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REVIEW

A systematic review of interventions conducted in clinical or community settings to improve dual-task postural control in older adults

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Maayan Agmon[1]
Basia Belza[2]
Huong Q Nguyen[2,3]
Rebecca G Logsdon[2]
Valerie E Kelly[4]

[1]The Cheryl Spencer Department of Nursing, Faculty of Social Welfare and Health Studies, University of Haifa, Israel; [2]School of Nursing, University of Washington, Seattle, WA, USA; [3]Department of Research and Evaluation, Kaiser Permanente, CA, USA; [4]School of Medicine, University of Washington, Seattle, WA, USA

Background: Injury due to falls is a major problem among older adults. Decrements in dual-task postural control performance (simultaneously performing two tasks, at least one of which requires postural control) have been associated with an increased risk of falling. Evidence-based interventions that can be used in clinical or community settings to improve dual-task postural control may help to reduce this risk.

Purpose: The aims of this systematic review are: 1) to identify clinical or community-based interventions that improved dual-task postural control among older adults; and 2) to identify the key elements of those interventions.

Data sources: Studies were obtained from a search conducted through October 2013 of the following electronic databases: PubMed, CINAHL, PsycINFO, and Web of Science.

Study selection: Randomized and nonrandomized controlled studies examining the effects of interventions aimed at improving dual-task postural control among community-dwelling older adults were selected.

Data extraction: All studies were evaluated based on methodological quality. Intervention characteristics including study purpose, study design, and sample size were identified, and effects of dual-task interventions on various postural control and cognitive outcomes were noted.

Data synthesis: Twenty-two studies fulfilled the selection criteria and were summarized in this review to identify characteristics of successful interventions.

Limitations: The ability to synthesize data was limited by the heterogeneity in participant characteristics, study designs, and outcome measures.

Conclusion: Dual-task postural control can be modified by specific training. There was little evidence that single-task training transferred to dual-task postural control performance. Further investigation of dual-task training using standardized outcome measurements is needed.

Keywords: physical therapy, balance, walking, motor learning, fall prevention

Introduction

In 2020, one out of five people in western countries will be 70 years of age or older.[1] Healthy aging is accompanied by changes in sensory and cognitive domains that may lead to balance and gait impairments.[2,3] Balance and gait impairments, in turn, contribute to recurrent falls, which are related to increased mortality and morbidity.[4] Thirty percent of adults over age 65, and 50% of those over age 85, are likely to have at least one fall.[5,6] Consequently, finding effective ways to decrease falls in the elderly may reduce disability and increase life expectancy.[7]

Although falls are multifactorial,[8] impaired postural control is one important factor contributing to falls. Postural control is defined as the ability to control the body's position in space for the purposes of stability and orientation,[9] and is critical

Correspondence: Maayan Agmon
University of Haifa, Abba Hushi 1,
Haifa, Israel
Tel +972 54 900 1609
Fax +972 4 828 8017
Email agmon.mn@gmail.com

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during standing balance and walking tasks. Much research has focused on the interplay between postural control and cognition,[10] using dual-task postural control paradigms to examine this relationship.[11] Dual-task performance refers to the ability to conduct two tasks simultaneously, with dual-task postural control referring to situations when at least one of the tasks involves postural control, such as walking while talking on the phone or while holding a tray. Evaluating dual-task performance is a complex process as it involves the evaluation of each task performed independently as well as in combination. One way of analyzing the performance is by calculating the dual-task cost, defined as the decline in dual-task compared to single-task performance of a task.[12–14]

Changes associated with aging may lead to deterioration with the performance of each individual task as well as with the dual-task combination. For example, the gait pattern is affected by age, with reduced stride length and gait speed as well as increased lateral sway and stride to stride variability among older adults.[15] Executive function is a set of cognitive skills required in order to plan, monitor, and conduct goal-directed complex actions,[16] and an important aspect of executive function that tends to deteriorate with aging is the ability to divide or switch attention between the different tasks.[17,18] This ability is critical for dual-task performance. In older adults, dual-task postural control deficits have been associated with declines in cognitive function[19,20] and increased risk for falls.[21–23]

Recent studies have demonstrated the potential for modification of dual-task performance among the elderly.[24,25] Specifically, the ability to divide attention between two tasks in order to conduct them simultaneously is modifiable following training.[26,27] An important aspect of effective motor learning is training specificity, which refers to training a specific task through repetitive exercises in order to achieve improvements in that task.[28] Training in dual-task performance is more complicated than training a discrete movement under single-task condition,[29] and the level of specificity required to improve dual-task performance is still unknown. Moreover, dual-task postural control performance is influenced by the types of tasks, their difficulty, and the outcome measured.[30,31]

There are a growing number of interventions aimed at improving dual-task postural control in healthy older adults. Wollesen and Voelcker-Rehage[24] performed a systemic review of the dual-task literature to examine the effects of specific versus general training and task combination on dual-task performance. They concluded that dual-task training is more effective than single-task for improving dual-task standing performance, whereas both dual-task and single-task training improved dual-task walking. The current review extends this effort by examining how the application of motor learning principles, such as training specificity, setting, dose, duration, and intensity, may impact the efficacy of dual-task interventions. A better understanding of the effective elements of previous training trials can inform future dual-task interventions designed to improve mobility and reduce fall risk in older adults. Thus, the aims of this systematic review are to: 1) examine the effectiveness of different interventions on dual-task postural control among healthy older adults; and 2) identify key elements of training protocols that effectively improve dual-task postural control in older adults.

Methods

Data sources and searches

A systematic search was performed of the following computerized electronic databases: PubMed (January 1966 through October 2013), CINAHL (January 1982 through October 2013), PsycINFO (January 1900 through October 2013), PEDro (January 1929 through October 2013), and Web of Science (January 1900 through October 2013). Search terms included combinations of the following key words: "dual-task"; "older adults" or "elderly"; "treatment" or "intervention" or "therapy" or "rehabilitation"; "gait" or "balance" or "postural control". References found by a manual search in identified articles were also reviewed and included as appropriate.

Inclusion criteria and study selection

To be included in this systematic review, a study had to meet the following criteria: 1) participants defined as healthy adults aged 60 years or older; 2) interventions were conducted in a community or clinical setting; 3) interventions required a minimum of 180 minutes of training over at least 3 total days; 4) dual-task postural control was measured as an outcome; and 5) the publication was written in English. Exclusion criteria included participants with a specific neurologic disorder, such as Parkinson's disease, Alzheimer's disease, dementia, or stroke.

Two reviewers (MA, VEK) screened the abstract search results and decided independently, based on inclusion and exclusion criteria, which studies to include. Results were compared and, when reviewer decisions differed, the full article was reviewed and evaluated to obtain agreement.

Data extraction and quality assessment

Reviewers, who were not blinded to the author or the journal, assessed the quality of each included study in terms of the grade of recommendation and the level of evidence provided using the scoring protocol developed by Portney and Watkins.[32] This scale includes ten levels of evidence divided into four levels of recommendations. The highest level of evidence is a meta-analysis and the lowest level is expert opinion.

Studies were summarized according to the following characteristics: methodological quality and level of evidence; study design; sample size; sample characteristics (age and sex); key characteristics of the training protocols (training specificity, content, setting, intensity); assessment time points; outcome measures (for postural control task and concurrent cognitive or motor task); and results. Data synthesis using a meta-analysis was not possible because of the variety of study designs, methodologies, and outcomes measured.

Results

The literature search yielded 162 publications that were screened, with 26 publications reviewed in full. Twenty-two publications met the inclusion criteria and were included in this review (Figure 1). Publications were excluded based on the following criteria: 1) not intervention trials (93 publications); 2) population was not appropriate (eg, included younger adults or older adults with a neurologic disorder; 43 publications); 3) did not measure dual-task performance as an outcome (3 publications); or 4) not written in English (1 publication).

Methodological quality and level of evidence

Twenty-two publications were included in this review, with two publications from the same intervention trial (Table 1).

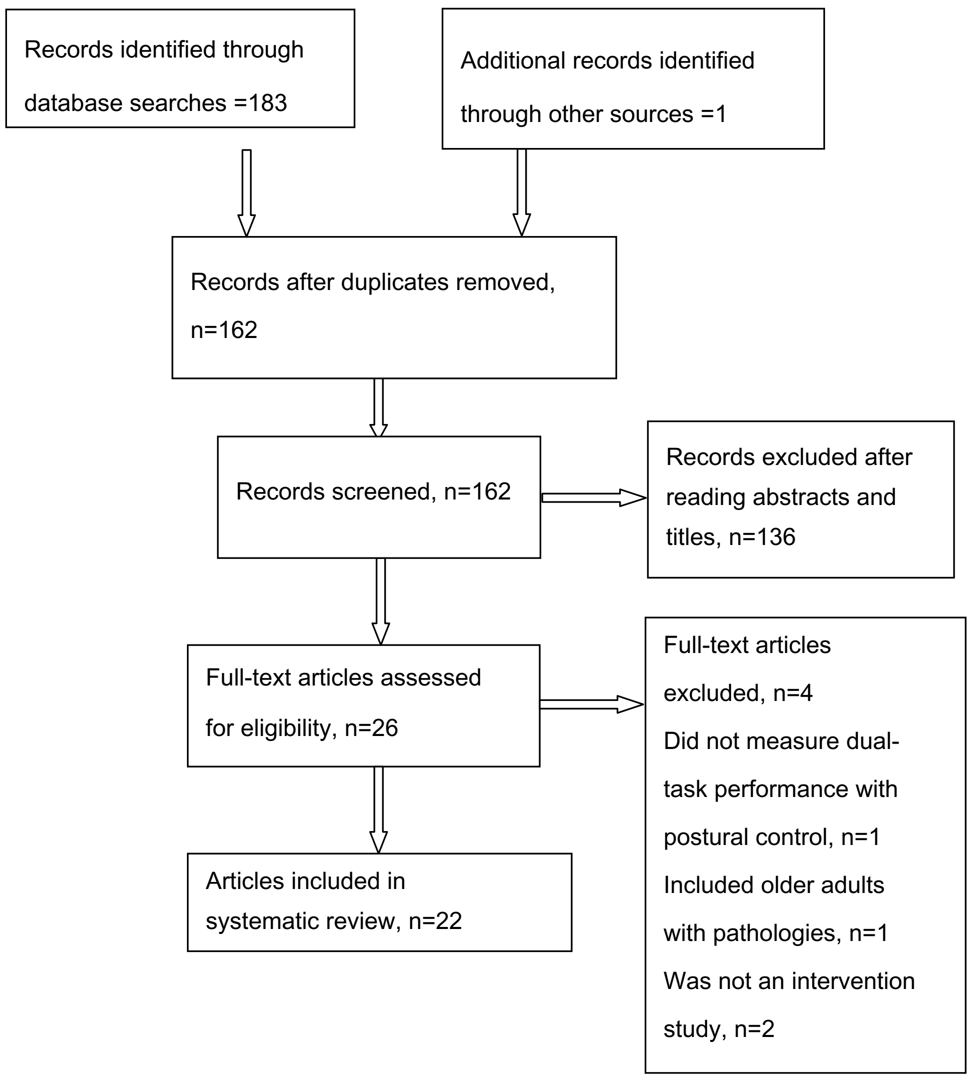

Figure 1 Flowchart of systematic literature search.

Table 1 Level of evidence (n=22)

Study	Level of evidence[32]	Design
Hiyamizu et al, 2012[33]	1b	RCT
Li et al, 2010[34]	1b	RCT
Melzer et al, 2013[35]	1b	RCT
Mozolic et al, 2011[36]	1b	RCT
Silsupadol et al, 2009A[26]	1b	RCT
Silsupadol et al, 2009B[27]	1b	RCT
Trombetti et al, 2011[37]	1b	RCT
Yamada et al, 2011[38]	1b	RCT
Donath et al, 2013[39]	2b	Preliminary RCT
Granacher et al, 2010[40]	2b	Preliminary RCT
Hall et al, 2009[41]	2b	Preliminary RCT
Pichierri et al, 2012[42]	2b	Preliminary RCT
Plummer-D'Amato et al, 2012[43]	2b	Preliminary RCT
Uemura et al, 2012[44]	2b	Preliminary RCT
Verghese et al, 2010[45]	2b	Preliminary RCT
You et al, 2009[46]	2b	Preliminary RCT
Agmon et al, 2012[47]	3	Uncontrolled pretest to posttest
Bisson et al, 2007[48]	3	Controlled pretest to posttest
Lajoie et al, 2004[49]	3	Controlled pretest to posttest
Melzer et al, 2009[50]	3	Case control
Toulotte et al, 2006[51]	3	Uncontrolled pretest to posttest
Silsupadol et al, 2006[52]	4	Case series

Notes: Levels of evidence: 1a, Systematic review of RCTs; 1b, Individual RCT with narrow confidence interval; 2a, Systematic review of cohort studies; 2b, Individual cohort study or low quality RCT; 3, Individual case-control or pretest-posttest study; 4, Case series or poor quality cohort and case-control studies; 5, Expert opinion.
Abbreviation: RCT, randomized clinical trial.

In terms of level of evidence, eight were considered to be level 1b (randomized clinical trials with narrow confidence intervals) and eight were considered to be 2b (low quality randomized clinical trials). These sixteen studies[26,27,33–46] had some methodological weaknesses; only one study included an intention-to-treat analysis,[37] and only four (two from the same trial) incorporated blinded assessors.[26,27,43,45] The other six were classified as level 3 (case-control or cohort)[47–51] and level 4 (case series).[52]

Sample characteristics

Studies were included in this review only if the participants were adults aged 60 years or older. Sample size ranged from three (one per group)[52] to 134.[37] The participants were predominantly female.

Sample characteristics varied across studies. Physical and cognitive functioning and the tests used to assess these characteristics varied. Most studies evaluated cognitive status using the mini-mental state examination with inclusion criteria typically based on scores of 24 out of 30 points.[26,27,41,46,48,50–52] Physical status was defined using performance-based tests, such as the Berg Balance Scale,[26,27,35] Tinetti Test,[37] Mini-Balance Evaluation Systems Test (Mini-BEST),[47] or the Dynamic Gait Index,[41] as well as self-reported walking abilities.[26,27,35,38,40,43–45,47–52] Fall history was specified only in four studies.[41,46,51,52] Living situation also varied across studies, though most studies involved participants who lived independently in the community (Table 2).

Training parameters of interventions

The training protocols incorporated in these studies varied with respect to training specificity (Table 3). Both single-task and dual-task approaches were used, and dual-task training incorporated various task combinations. Of the studies incorporating dual-task interventions,[26,27,33–38,43–46,52] eleven included postural control tasks as one of the tasks,[26,27,33,35–38,43,44,46,52] while two trained dual-task performance on two cognitive tasks.[34,45] The other nine studies[39–42,47–51] assessed the effects of single-task postural control training on dual-task postural control.

The studies that trained dual-task postural control used different combinations of tasks, with different levels of difficulty in both the cognitive and the postural tasks. For example, Trombetti et al[37] combined walking as the postural control task with a variety of motor (eg, handling musical instruments) and cognitive (eg, responding to changes in the beat of the music) tasks. Plummer-D'Amato et al[43] trained three different postural control domains (balance, gait, and agility) in combination with four different cognitive tasks (random number generation, word association, backward recitation of words or number sequences, and working memory).

Because dual-task performance can be modified by focusing attention on one task or another, the effect of dual-task training may be influenced by the instructions provided.[53] In this review, only the three studies conducted by Silsupadol et al[26,27,52] specifically examined the impact of different instructions on dual-task postural control. These studies compared the effect of two sets of instructions – variable priority instructions and fixed priority instructions – on dual-task performance following the same training. Variable priority instructions required the participant to focus on one task at a time (either the postural or the cognitive task) while the fixed priority instructions required the participant to focus on both the postural and cognitive tasks at all times.

Interventions were conducted either one-on-one[26,27,36,45,46,48,49,52] or in group settings (four to 24 people per group),[33–35,37–44,47,50,51] with varying levels of supervision.

Table 2 Studies included in the review (n=22)

Study	Sample size, n (sex, F/M)	Group (sample size, n): mean (SD) age, years	Sample characteristics			
			Physical	Cognitive	Living situation*	Fall history
Hiyamizu et al 2012[33]	36 (26/10)	Intervention (17): 72.0 (5.1) Control (19): 71.2 (4.4)	Not specified	Not specified	Community-dwelling	With or without risk of falls
Li et al, 2010[34]	20 (13/7)	Intervention (10): 74.6 (5.7) Control (10): 77.7 (7.1)	Healthy older adults without balance problem	Not specified	Community-dwelling	Without
Melzer et al, 2013[35]	66 (49/17)	Intervention (33): 78.3 (6.2) Control (33): 75.7 (6.6)	BBS >45 Independently ambulatory: cane acceptable, not walker	MMSE >24	Community-dwelling and in senior living facility	Not specified
Mozolic et al, 2011[36]	66 (35/31)	Intervention (33): 69.4 (3.2) Control (33): 69.4 (2.5)	Not specified	MMSE ≥5th percentile for participant age and education level	Community-dwelling	Not specified
Silsupadol et al, 2009A[26]	21 (17/4)	Single-task (7): 74.7 (7.8) DT fixed priority (8): 74.3 (6.1) DT variable priority (6): 76.0 (4.6)	Balance impairment defined as BBS ≤52 and/or self-selected gait speed ≤1.1 m/s	MMSE >24	Community-dwelling	With or without
Silsupadol et al, 2009B[27]	21 (17/4)	Single-task (7): 74.7 (7.8) DT fixed priority (8): 74.3 (6.1) DT variable priority (6): 76.0 (4.6)	Balance impairment defined as BBS ≤52 and/or self-selected gait speed ≤1.1 m/s	MMSE >24	Community-dwelling	With or without
Trombetti et al, 2011[37]	134 (129/5)	Early intervention (66): 75.0 (8.0) Delayed intervention (68): 76.0 (6.0)	Increased risk of falling defined by meeting at least one of the following criteria: 1) one or more self-reported falls after age of 65 years; 2) Tinetti Test >2 of 7; 3) one or two criteria of physical frailty	Not specified	Community-dwelling	At risk of fall
Yamada et al, 2011[38]	84 (65/19)	Intervention (41): 83.0 (6.7) Control (43): 82.9 (5.5)	Ability to walk independently	Rapid Dementia Screening Test ≤4	Community-dwelling	Not specified
Donath et al, 2013[39]	18 (9/9)	Intervention (9): 71.4 (4.7) Control (9): 73.1 (6.7)	At least moderately active	Not specified	Community-dwelling	Not specified
Granacher et al, 2010[40]	20 (14/6)	Intervention (11): 71.9 (4.8) Control (9): 74.9 (6.3)	Able to walk without an assistive device	Not specified	Independent, community-dwelling	Not specified
Hall et al, 2009[41]	15 (10/5)	Intervention (8) Control (7) All participants: 72.2 (7.7); mean and SD not stated by group	Dynamic Gait Index score ≤19	MMSE ≥24	Community-dwelling	With a history of falls or at risk of falls
Pichierri et al, 2012[42]	15 (9/6)	Intervention (9): 83.6 (3.4) Control (6): 86.2 (4.8)	Able to stand upright for at least 5 minutes	MMSE >22	Care homes	Not specified
Plummer-D'Amato et al, 2012[43]	17 (16/1)	Dual-Task (10): 76.6 (5.6) Single-Task (7): 76.6 (6.0)	Able to walk independently at least 0.5 m/s without an assistive device	Able to follow three steps command	Community-dwelling	Without
Uemura et al, 2012[44]	15 (12/3)	Intervention (8): 82.4 (5.9) Control (7): 82.5 (6.8)	Able to walk independently or with cane, no regular exercise in the previous 12 months	Not specified	Community-dwelling	Not specified
Verghese et al, 2010[45]	24 (15/9)	Intervention (12): 77.4 (7.0) Control (12): 79.9 (7.5)	Sedentary with gait velocity <1.0 m/s	MMSE >25	Community-dwelling	Not specified

(*Continued*)

Table 2 (*Continued*)

Study	Sample size, n (sex, F/M)	Group (sample size, n): mean (SD) age, years	Sample characteristics: Physical	Cognitive	Living situation*	Fall history
You et al, 2009[46]	13 (11/2)	Intervention (8) Control (5) All participants: 68.3 (6.5); mean and SD not stated by group	Independently ambulatory	MMSE ≥24	Independent, community-dwelling	At least one fall in the past year
Agmon et al, 2011[47]	30 (27/3)	Intervention (30): 74.5 (7.9)	Able to walk 10 meters independently	Not specified	Community-dwelling	Not specified
Bisson et al, 2007[48]	24 (14/10)	Virtual reality (12): 74.4 (3.7) Bio feedback (12): 74.4 (4.9)	Able to walk without an assistive device	MMSE ≥20	Community-dwelling	Without
Lajoie et al, 2004[49]	24 (20/4)	Intervention (12): 70.3 Control (12): 71.4 SD not stated by group	Able to stand and walk without an aid	Not specified	Community-dwelling and residential care facilities	Not specified
Melzer et al, 2009[50]	48 (Not specified)	Reporting exercise (24): 8.1 (6.19) Reporting inactive (24): 78.9 (5.1)	Able to walk with no aids	MMSE >24	Independent, in retirement homes	Not specified
Toulotte et al, 2006[51]	16 (16/0)	With history of falls (8): 71.1 (5.0) Without history of falls (8): 68.4 (4.5)	Able to walk without an assistive device	MMSE ≥24	Not specified	Half with a history of fall within 2 years, half without
Silsupadol et al, 2006[52]	3 (2/1)	Single-task (1): 82 Dual-task fixed priority (1): 90 Dual-task variable priority (1): 93	Able to walk 9 meters without the assistance of another person	MMSE ≥24	Independent	With

Notes: *The papers defined the living situation of study's participants differently. Here we used their definition.
Abbreviations: BBS, Berg Balance Scale; F, female; M, male; MMSE, mini-mental state exam; m/s, meters per second; SD, standard deviation.

There is no indication that one approach was more effective than the other.

Outcome measures

Balance and walking under both single-task and dual-task conditions was assessed using a variety of measures (Table 4). Therefore, there was no common set of standardized measures that could be used to compare changes in dual-task postural control across the studies (Table 2). Measures of single-task balance and walking included the Berg Balance Scale, the Dynamic Gait Index, the Timed Up and Go test, postural sway, and various gait parameters (speed, gait stability, center of mass or center of pressure, and variability) assessed during both simple and complex walking tasks. In addition, a number of studies incorporated measures of balance confidence or self-efficacy (Activities-specific Balance Confidence Scale, Falls Efficacy Scale) or function (Late Life Function and Disability Index) to examine the effects of training protocols on balance self-efficacy and functioning in daily life.

Measures of dual-task balance and walking included postural sway and gait parameters (speed, stability, variability). For dual-task balance and walking, performance on a variety of concurrent cognitive and motor tasks was also assessed. Examples of motor tasks included separating two linked rings or throwing and catching a ball. Examples of cognitive tasks included arithmetic tasks (eg, serial-3 subtractions), working memory tasks (eg, n-back test), or choice reaction time tasks (eg, auditory Stroop test). Dual-task performance was also evaluated using the dual-task cost calculation. In the studies that trained dual-task postural control, some assessed the efficacy of the intervention using trained task combinations[40] while others measured at least one novel task.[26,27,52]

Dual-task performance changes

From the 22 publications included in this review, 18 demonstrated improvement in some aspect of dual-task performance[26,27,33–40,42,44–49,51,52] whereas four did not.[41,43,50,54] Of those showing improvement, three studies[26,27,52] demonstrated improvement for both the postural control task and the concurrent cognitive or motor task. Seven studies demonstrated improvements in the dual-task cost for either postural control tasks or cognitive tasks, but not both.[37,40,46–49,51] The other eight did not measure dual-task cost and demonstrated improvement on only one aspect of the tasks combination.[33–36,38,39,42,44]

Table 3 Study characteristics (n=22)

Study	Protocol			Setting	Content (by group)
	Time (minutes)	Frequency	Duration		
Hiyamizu et al, 2012[33]	60	Two times weekly	12 weeks	Group setting	1) Intervention: calculations, visual searches, and verbal fluency tasks were performed simultaneously during the balance training 2) Control: strength, balance, and walking training
Li et al, 2010[34]	60	Five sessions at least 2 days apart	Approximately 5 weeks	Group setting (four to six people)	1) Intervention: computerized cognitive dual-task training: visual discrimination tasks 2) Control: no intervention
Melzer et al, 2013[35]	60	Two times weekly	24 weeks	Group setting	1) Intervention: balance exercise in five different levels including perturbation and dual-task exercise 2) Control: no intervention
Mozolic et al, 2011[36]	60	One time weekly	8 weeks	Individual training	1) Intervention: cognitive training focused on visual and auditory selective attention 2) Control: education lectures
Silsupadol et al, 2009A[26]	45	Three times weekly	4 weeks	One on one	1) Single-task balance training 2) Dual-task balance training with fixed priority instructions 3) Dual-task balance training with variable priority instructions
Silsupadol et al, 2009B[27]	45	Three times weekly	4 weeks	One on one	1) Single task balance training 2) Dual-task balance training with fixed priority instructions 3) Dual-task balance training with variable priority instructions
Trombetti et al, 2011[37]	60	One time weekly	25 weeks	Group setting	1) Multitask exercises based on Jaques-Dalcroze music education (eg, walking in time to music, responding to changes in music, walk and turn, exaggerated upper body movements)
Yamada et al, 2011[38]	20	Two times weekly	24 weeks	Group setting	1) Intervention: DVD seated based exercise, 15 minutes regular exercise, and 5 minutes dual-task verbal fluency while sitting and stepping 2) Control: no intervention
Donath et al, 2013[39]	60	Two times weekly	6 weeks	Group setting	1) Intervention: specific progressive fall training includes martial arts and different falls on different mats 2) Control: three educational lessons on fall prevention knowledge
Granacher et al, 2010[40]	60	Three times weekly	6 weeks	Group setting	1) Balance training (standing on unstable surfaces, single leg stance with increased flexion, catching and throwing a ball)
Hall et al, 2009[41]	90 Tai Chi 60 control	Two times weekly	12 weeks	Group setting	1) Intervention: Tai Chi 2) Control: health-related topics
Pichierri et al, 2012[42]	60	Two times weekly	12 weeks	Group setting	1) Progressive resistance training, progressive postural balance training, progressive dance video gaming
Plummer-D'Amato et al, 2012[43]	45	One time weekly	4 weeks	Group setting	1) Intervention: balance, gait, and agility. The balance and gait activity combined with simultaneously cognitive tasks (number generation, word association, backward recitation, and working memory) 2) Control: balance, gait, and agility

(*Continued*)

Table 3 (*Continued*)

Study	Protocol			Setting	Content (by group)
	Time (minutes)	Frequency	Duration		
Uemura et al, 2012[44]	35	One time weekly	24 weeks	Group setting for 30 minutes plus 5 minutes dual-task training	The intervention and control received 30 minutes of regular exercises. At the end of each session, each group received 5 minutes of different dual-task exercises: 1) Intervention: dual-task switch exercises 2) Control: steady state gait under dual-task
Verghese et al, 2010[45]	24	Three times weekly at least 1 day apart	8 weeks	Individual training	1) Intervention: computerized cognitive training: auditory and cross modality tasks aimed at training attention and executive function 2) Control: received information about the importance of physical activity
You et al, 2009[46]	30	Five times weekly	18 total sessions over 6 weeks	One on one	1) Walking with cognitive task (memorizing and computing tasks) 2) Walking while listening to music
Agmon et al, 2012[47]	60	Three times weekly	6 weeks	Group setting	1) Enhance Fitness training
Bisson et al, 2007[48]	30	Two times weekly	10 weeks	One on one	1) Virtual reality ("juggling" a virtual ball) 2) Visual biofeedback (COP position)
Lajoie et al, 2004[49]	60	Two times weekly	8 week	One on one	1) Computerized feedback and postural training
Melzer et al, 2009[50]	60	Three times weekly	3 years	Group setting	1) General training (Tai Chi, Feldenkreis, walking)
Toulotte et al, 2006[51]	60	Two times weekly	3 months	Group setting	1) Exercise program: strengthening, flexibility, static balance, dynamic balance
Silsupadol et al, 2006[52]	45	Three times weekly	4 weeks	One on one	1) Single task balance training 2) Dual-task balance training with fixed priority instructions 3) Dual-task balance training with variable priority instructions

Abbreviation: COP, center of pressure.

Table 4 Study outcomes (n=22)

Study	Assessment points	Dual-task performance measures	Results	Dual-task improvement
Hiyamizu et al, 2012[33]	1) Pretest 2) Posttest	1) Sway length of COG while performing Stroop test 2) The rate of Stroop task (accurate number/total numbers × 100) while maintaining standing position on a force plate	1) Nonsignificant improvement 2) Significant improvement in the intervention group	Yes, cognitive under dual-task
Li et al, 2010[34]	1) Pretest 2) Posttest	Each physical outcome was tested concurrently with n-back working memory task: 1) Single support standing balance with eyes open and closed (four trials each) and involved standing on the dominant leg for 10 seconds per trial 2) Double-support standing balance under three conditions: stable platform, visual surround sway, and platform sway 3) Sit to stand test 4) Gait speed	1) Significant improvement 2) Significant improvement 3) Nonsignificant improvement 4) Nonsignificant improvement	Yes, motor under dual-task
Melzer et al, 2013[35]	1) Pretest 2) Posttest	Voluntary step execution test under dual-task	Significant improvement	Yes, motor
Mozolic et al, 2011[36]	1) Pretest 2) Posttest	Walking while reciting words, measured number of recited words	Number of words recited significantly improved Dual-task cost did not improve	Yes, cognitive
Silsupadol et al, 2009A[26]	1) Pretest 2) Posttest	1) Narrow-base walking with serial-3 subtractions (trained dual-task condition): a) Walking: COM-AJC b) Serial-3 subtractions: response rate and number of errors 2) Obstacle crossing with auditory Stroop task (novel dual-task condition): a) Walking: COM-AJC b) Auditory Stroop task: verbal reaction time	1) a) Improved for all groups with greatest improvement for those trained with variable priority instructions b) Response rate improved only in the VP group; number of errors did not differ between groups 2) a) Did not improve for any group b) Did not improve for any group	Yes, both cognitive and walking tasks (for the trained task only) under dual-task
Silsupadol et al, 2009B[27]	1) Pretest 2) After 2 weeks 3) Posttest 4) 12 weeks after the intervention	Gait speed (while responding to addition/subtraction questions)	Improved for the trained dual-task groups (variable priority and fixed priority) but not for the control group (single-task)	Yes, motor under dual-task
Trombetti et al, 2011[37]	1) Pretest 2) Posttest 3) 12 months	Walking in self-selected, slow and fast speeds while counting backward by one from 50: 1) Gait speed: gait velocity, stride length, cadence 2) Dynamic balance: double support %, step width 3) Gait variability: stride time variability, stride length variability	1) Stride length improved in the intervention group after 6 months 2) No significant changes 3) Decrease in stride length variability after 6 months, maintained at 12 months	Yes, motor under dual-task

(*Continued*)

Table 4 (*Continued*)

Study	Assessment points	Dual-task performance measures	Results	Dual-task improvement
Yamada et al, 2011[38]	1) Pretest 2) Posttest	Gait speed while walking 10 meters carrying a ball on a tray. Dual-task cost calculated for both tasks	Walking time under manual task improved Dual-task cost improved for walking task	Yes, motor
Donath et al, 2013[39]	1) Pretest 2) Posttest	1) AP and ML (COP) under motor dual-task 2) Gait variability with motor dual-task	Improvement only for the intervention group in both dual-tasks measure	Yes, motor
Granacher et al, 2010[40]	1) Pretest 2) Posttest	1) Gait velocity under dual and triple tasks 2) Cognitive performance while walking 3) Motor performance while walking (contact ring time)	1) Nonsignificant improvement 2) Nonsignificant improvement 3) Significant improvement in the intervention group but not in the control group	Yes, motor under dual-task
Hall et al, 2009[41]	1) Pretest 2) Posttest	Dual-task cost for postural and cognitive measures	Nonsignificant improvement	No
Pichierri et al, 2012[42]	1) Pretest 2) Posttest	Voluntary step execution test under dual-task condition	Significant improvement of initiation time of forward and backward steps execution	Yes, motor
Plummer-D'Amato et al, 2012[43]	1) Pretest 2) Posttest	6 minutes obstacle negotiation under single and dual-task (dual-task cost calculated for each task)	Nonsignificant improvement	No improvement
Uemura et al, 2012[44]	1) Pretest 2) Posttest	1) Gait initiation under dual-task 2) Steady state gait (10 meters) under dual-task	1) Improvement only for the intervention group 2) Improvement for both groups but more effective for the intervention group	Yes, motor under dual-task
Verghese et al, 2010[45]	1) Pretest 2) Posttest	Gait velocity while talking: reciting the alternate alphabet	Significant improvement	Yes, motor under dual-task
You et al, 2009[46]	1) Pretest 2) Posttest	1) Gait velocity under dual-task 2) AP and ML (COP) 3) Memory performance data	1) Nonsignificant improvement in the intervention group, but significant improvement in the control group 2) Nonsignificant improvement in AP and ML COP 3) Significant improvement in the intervention group but not in the control group	Yes, cognitive under dual-task
Agmon et al, 2012[47]	1) Pretest 2) Posttest	1) Timed Up and Go cognitive and 1 minute walk with verbal fluency a) Gait speed and walking under two tests b) Dual-task cost for walking c) Dual-task cost cognitive	a) Significant improvement for both tests b) Nonsignificant improvement for both tests c) Significant improvement for the Timed Up and Go and decline for 1 minute walk with verbal fluency	No
Bisson et al, 2007[48]	1) Pretest 2) Posttest 3) 1 month after intervention	1) Reaction time under dual-task condition 2) Postural sway under dual-task conditions	1) Significant improvement in both groups at posttest and 1 month follow-up 2) No training effect	Yes, cognitive under dual-task
Lajoie et al, 2004[49]	1) Pretest 2) Posttest 3) 2 weeks after intervention	1) Reaction time under dual-task condition 2) Postural sway under dual-task condition	1) Significant improvement in the intervention group at posttest and 2 week follow-up compared to pretest, but not in the control group 2) Nonsignificant improvement	Yes, cognitive under dual-task
Melzer et al, 2009[50]	1) Single posttest measurement	Voluntary step execution test under dual-task	Only the preparation phase of dual-task step execution was faster in the exercise group compared to the control group	No improvement

Toulotte et al, 2006[51]	1) 3 months before training (T0) 2) 2 days before training (T1) 3) 2 days after training (T2) 4) 3 months after training (T3)	1) Timed Up and Go while holding glass full of water: a) Walking speed	a) T0 to T1: no change for either group; T1 to T2: increased for both groups; T2 to T3: decreased for both groups	Yes, motor under dual-task
		b) Stride time	b) T0 to T1: no change for either group; T1 to T2: decreased for both groups; T2 to T3: increased for both groups	
		c) Single support time	c) T0 to T1: increased for both groups; T1 to T2: decreased for both groups; T2 to T3: increased for both groups	
		d) Cadence	d) T0 to T1: no change for either group; T1 to T2: increased for both groups; T2 to T3: decreased for nonfallers	
		e) Stride length	e) T0 to T1: no change for either group; T1 to T2: increased for both groups; T2 to T3: decreased for both groups	
Silsupadol et al, 2006[52]	1) Pretest 2) After 2 weeks 3) 12 weeks after intervention	Timed Up and Go cognitive	Significant improvement in all three participants. Greater improvement in the dual-task training participants	Yes, both cognitive and motor under dual-task

Abbreviations: AP and ML COP, anterior–posterior and medial–lateral center of pressure; COM-AJC, center of mass-ankle joint center inclination; VP, variable priority; COG, center of gravity.

Retention

Most studies measured outcomes immediately before and after the intervention, with only five studies examining retention of improvements at different time points after the end of the intervention.[27,37,48,49,52] Two studies demonstrated improvements in dual-task cognitive performance that were retained at 2 weeks[48,49] and 1 month postintervention.[48] Three studies showed some degree of retention in dual-task motor performance for periods ranging from 2 months to 6 months postintervention.[27,37,52]

Transfer

Eight studies assessed whether training benefits transferred to untrained tasks.[26,34,36,38,41,45,47,52] Three studies[26,38,52] examined the effect of dual-task postural control training on novel or untrained dual-task postural control tasks. Silsupadol et al[26,52] showed no transfer effect, while Yamada et al[38] demostrated a transfer effect. Two studies[41,47] examined whether single training benefits transferred to dual-task postural control, and showed negative results. Three studies[34,36,45] measured the effect of cognitive dual-task training on dual-task performance involving a postural control task and showed transfer to some aspects of dual-task performance (see Table 3).

Discussion

This investigation of the literature on dual-task training demonstrates the potential to increase postural control, thereby improving balance and walking ability in older adults. Furthermore, this systematic review builds on previous research by examining specific training parameters that may impact the efficacy of dual-task interventions.

Training specificity

Overall, evidence supports the effectiveness of specific training to improve dual-task postural control among healthy older adults. Training specificity is a key element of motor learning.[55] However, the definition of training specificity is not obvious within the dual-task paradigm since the intended outcome of interventions could include either an improved ability to divide attention between both tasks or to preferentially improve performance of the postural control task. The majority of studies that incorporated direct dual-task training demonstrated improvement on some aspect of dual-task postural control, with only one exception.[43] Interventions that trained single-task postural control demonstrated improvement on measures of single-task balance and walking but not on dual-task postural control, with one exception.[39] Thus, training dual-task performance specifically, rather than just single-task performance, appears to be a crucial element for interventions that aim to improve dual-task performance. This notion was supported by several studies with the highest level of evidence included in the review.[26,27,33–35,37,38]

Training content

The interventions that directly trained dual-task postural control employed a variety of task combinations with different levels of difficulty in the postural control and concurrent cognitive or motor tasks. Some task combinations required mainly mathematical skills for the cognitive task[26,27,52] whereas others required verbal and memory skills[41] or auditory skills.[37] For the postural control task, most studies used walking[26,27,40,46] or standing[35,42,49,50] whereas a few used more complicated tasks such as walking within a narrow path[26] or obstacle crossing.[43] Two studies used two motor tasks such as standing while catching and throwing a ball,[40] and walking while holding a tray.[39] The only study[43] that specifically trained dual-task performance but did not show specific dual-task performance improvements identified a lack of specificity of outcome measures relative to the trained tasks as well as insufficient training hours (4 hours total) as potential explanations for this finding. While the current research suggests that a variety of trained task combinations can improve dual-task performance, future studies should compare how different combinations of tasks impact the efficacy of training.

The impact of specific task combinations on dual-task performance has been widely discussed. Recent reviews[30,31] have examined the effect of different concurrent tasks on walking. Al-Yahya et al[31] reported that tasks involving internal interference (ie, requiring top-down processing and driven by factors that are internal to the participant[56] such as verbal fluency or mathematical tasks) have a greater influence on gait parameters than external interference or bottom-up tasks (eg, reaction time tasks). Chu et al[30] assessed the predictive value of different task combinations for predicting falls. Their meta-analysis indicated that the combination of a mental tracking task and walking is a good predictor for falls among the elderly. Among the studies in this review, only seven studies used this combination in either the training protocol[26,27,38,43,46,52] or outcome measure.[26,27,36,43,45,47,52] Since fall prevention is an important goal of dual-task interventions, future studies should consider incorporating mental tracking tasks in combination with walking in their protocol and/or outcome measurement.

Instructions and feedback

Variable priority instructions, in which participants were asked to shift their attention back and forth between tasks, appeared to be more effective for improving performance than fixed priority instructions, in which participants focused on either the postural control task or the concurrent cognitive or motor task.[26,27,52] However, this direct comparison of instructions was limited to only three studies, one of which was a case series with only three participants. Thus, determining the most effective instructions for dual-task training merits further investigation.[57]

Moreover, the effect of feedback[55] was not explored by any of these investigations, and different forms of feedback may influence motor learning differently among older adults.[58] Feedback focused on knowledge of results (for example, how many meters someone walks) is more effective than feedback focused on knowledge of performance (the nature of the movement). Tailored feedback during dual-task training could target each task separately or both tasks simultaneously. Nevertheless, even the effect of feedback during motor learning of a single task among the elderly was not clear.[59] Several issues should be addressed regarding the optimal use of feedback during dual-task training, including: 1) whether feedback is more effective than the absence of feedback during dual-task training among the elderly; and 2) whether feedback on one task at a time is more effective that feedback on both tasks simultaneously during dual-task training.

Training parameters reflecting motor learning

Several parameters of dual-task training may promote motor learning. The setting of training may influence efficacy. The interventions reviewed here were conducted in two distinct settings: group training and one-on-one training. Similar rates of success were found in both settings; ten out of 13 interventions conducted in a group setting[26,27,33,35,37–40,42,44,51] demonstrated improvement in some aspects of dual-task, while six out of ten conducted in one-on-one settings[34,36,45,46,48,49] demonstrated successful outcomes. The dose of intervention is an important factor influencing motor learning. The total training hours varied from 5 hours[48] to 25 hours[37] and were spread from 1 week to over 25 weeks.[37] For studies that showed improvement in dual-task performance, the length of training sessions ranged from 20 minutes[38] to 60 minutes.[33–37,39–42,47,49–51] Among studies with the highest methodological quality, Silsupadol et al[26,27] conducted the most intensive training, with three sessions per week for 1 month, but Trombetti et al[37] conducted the longest intervention, with one session per week for 25 weeks. Both of these studies demonstrated some degree of improvement in dual-task walking, with some retention of benefits, providing support for a high training dose. Among the studies in this review, the variability in training dose, including session intensity, session frequency, and training duration, makes determining the optimal dose of dual-task training challenging.

Outcome measures

There is no gold standard for dual-task assessment, and the studies in this review used various dual-task combinations for their outcome measures. For example, the postural control tasks included obstacle crossing,[26,43] over ground walking,[34,40,44,45] or standing on a force plate.[48] Within similar tasks, a variety of different parameters were assessed. For example, the parameters used to assess performance during walking included frontal plane inclination angle,[26] gait variability,[37,39] or gait speed.[27,40,45]

Recent research emphasizes the importance of calculating dual-task cost to understand the underlying mechanism of improvement in dual-task performance[7] and as a sensitive means of assessing fall risk.[13,14] Dual-task cost is often calculated using the formula:

$$(\text{dual-task} - \text{single task})/\text{single task} \times 100 \qquad [1]$$

and expressed as percentage. Using dual-task cost elucidates the mechanisms underlying the improvement by demonstrating whether improvements are achieved in both tasks or whether improvements in one task occur at the expense of the other task.[7] Among the studies included in the current review, only three[41,43,47] calculated the dual-task cost; therefore, comparisons between studies are limited. Agmon et al[47] showed that there was a change in the trade-off between cognitive and motor costs between pre- and postintervention. This finding demonstrates changes in prioritization between tasks, but not actual improvement with training.

Retention

Retention of motor skills for up to 1 year has been demonstrated in humans in a laboratory setting.[60] Among the studies demonstrating the highest level of evidence, Trombetti et al[37] demonstrated the longest retention (12 months), although this was only a partial retention of improvements. Future studies should investigate which practice conditions promote optimal retention as well as the effects of interventions that incorporate ongoing or maintenance programs.

Transfer

Some studies included in this review demonstrated evidence of transfer from trained tasks to novel tasks, but this finding was not uniform. Several studies demonstrated that dual-task postural control training transferred to improvements in novel dual-task combinations.[26,38,52] Interestingly, three studies that trained cognitive dual-task performance demonstrated improvements on dual-task postural control.[34,36,45] Participants in these studies were trained, while sitting, on tasks that required switching and dividing attention, and the impact on dual-task walking[36,45] and standing[34] was assessed. These studies illuminate the potential to improve dual-task postural control by training two cognitive tasks; a protocol that emphasizes the ability to divide or rapidly shift attention. However, these findings were not consistent and may depend on the level of difficulty of the trained tasks compared to the measured task.[43]

Future directions

This review highlights several questions that merit further exploration. First, although the existing research provides support for the ability to improve dual-task performance, particularly following response to specific dual-task training, it is not clear what effects these improvements have on function in daily life or fall risk. Outcome measures could be expanded to include functional measurements of dual-task performance relevant to daily life, such as putting on a shirt while standing or walking while talking on the phone. In order to understand the influence of dual-task interventions on falls prevention, future studies should incorporate prospective falls assessments over longer-term follow-up periods.

Second, there is a need to further examine the effect of different motor learning parameters, and the interaction between them, on dual-task acquisition, retention, and transfer. These might include the influence of instructions or different modes of feedback, the specificity of training, and the effect of dose on the response to training. In addition, further exploration is needed to determine the efficacy of training within subgroups of older adults, such as those with and without a history of falls or with different cognitive abilities.

Third, Li et al[61] emphasized the importance of adopting an ecological perspective when training and measuring dual-task performance. Thus, finding new ways to address dual-task performance in valid ecological environments needs to be explored. Recently, Mirelman et al[62] suggested a treadmill with a virtual reality protocol aimed at fall reduction. Such protocols should be tested first on subjects in clinical settings, followed by testing in home-based users. Home-based virtual reality training has the potential to reach larger populations in a complex and safe environment.[63]

Finally, in order to strengthen the evidence base for improving dual-task postural control, future studies should include larger, more representative samples and use a standard set of outcome measures to allow cross-study comparison. Outcome measures should include walking speed and stride-to-stride variability,[7] standard cognitive tasks (such as those that require mental tracking[30] or internal interference processing),[31] and calculation of dual-task cost for both tasks.[64]

Limitations

Sixteen randomized clinical trials[26,27,33–46] evaluated the effectiveness of training on dual-task performance on a total of 516 subjects with heterogeneous measures that precluded quantitative synthesis or meta-analysis. Furthermore, the quality of evidence in the present review was mixed, with a risk of bias because some studies did not use randomization. The sample was predominately female, limiting the ability to investigate sex differences in intervention efficacy.

Studies incorporated different intervention protocols and various outcome measures to assess the effectiveness of the interventions. This variability made it difficult to identify specific recommendations about the optimal content or duration of dual-task interventions. The lack of long-term follow-up limits the ability to determine whether the benefits of these interventions were retained, as well as the ability to understand the impact of dual-task postural control training on fall risk.

Conclusion

A synthesis of research examining the effect of different interventions on dual-task postural control suggests that interventions training for balance under single-task conditions can improve balance under single-task conditions, but this improvement does not transfer to dual-task performance.[41,47,50] Instead, dual-task training appears to be necessary to improve dual-task performance. While variability amongst studies makes it difficult to identify optimal parameters of interventions, it appears that effective interventions can be conducted in either group or one-on-one settings, with a variety of task combinations incorporated into the intervention. The shortest training schedule of 20 minutes twice a week for 24 weeks[38] as well as only five sessions of 1 hour each[34] demonstrated improvement in some aspects of dual-task performance.

Future investigations of interventions to improve dual-task postural control should include focused dual-task training and address tasks that have the highest correlation with fall risk. Moreover, long term follow-up with regard to fall occurrence and daily function should be incorporated in order to better understand whether improved dual-task postural control impacts these areas. Future research should also focus on motor learning elements that may extend the retention of dual-task training benefits in order to determine the most effective protocols. Finally, in order to achieve comparability between interventions, an agreed-upon set of outcome measures should be defined and dual-task cost calculation should be included.

Disclosure

The authors report no conflicts of interest in this work.

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