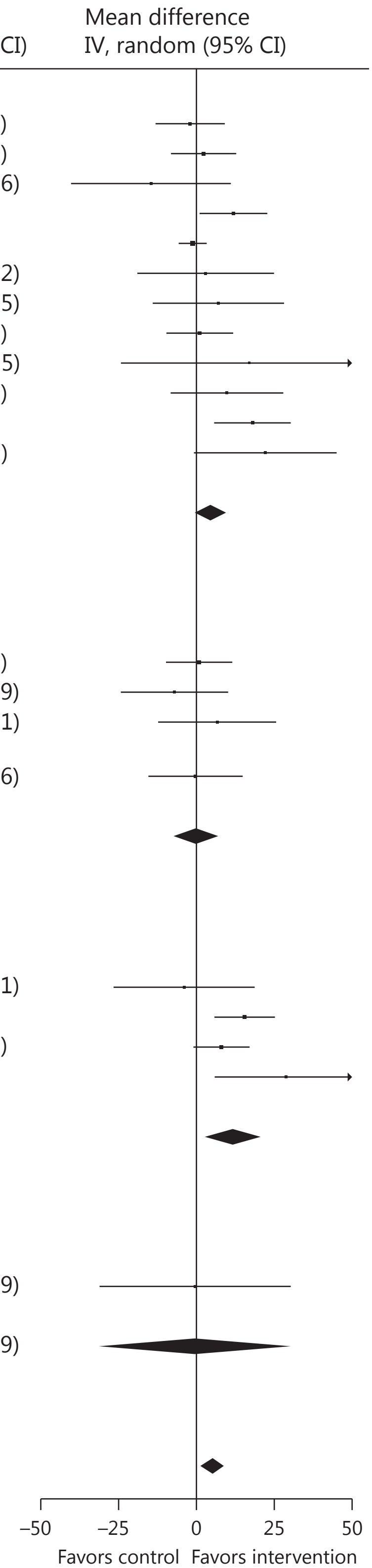

Fig. 6. Meta-analysis of DTC on gait speed (%). SE = Standard error; IV = inverse variance.

Study or subgroup	Mean difference	SE	Weight, %	Mean difference IV, random (95% CI)
Intervention vs. active (exercise) control				
Cadore [44], 2014 (arithmetic task)	–2.01	5.678	6.4	–2.01 (–13.14, 9.12)
Cadore [44], 2014 (verbal fluency task)	0.87	5.433	6.8	0.87 (–9.78, 11.52)
de Bruin [17], 2013	2.3	5.347	6.9	2.30 (–8.18, 12.78)
Hiyama [48], 2012	11.89	5.55	6.6	11.89 (1.01, 22.77)
Silsupadol [50], 2009 (dual FP group)	2.97	11.201	2.2	2.97 (–18.98, 24.92)
Silsupadol [50], 2009 (dual VP group)	7.05	10.764	2.3	7.05 (–14.05, 28.15)
Uemura [16], 2012	17	21.048	0.7	17.00 (–24.25, 58.25)
Yamada [57], 2010	9.8	9.232	3.0	9.80 (–8.29, 27.89)
Yamada [58], 2011 (cognitive task)	17.99	6.372	5.4	17.99 (5.50, 30.48)
Yamada [58], 2011 (motor task)	8.05	4.671	8.2	8.05 (–1.10, 17.20)
Yamada [56], 2011	22.111	11.695	2.0	22.11 (–0.81, 45.03)
Subtotal (95% CI)			50.5	6.88 (2.75, 11.01)
Heterogeneity: $\tau^2 = 2.27$, $\chi^2 = 10.48$, d.f. = 10 ($p = 0.40$), $I^2 = 5\%$				
Test for overall effect: $Z = 3.27$ ($p = 0.001$)				
Intervention vs. inactive (no exercise) group				
Granacher [21], 2010 (cognitive task)	–14.61	13.095	1.6	–14.61 (–40.28, 11.06)
Granacher [21], 2010 (motor task)	–3.96	11.567	2.0	–3.96 (–26.63, 18.71)
Granacher [21], 2010 (triple task)	–0.41	15.664	1.2	–0.41 (–31.11, 30.29)
Halvarsson [47], 2011	–7.05	10.27	2.5	–7.05 (–27.18, 13.08)
Halvarsson [46], 2014 (training + physical activity)	6.65	9.672	2.8	6.65 (–12.31, 25.61)
Halvarsson [46], 2014 (training group)	–0.29	8.112	3.7	–0.29 (–16.19, 15.61)
Manor [49], 2014	–1.2	2.299	14.9	–1.20 (–5.71, 3.31)
Trombetti [53], 2011	1.08	5.473	6.7	1.08 (–9.65, 11.81)
Yamada [55], 2011 (cognitive task)	17.99	6.281	5.6	17.99 (5.68, 30.30)
Yamada [55], 2011 (motor task)	8.05	4.604	8.4	8.05 (–0.97, 17.07)
Subtotal (95% CI)			49.5	2.53 (–2.48, 7.55)
Heterogeneity: $\tau^2 = 17.58$, $\chi^2 = 13.08$, d.f. = 9 ($p = 0.16$), $I^2 = 31\%$				
Test for overall effect: $Z = 0.99$ ($p = 0.32$)				
Total (95% CI)			100.0	4.83 (1.43, 8.24)
Heterogeneity: $\tau^2 = 14.93$, $\chi^2 = 27.57$, d.f. = 20 ($p = 0.12$), $I^2 = 27\%$				
Test for overall effect: $Z = 2.78$ ($p = 0.005$)				
Test for subgroup differences: $\chi^2 = 1.72$, d.f. = 1 ($p = 0.19$), $I^2 = 41.9\%$				

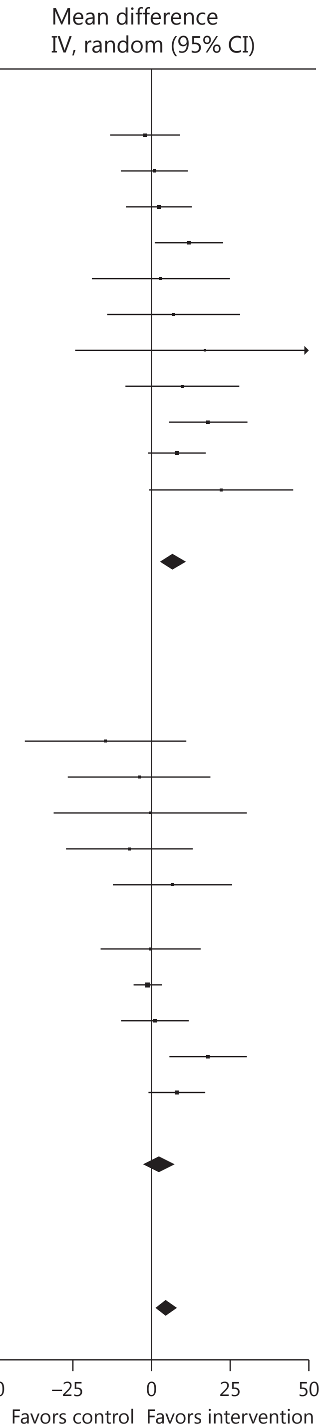

Fig. 7. Subgroup meta-analysis of DTC on gait speed (%). SE = Standard error; IV = inverse variance.

of publication bias [23, 60]. Publication bias did not appear present for single-task gait speed, dual-task gait speed, or DTC for subgroup analysis. Furthermore, asymmetry appeared absent for single-task gait speed and DTC for comparison of intervention versus active and intervention versus control but seemed present for dual-task gait speed. However, it is important to note that the asymmetry could be a result of heterogeneity of the treatment effects. This is further supported by the fact that heterogeneity was most prevalent in this comparison ($p = 0.0001$, $I^2 = 61\%$) [60, 61].

Discussion

Summary of Evidence

The aim of this meta-analysis was to estimate the effect size of physical exercise interventions compared to control interventions or no intervention on the performance of dual-task walking among older adults. Compared to the most recent systematic review and meta-analysis [13], which pooled only 8 RCTs to examine treatment effects on dual-task gait speed, the current review included 21 comparisons from 14 RCTs. Due to the number of included trials, we were also able to conduct subgroup analyses based on the type of dual-task assessment and the type of control group. Overall, this review found that the mean difference between intervention and control groups significantly favored the intervention for single-task gait speed, dual-task gait speed, and DTC on gait speed. There was a larger treatment effect on dual-task gait speed than on single-task gait speed. Indeed, the intervention effect on single-task gait speed was small and unlikely to be clinically important. In contrast, a mean difference of 0.11 m/s in dual-task gait speed between the intervention and control may be clinically significant [62].

The current results for dual-task gait speed are in conflict with the recent meta-analysis of Wang et al. [13], who found no significant difference in the treatment effect between dual-task intervention and single-task or no intervention. One reason for this difference may be the larger number of studies included in our review. Additionally, most of the studies in the analysis of Wang et al. [13] included active control groups that performed similar gait and balance exercises as the experimental group, which may have diminished the mean between-group difference. However, our subgroup analyses indicated no significant difference in the benefit of physical exercise intervention when compared to active or inactive control groups. The finding that the treatment effect for all outcomes was not greater compared to that of the inactive control groups is unexpected. One plausible explanation is that this occurred due to differences across the studies in terms of the nature, frequency, and duration of the interventions, as illustrated in table 3. Together with the heterogeneity of the treatment effects on dual-task outcomes between the trials, these findings suggest that some interventions have larger effects than others. Nonetheless, there is evidence from this meta-analysis that physical exercise interventions, regardless of whether they involve dual-task activities, can improve dual-task gait speed and reduce DTC on gait speed in older adults with a moderate-to-high fall risk.

There was little evidence from this systematic review for the effects of physical exercise interventions on other aspects of dual-task walking, and the findings for gait variability were equivocal. Three studies reported a significant reduction in the variability of spatial and/or temporal gait parameters during dual-task walking in the intervention groups [51, 53, 55], while another 3 studies found no significant changes in gait variability [21, 43, 45]. The contrasting results may be due to the type of intervention and/or the nature of the dual-task assessment. For example, Theill et al. [51], who demonstrated a significant reduction in the step duration variability during dual-task walking, required a turn after walking 10 m, which by nature of the task would produce a greater step-to-step variability than straight-line walking without a turn. The average dual-task gait variability reported by Theill et al. [51] was greater than that reported by Granacher et al. [21], who measured straight-line walking over 10 m.

The current meta-analysis revealed significant benefits after intervention compared to control for DTC on gait speed; however, there was a severe lack of data on DTC on the non-gait tasks. Indeed, only 1 study analyzed the DTC on both gait and non-gait tasks [42]. Thus, while the findings from our meta-analysis indicate that there is a small treatment effect in favor of physical exercise intervention compared to controls for reducing DTC on gait speed, without knowing whether there are reciprocal improvements in dual-task performance in the non-gait task, it is not possible to draw conclusions about the treatment effects on overall dual-task ability [63]. That is, we cannot determine whether changes in DTC on gait speed after the intervention were due to an actual improvement in dual-task ability or simply the use of a different strategy (e.g., shift in relative task prioritization) during dual-task walking.

Limitations

Only 4 studies (2 RCTs) [45, 52, 53, 57] included a follow-up evaluation after the post-intervention assessment; therefore, this analysis was limited to examining short-term effects based on outcomes measured immediately after the intervention. Twelve potentially eligible studies were excluded from this review because they were not published in English. Although two thirds of the studies included participants with a history of falls, differences in outcomes between fallers and nonfallers were not reported, with one exception [52]. Our statistical analysis focused exclusively on gait speed, and we included only studies that measured unobstructed dual-task walking in order to maximize homogeneity for comparison. It is possible that the interventions in the included (and some excluded) studies may have demonstrated significant effects on gait in other everyday mobility tasks (e.g., transfers or negotiating obstacles), but these have been considered in other reviews [6, 13, 14]. There remains a limited number of well-conducted trials examining treatment-related effects of other gait parameters during dual-task walking. Despite these limitations, our analysis included primarily good- to excellent-quality studies; only 4 studies (none included in the meta-analysis) were of fair quality. Moreover, we conformed to the PRIMSA guidelines [19] for conducting and reporting this review, further ensuring that the results are robust.

Conclusion

Physical exercise interventions can improve dual-task walking in older adults primarily by increasing the speed at which individuals walk in dual-task conditions. Currently, evidence concerning whether physical exercise interventions reduce the overall dual-task interference during unobstructed walking is greatly lacking, mainly due to the failure of studies to measure and report reciprocal dual-task effects on the non-gait task. Future studies should include measures of relative dual-task effects as well as absolute measures of dual-task performance. It is also imperative that future investigations report the single- and dual-task data for both gait and non-gait tasks so that the effects of interventions on the dual-task strategy (i.e., attention allocation) and overall dual-task ability can be established.

Disclosure Statement

There are no conflicts of interest for any of the authors.

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