Archives of Gerontology and Geriatrics 121 (2024) 105368

Contents lists available at ScienceDirect

Archives of Gerontology and Geriatrics

journal homepage: www.elsevier.com/locate/archger

Review

Effect of dual-task training on balance in older adults: A systematic review and meta-analysis

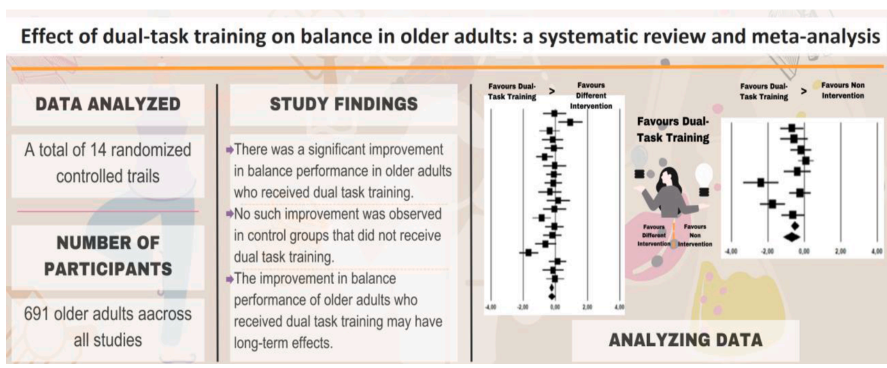
Seda Ercan Yildiz [a,*], Oznur Fidan [b], Cagrı Gulsen [b], Ertugrul Colak [c], Gulsum Aydan Genc [d]

[a] *Department of Audiology, Eskisehir Osmangazi University, Buyukdere Neighborhood, Meşelik Campus, Eskisehir 26040, Turkey*
[b] *Department of Physical Therapy and Rehabilitation, Eskisehir Osmangazi University, Eskisehir, Turkey*
[c] *Department of Biostatistics, Eskisehir Osmangazi University, Eskisehir, Turkey*
[d] *Department of Audiology (Retired), Hacettepe University, Ankara, Turkey*

HIGHLIGHTS

- Dual task training (DTT) improves balance in older adults.
- DTT enhances balance in older adults compared to different interventions.
- DTT provides notable benefit in older adults compared to no intervention.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Balance
Balance training
Dual-task
Dual-task training
Older adults

ABSTRACT

Purpose: Our review aims to analyze the effect of dual-task training (DTT) on balance in healthy older adults.
Methods: PubMed, EbscoHost, Web of Science (WOS), Scopus, Cochrane Library, MEDLINE, EBSCO Open Dissertations, ULAKBIM (TR Index) and YOK (Council of Higher Education Thesis Center) databases and the gray literature were searched. The quality of the studies was assessed with the Cochrane Risk of Bias tool and statistical analysis of the data was performed with Comprehensive Meta-Analysis (CMA) software. A funnel plot and Egger's test were used to detect publication bias. Fourteen studies with 691 participants were included.
Results: According to the results of our study, DTT was found to have a significant benefit on balance in older adults than the non-intervention group (standardized mean difference (SMD): -0.691: -1.153, -0.229, 95 % confidence interval (CI)). Furthermore, DTT was superior to different intervention groups in improving balance in older adults (SMD: -0.229: -0.441, -0.016, 95 % CI).
Conclusion: The findings of this review suggest that DTT may be an effective intervention to improve balance in healthy older adults.

* Corresponding author.
E-mail address: sercan@ogu.edu.tr (S. Ercan Yildiz).

https://doi.org/10.1016/j.archger.2024.105368
Received 3 November 2023; Received in revised form 26 January 2024; Accepted 7 February 2024
Available online 9 February 2024

1. Introduction

The process of getting older is linked to a reduction in both physical and cognitive abilities that can impact one's independence and overall well-being (Anton et al., 2015; Gallou-Guyot et al., 2020; Pereira Oliva et al., 2020; Wollesen et al., 2020). The locomotor system alters as we age, and cognitive working efficiency declines (Wollesen et al., 2020). Impaired motor and/or cognitive function is frequently brought on by the aging process, which also causes limited resources, decreased productivity, and increased interaction between tasks (Wollesen et al., 2016). Performing daily tasks often requires the ability to simultaneously complete both physical and mental activities. In addition, multitasking with reduced motor/cognitive performance is associated with gait variability, poorer executive function and higher risk of falls in older adults (Agmon et al., 2014; Nieborowska et al., 2018). Therefore, it is important for older people to have sufficient cognitive and physical resources to maintain their independence and to be able to use them effectively. The constant exposure to various types of multitasking activities in daily life, such as shopping, paying for items while in line, or moving while talking on the phone, underlines the importance of this issue.

Various research studies investigate the correlation between aging and an extensive range of mental and physical disorders (Pereira Oliva et al., 2020). In older adults, the decline in motor function is a significant issue that increases the likelihood of falling. The general deterioration of balance and motor performance due to a sedentary lifestyle leads to a higher risk of falling (Norouzi et al., 2019). Falls are an important cause of mortality and morbidity in the older individuals and motor function is of great importance as it is modifiable among fall risks (Guirguis-Blake et al., 2018). Therefore, it is crucial to identify factors that may lead to falls, such as balance and gait abnormalities and medication side effects, and determine appropriate interventions within the scope of fall prevention strategies (Guirguis-Blake et al., 2018).

Dual-task (DT) refers to the skill of performing two or more cognitive and physical tasks together (MacPherson, 2018). Many daily activities, like carrying objects while walking, require DT performance. Structural changes in the brain related to attention and executive function in older adults' prefrontal areas affect DT performance adversely (Braver & Barch, 2002; West, 1996). In DT conditions, older adults have reduced motor skills, such as balance and walking, compared to younger adults, associated with decline in cognitive function with aging (Boisgontier et al., 2013; Brustio et al., 2017). Therefore, exercises that improve DT performance must be included in older adults' balance training. Dual-task training (DTT) is a type of training in which cognitive and motor stimuli are applied at the same time (Agmon et al., 2014; Pantoja-Cardoso et al., 2023). Previous studies have used a variety of strength training exercises, including resistance, balance, endurance, and flexibility, to help reduce the risk of falling (Pham, 2023). One study shows that both DTT and functional training (FT) do not increase the cognitive flexibility in older women, but still, DTT and FT interventions may benefit older people (Pantoja-Cardoso et al., 2023). In recent years, interest in DTT has been increasing. Studies have emphasized that cognitive-motor dual-task training improves dual-task motor performance (e.g., carrying a ball on a tray) more than single-task training (Agmon et al., 2014; Brustio et al., 2018; Gregory et al., 2016; Silsupadol et al., 2006). DTT has also been shown to improve on dual tasks, which in turn reduces the risk of falls (Pham, 2023). Although there are some reviews investigating the clinical effect of DTT on balance in people with different neurological disorders like Parkinson's, stroke, and multiple sclerosis, we did not find any reviews focusing on the effect of DTT on healthy older adults (De Freitas et al., 2018; Morelli & Morelli, 2021; Zhang et al., 2022). There is still insufficient evidence regarding the benefits of DTT on balance, DT gait and cognitive function in older adults, as also mentioned by researchers such as He et al. (2018) (He et al., 2018). Therefore, although DTT has the potential to improve multiple functions in patients, the potential clinical importance of the treatment effect is still unclear (Plummer & Iyigün, 2018). The aim of this systematic review is to expand our understanding of the benefits of DTT on balance in typically healthy older adults.

2. Methods

2.1. Protocol and registration

This study was registered in the International Register of Prospective Systematic Reviews (PROSPERO) with protocol number CRD42023387279. In addition, Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) were taken as a guide while conducting our study (Supplemental Table S1) (Moher et al., 2009).

2.2. Eligibility criteria

The eligible studies for our study were identified using the PICOS (population, intervention, comparison, outcome, study design) approach.

Population: Typical healthy older individuals aged 65 years and older.

Older adults who are functionally independent, can walk independently or with assistive devices were considered typical healthy. Older adults with the following conditions were excluded: major cognitive issues (e.g. Alzheimer's disease, dementia), major orthopedic problems (e.g. lower limb fractures), neurological disease (e.g. stroke, Parkinson disease) or any other comorbidities that restrict mobility.

Intervention: DTT (motor or cognitive tasks)

Studies evaluating the efficacy of various forms of DTT without a control group were excluded. Comparison: Any other type of intervention without DT (e.g. conventional physiotherapy, balance training, gait training etc.), placebo or non-intervention.

Outcomes: Balance-related measures (laboratory measures such as sensory organization test, center of pressure, clinical measures (Berg Balance Scale, Activities-Specific Balance confidence and Timed Up and Go Test etc.).

Study Design: Randomized controlled trials (RCT) or pilot RCT in English and Turkish.

2.3. Search strategy

On February 8–10, 2023, a literature search was performed using PubMed, EbscoHost, Web of Science (WOS), Scopus, Cochrane Library, MEDLINE, EBSCO Open Dissertations, ULAKBIM (TR Index) and YOK (Council of Higher Education Thesis Center) databases. Additionally, a grey literature (conference papers, theses and dissertations, committee reports etc.) search was performed and the reference lists of the included articles were manually checked to ensure that no relevant studies were missed. The literature search was performed using the following keywords with the combination of Boolean operators 'AND' and 'OR': older adults, elderly people, elderly individuals, healthy elderly, old, dual task training, dual-task training, multi task training, balance, static balance, dynamic balance, functional balance, postural balance (Supplemental Table S2).

2.4. Study selection

Two researchers (OF and SEY) independently screened the databases for identifying trials for possible inclusion criteria of the PICOS strategy in this review. The studies obtained after the search were recorded in EndNote™ 20 (Clarivate Analytics, USA) and the selection of eligible studies was made through this application. First, duplicate articles were eliminated. After screening the titles and abstracts, the full texts of the studies that met the PICOS criteria were scanned in the final stage. If the full text was not available or relevant data were missing, the author of the study was contacted via email. Any disagreements were discussed and resolved by two authors. If needed, consensus was achieved by a third researcher (CG).

2.5. Data extraction

Data extraction was performed by two independent authors (SEY and OF) using the data extraction form. The general characteristics of the study (authors, year, country where the study was conducted, study design), participants' characteristics (age, sex, number of the individuals of each group), detailed information of DTT (type of training, frequency, dosage, treatment duration) and comparison group (different intervention: type, frequency, dosage and treatment duration or placebo/ non-intervention), outcome measures and main results were recorded. Disagreements were resolved through discussion between the authors.

2.6. Assessment of risk of bias

Two independent review authors (SEY and OF) independently evaluated the risk of bias of the included articles using Cochrane's risk of bias tool (Higgins et al., 2011). Cochrane Risk of Bias checklist consisted of six items: (1) selection bias, (2) performance bias, (3) detection bias, (4) attrition bias (5), reporting bias and (6) other biases. In cases where there was disagreement, consensus was achieved through discussion between the authors or by consulting a third author (CG).

2.7. Data analysis

The mean and standard deviation (SD) values of the outcome measures (pre-intervention and post-intervention) of the included studies and the sample sizes (N) of groups were recorded for meta-analysis using the Microsoft® Excel® program (Microsoft 2016, Santa Rosa, California). Power analysis was calculated using the "dmetar" package in the R program.

Statistical analysis of the data was carried out with Comprehensive Meta-Analysis software Version 3 (CMA V3, Biostat Inc, NJ, USA). The standardized mean difference (SMD) of the data was calculated and reported in 95 % confidence intervals (CI). SMD and pre-post correlations were calculated using the formulas in sections "Standardized Mean Differences d and g" on page 25, "Computing d and g from studies that use pre-post scores or matched groups" on page 28 and "Converting from d to r" on page 48 in the book of titled "Introduction to Meta-Analysis" (Borenstein et al., 2021). I^2 statistical test was used to determine heterogeneity. If I^2 is greater than 50 %, heterogeneity is considered high and a random-effects model is used to analyze the pooled results (Higgins & Thompson, 2002). Egger tests (Egger et al., 1997) and Funnel plots were used to assess publication bias. In case of significant heterogeneity, the study with the largest effect size was excluded from the meta-analysis and sensitivity analyses were performed. Meta-regression analysis was employed to investigate potential moderating influence of participant sex distribution (male/female).

3. Results

3.1. Study selection

As a result of the database search at the beginning of the study, 596 studies were reached. When the repeated studies were eliminated, the title analysis of the remaining 378 studies was carried out. 321 studies were eliminated from the title. As a result of the summary review of the remaining 66 studies, 27 articles whose full texts were reached were examined according to the inclusion criteria and 13 studies were eliminated during the full-text screening phase (Supplemental Table S3). 11 studies were eliminated because they did not comply with the PICOS strategy of our study. One study was excluded because its data were the same as the data in the previous study conducted by the same author. Data of one study could not be accessed although requested from the author (for detail see Supplemental Table S3). A total of 14 articles (Balci et al., 2022; Brustio et al., 2018; Hiyamizu et al., 2012; Javadpour et al., 2022; Li et al., 2010; Norouzi et al., 2019; Park, 2022; Plummer-D'Amato et al., 2012; Poyraz, 2017; Rajalaxmi et al., 2022; Rezola-Pardo et al., 2019; Sedaghati et al., 2022; Yamada, Aoyama, Hikita et al., 2011, 2011) meeting the inclusion criteria were included in the study (Fig. 1). Of these articles, three were pilot randomized controlled trials (Li et al., 2010; Norouzi et al., 2019; Plummer-D'Amato et al., 2012) and 11 were randomized controlled trials (Balci et al., 2022; Brustio et al., 2018; Hiyamizu et al., 2012; Javadpour et al., 2022; Park, 2022; Poyraz, 2017; Rajalaxmi et al., 2022; Rezola-Pardo et al., 2019; Sedaghati et al., 2022; Yamada, Aoyama, Hikita et al., 2011, 2011). Since three groups were compared in some studies, data were entered separately for each group in the analyses (Balci et al., 2022; Brustio et al., 2018; Javadpour et al., 2022).

3.2. Characteristics of included studies

The included trials were published between 2010 and 2022 and their characteristics are shown in Table 1. The countries where the included studies were carried out are Italy, Iran, Canada, Korea, USA, Turkey, India, Spain, Japan. The data of 691 participants were analyzed in the studies. Participants have an average of age, with a minimum of 67.65 $\pm$2.42 and a maximum of 85.3 $\pm$ 7.1.

Studies ranged from 4 sessions to 60 sessions of DTT. In addition, the duration of the training sessions varies between 20 min and 60 min. One study did not provide information about the dosage of the intervention (Li et al., 2010). Among the included studies, 1 study used computer-assisted double-task training(Li et al., 2010).

The most commonly used balance assessment method in the included studies was timed-up and go (TUG) (Balci et al., 2022; Brustio et al., 2018; Hiyamizu et al., 2012; Javadpour et al., 2022; Park, 2022; Plummer-D'Amato et al., 2012; Rezola-Pardo et al., 2019; Sedaghati et al., 2022; Yamada, Aoyama, Hikita et al., 2011, 2011) and BBS (Balci et al., 2022; Norouzi et al., 2019; Poyraz, 2017; Rajalaxmi et al., 2022). Other tests used in the study are functional reach test (FRT), one leg standing test (OLST), four square step test (FSST), fullerton advanced balance (FAB), activities-specific balance confidence (ABC), sensory organization test (SOT), timed-up and go-dual (TUG-D) (Table 1). The TUG was originally developed to assess the functional mobility of older adults (Podsiadlo & Richardson, 1991). However, it is widely used as a measure of balance in clinical settings (Sibley et al., 2011). It is also reported that the TUG is a valid tool for screening balance deficits and evaluating fall risk of older adults (Nightingale et al., 2019). Moreover, it is suggested that the TUG is significantly correlated with BBS and can be used comparable to the BBS (Bennie et al., 2003). Also, studies used the TUG were included in most of the other meta-analyses investigating the effect of DTT on balance in other conditions (Martino Cinnera et al., 2021; Shu et al., 2022). Therefore, we included studies that used TUG as a measure of balance. Regarding follow-up evaluation, only 1 study performed 1 follow-up after 12 weeks.

3.3. Quality assessment of included studies

The risk of bias assessment is given in Figs. 2 and 3. The colors green, yellow and red are associated with low risk, uncertain risk and high risk of bias, respectively. As a method of randomization, four studies (Hiyamizu et al., 2012; Park, 2022; Plummer-D'Amato et al., 2012; Yamada, Aoyama, Hikita et al., 2011) used a computer-generated random number sequence method, two studies (Javadpour et al., 2022; Yamada, Aoyama, Tanaka et al., 2011) used a blocked randomization method and one study (Sedaghati et al., 2022) used a lottery method (selection bias). Eight studies did not describe the allocation concealment method (Balci et al., 2022; Brustio et al., 2018; Li et al., 2010; Norouzi et al., 2019; Park, 2022; Poyraz, 2017; Rajalaxmi et al., 2022; Sedaghati et al., 2022) (selection bias). One study (Rajalaxmi

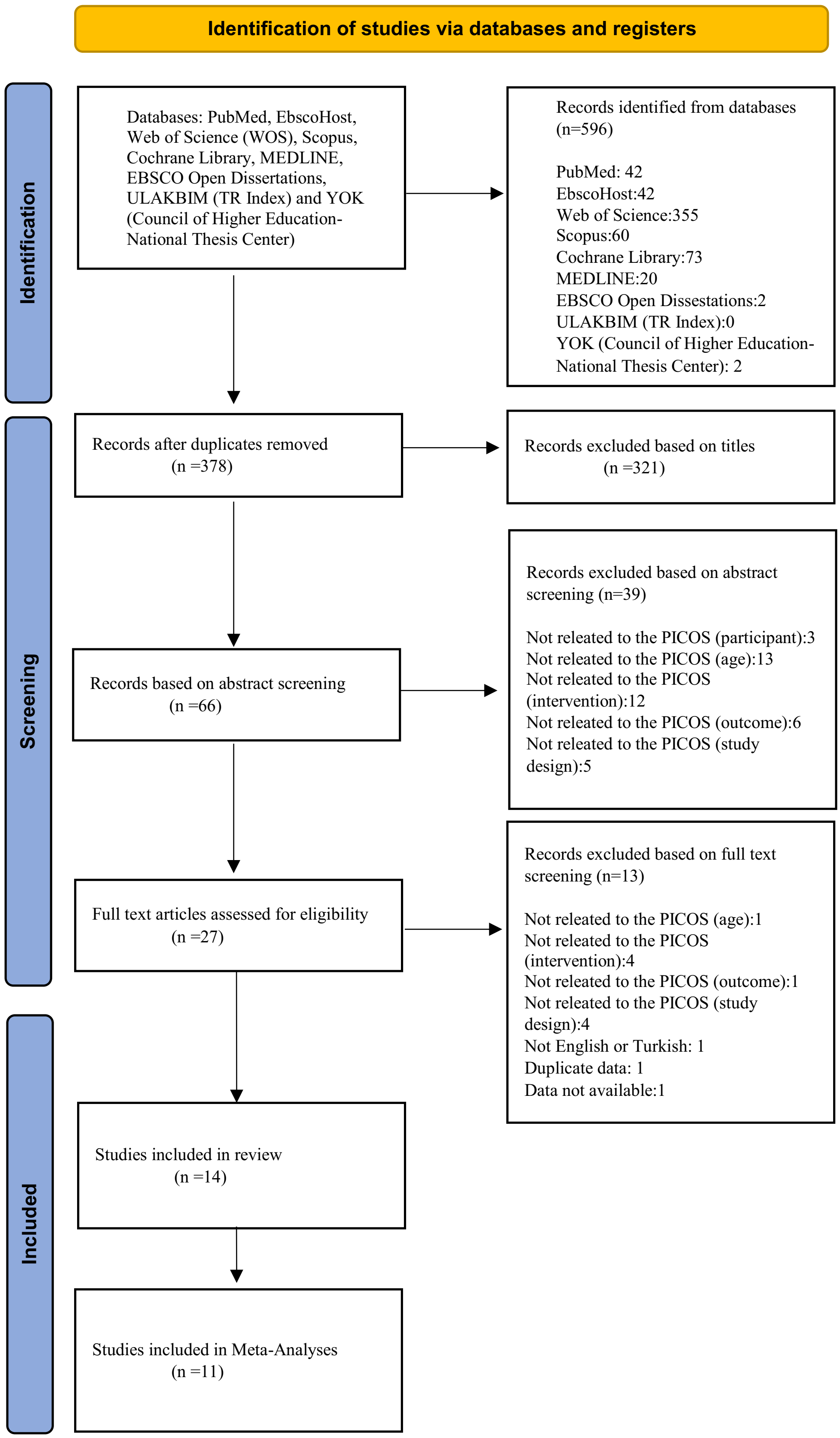


Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

Table 1
The characteristics of the included studies.

Author, Year, Country	Population (N)	Female/ Male	Mean age	Intervention group	Control group	Duration of the intervention	Frequency of the intervention	Follow-up time	Measurement tools	Results
Balci et al., 2022, Turkey	IG:15 $CG_{(ST)}$: 15 $CG_{(PCT)}$:15	IG: 13/2 $CG_{(ST)}$: 13/2 $CG_{(PCT)}$:13/2	IG: 71.8 ± 4.1 $CG_{(ST)}$: 69 ±5.1 $CG_{(PCT)}$:71.3 ± 4.2	Cognitive activities with BT+GT	$CG_{(ST)}$:BT+GT $CG_{(PCT)}$: 30 min CGT,5 min rest, 30 min BT+GT	4 weeks	Three times a week, 30 min	–	TUG, BBS	Sd in TUG between groups in favor of successive PCT. Sd in FES between groups in favor of ST. Sd in BBS between groups in favor of PCT.
Brustio et al., 2018, Italy	IG:19 $CG_{(ST)}$: 19 $CG_{(NI)}$:22	IG:14/5 $CG_{(ST)}$: 14/5 $CG_{(NI)}$:14/8	IG:74.3 ± 2.6 $CG_{(ST)}$: 75.2 ± 3.4 $CG_{(NI)}$:74±3.2	Motor task with BT+GT	$CG_{(ST)}$:BT+GT $CG_{(NI)}$:No intervention	16 weeks	Twice a week, 60 min	–	TUG, FSST	Sd in TUG and FSST between groups in favour of the DTT.
Hiyamizu et al., 2012, Japan	IG:17 CG: 19	IG:10/7 CG: 16/3	IG:72.9 ± 5.1 CG:71.2 ± 4.4	Cognitive activities with BT+SE	BT+SE	3 months	Twice a week, one hour	–	TUG, FRT	No Sd in TUG and FRT between groups.
Javadpour et al., 2022, Iran	IG:23 $CG_{(ST)}$: 23 $CG_{(NI)}$:23	IG:18/5 $CG_{(ST)}$: 16/7 $CG_{(NI)}$:15/8	IG:68.86 ±3.48 $CG_{(ST)}$: 67.65 ±2.42 $CG_{(NI)}$:69.34 ±3.77	Cognitive activities with BT	$CG_{(ST)}$:BT $CG_{(NI)}$:No intervention	6 weeks	Three sessions per week, 40–60 min	–	TUG, FAB, ABC	Sd in TUG, FAB and ABC between groups in favour of the DTT and ST. No sd between DTT and ST.
Li et al., 2010, Canada	IG:10 CG: 10	IG:7/3 CG: 6/4	IG:74.6 ± 5.7 CG: 77.7 ± 7.1	Computerized DTT using the first visual task pair	No intervention	5 sessions	At least two days apart	–	SOT	Sd in alignment between groups in favor of DTT.
Norouzi et al., 2019, Iran	IG_{mMtt}:20 IG_{mCtt}:20 CG:20	-/-	IG_{mMtt}:68.31 ±4.12 IG_{mCtt}:68.51 ±3.65 CG:68.10 ±3.71	IG_{mMtt}: Resistance training plus mMtt IG_{mCtt}: Resistance training plus mCtt	No intervention	4 weeks	Three group sessions per week, 60–80 min	12 weeks	BBS	Sd in BBS between groups in favour of the mCtt.
Park, J.H, 2022, Korea	IG:29 CG: 29	-/-	IG:71.76 ±3.14 CG: 70.97 ±2.78	Cognitive activities with BT	BT	6 weeks	Twice a week, 45 min	–	TUG, OLST	Sd in TUG and OLST in favour of the DTT.
Plummer-D'Amato, 2012, USA	IG:10 CG: 7	IG:9/1 CG:7/0	IG:76.6 ± 5.6 CG:76.7 ± 6	Cognitive activities with BT+GT	BT+GT	4 weeks	Once a week, 45 min	–	TUG, ABC	No sd in TUG and ABC between groups.
Poyraz,T, 2017, Turkey	IG: 14 CG:15	IG:8/16 CG:9/6	IG:75.93 ±5.81 CG:75±5,12	Cognitive activities with BT	BT	6 weeks	Twice a week, 30–40 min	–	TUG, BBS	No sd in TUG and BBS between groups.
Rajalaxmi et al., 2022, India	IG:25 CG:25	-/-	IG:75.93 ±5.81 CG:75±5.12	Cognitive activities with BT	PNF pattern exercise	12 weeks	5 sessions per week	–	BBS	Sd in BBS between groups in favor of the DTT.
Rezolo-Pardo et al., 2019, Spain	IG:42 CG:43	IG:29/13 CG:28/15	IG:84.9 ± 6.7 CG:85.3 ± 7.1	Cognitive activities with PE	BT+SE	3 months	Two sessions per week, 1 h	–	TUG	No sd in TUG between groups.
Sedaghati et al., 2022, Iran	IG:14 CG:14	IG:7/7 CG:7/7	IG:70.42±2.7 CG:71.07 ±2.26	Executive functions with BT and SE	Conventional care	8 weeks	Three times a week, 1 h	–	TUG (with and without DT), BBS	Sd in TUG, TUG-D and BBS between groups in favor of the DTT.
Yamada et al. 2011a, Japan	IG:24 CG:26	IG:18/6 CG:20/6	IG:80.3 ± 5.4 CG:81.2 ± 7.6	Seated stepping exercises (muscle strength and BT) plus DT stepping exercises	Seated stepping exercises (muscle strength and BT)	24 weeks	Once a week, 50 min	–	TUG, FRT, OLST	No sd TUG, FRT, OLST between groups.
Yamada et al. 2011b, Japan	IG:41 CG:43	IG:33/8 CG:32/11	IG:83±6.7 CG:82.9 ± 5.5	DVD-based seated DT stepping exercise: verbal fluency task while stepping	No exercise program	24 weeks	Twice a week, 20 min	–	TUG	No sd in TUG between groups.

Abbreviations: ABC, activities-specific balance confidence; BBS, berg balance scale; BT, balance training; CG, control group; DT, dual-task; DTT, dual-task training; FAB, fullerton advanced balance; FES, falls efficacy scale; FRT, functional reach test; FSST, four square step test; GT, gait training; IG, intervention group, mCtt, motor-cognitive dual-task training; min, minutes; mMtt, motor-motor dual-task training; OLST, one leg stance test; NI, no intervention; PCT, physical-cognitive training; PE, physical exercises; PNF, proprioceptive neuromuscular facilitation; Sd, significant difference; SE, strength exercises; SOT, sensory organization test; ST, single task; TUG, timed-up and go; TUG-D, timed-up and go-dual.

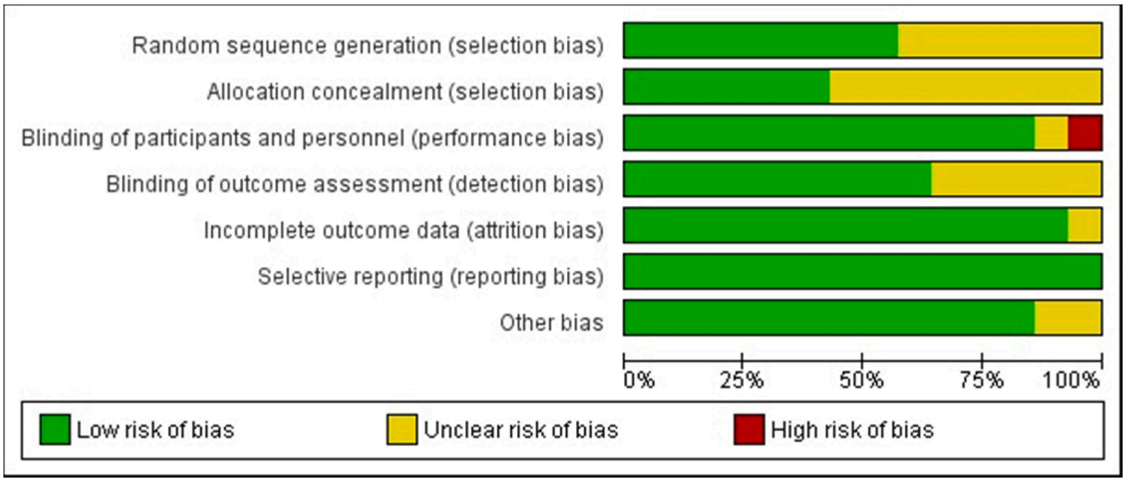


Fig. 2. Risk of bias graph of the included studies.

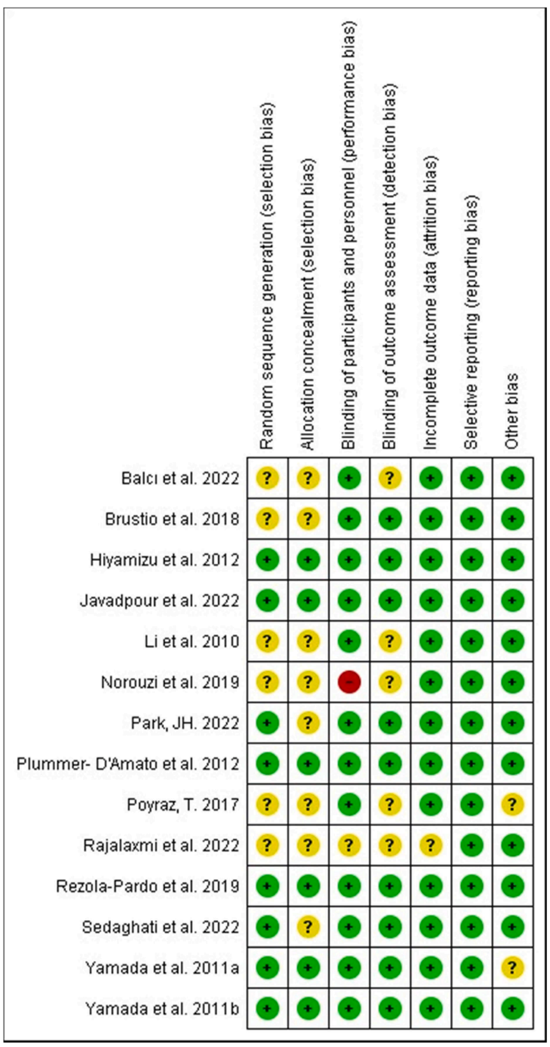


Fig. 3. Risk of bias summary: Methodological quality of each item for the each included study.

et al., 2022) had inadequate information on blinding of participants and personnel and in one study, it was stated that the fact that the participants were not blinded may affect the results of the study by affecting expectations and motivation (Norouzi et al., 2019) (performance bias).

In five studies (Balci et al., 2022; Li et al., 2010; Norouzi et al., 2019; Poyraz, 2017; Rajalaxmi et al., 2022) there was no blinding of outcome assessors or no information on blinding of evaluators; in other studies, assessors were unaware of intervention (detection bias). Only one study did not report adequately on missing outcome data (Rajalaxmi et al., 2022) (attrition bias). The risk of selective reporting was low in all studies (reporting bias). Furthermore, only two studies did not provide any information about funding source or conflict of interest (other biases) (Poyraz, 2017; Yamada, Aoyama, Tanaka et al., 2011). Overall, five studies met the criteria for 'low risk' bias in all bias domains according to the Cochrane Collaboration Risk of Bias tool (Hiyamizu et al., 2012; Javadpour et al., 2022; Plummer-D'Amato et al., 2012; Rezola-Pardo et al., 2019; Yamada, Aoyama, Hikita et al., 2011).

3.4. Meta-analysis report

3.4.1. Dual-task training versus different intervention

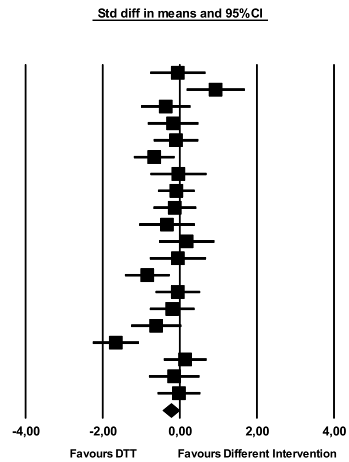
Ten studies comparing the effects of DTT and other interventions on balance were found, with nine of them being included in the analysis. One study included only 4 sessions of training and was excluded from the analysis because the dose of the intervention was insufficient and not well matched to other studies in the sample (Plummer-D'Amato et al., 2012). As a result of the power analysis of the studies used to compare the DTT group with the different intervention, the result was 94.12 % in the fixed-effect model, and 66.34 % in the random-effects model (moderate heterogeneity assumed). In these studies, the duration of DTT changed between 12 sessions and 60 sessions. In the included studies, the interventions compared with DTT were as follows: two studies balance and gait training, one study Proprioceptive Neuromuscular facilitation (PNF), three studies strength and balance, three studies balance training and one study balance, gait and cognitive exercises. No statistical difference was found between groups in five studies. A significant difference was found in favor of DT in three studies and in favor of different intervention in one study.

The result of our meta-analysis demonstrated a significant benefit of DTT on balance in older adults compared to different interventions (SMD: −0.229 [95 % CI −0.441, −0.016] $p = 0.035$, I^2 =57,68) (Fig. 4). The funnel plot showed no evidence of publication bias Supplemental Figure S1. According to Egger's test for a regression intercept, there was no evidence of publication bias ($p = 0.327$). Result of meta-regression analysis showed that participant sex distribution (male/female) did not affect the balance performance between the groups (β=−0,21; 95% CI −1,1103 to 0,68; $p = 0.637$; R^2=0.00).

3.4.2. Dual-task training versus non-intervention

Six studies that compared the effects of DTT and no intervention on

Model	Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
		Statistics for each study						
	Balci,2022,Comparison1 (TUG)	-0,051	0,365	0,133	-0,766	0,665	-0,139	0,890
	Balci,2022,Comparison2 (TUG)	0,931	0,384	0,148	0,177	1,684	2,421	0,015
	Brustio,2018,Comparison 1(TUG)	-0,363	0,327	0,107	-1,004	0,278	-1,109	0,267
	Hiyamizu, 2012 (TUG)	-0,174	0,334	0,112	-0,829	0,482	-0,519	0,604
	Javadpour,2022,Comparison 1 (TUG)	-0,098	0,295	0,087	-0,676	0,481	-0,331	0,741
	Park,2022(TUG)	-0,662	0,270	0,073	-1,190	-0,133	-2,453	0,014
	Poyraz,2017(TUG)	-0,035	0,372	0,138	-0,764	0,693	-0,095	0,925
	Rezolo-Pardo,2019 (TUG)	-0,088	0,243	0,059	-0,564	0,388	-0,362	0,717
	Yamada,2011a (TUG)	-0,128	0,283	0,080	-0,684	0,427	-0,453	0,651
	Balci,2022,Comparison1 (BBS)	-0,331	0,368	0,135	-1,052	0,389	-0,901	0,368
	Balci,2022,Comparison2 (BBS)	0,180	0,366	0,134	-0,537	0,897	0,492	0,622
	Poyraz, 2017(BBS)	-0,049	0,372	0,138	-0,777	0,680	-0,131	0,896
	Rajalaxmi,2022 (BBS)	-0,842	0,295	0,087	-1,420	-0,263	-2,852	0,004
	Javadpour,2022,Comparison 1 (ABC)	-0,052	0,295	0,087	-0,630	0,526	-0,175	0,861
	Javadpour,2022,Comparison 1 (FAB)	-0,196	0,296	0,087	-0,775	0,383	-0,663	0,507
	Brustio,2018,Comparison 1(FSST)	-0,611	0,332	0,110	-1,261	0,040	-1,840	0,066
	Park,2022(OLST)	-1,658	0,304	0,093	-2,254	-1,061	-5,446	0,000
	Yamada,2011a (OLST)	0,140	0,283	0,080	-0,415	0,696	0,494	0,621
	Hiyamizu, 2012 (FRT)	-0,144	0,334	0,112	-0,799	0,511	-0,430	0,667
	Yamada,2011a (FRT)	-0,022	0,283	0,080	-0,576	0,533	-0,077	0,939
Random		-0,229	0,108	0,012	-0,441	-0,016	-2,110	0,035



Meta Analysis

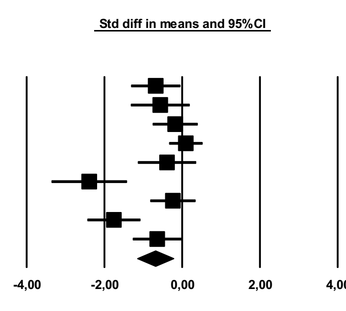
Model	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
Model		Effect size and 95% confidence interval					Test of null (2-Tail)		Heterogeneity				Tau-squared			
Fixed	20	-0,243	0,070	0,005	-0,380	-0,106	-3,480	0,001	44,896	19	0,001	57,680	0,134	0,076	0,006	0,366
Random effects	20	-0,229	0,108	0,012	-0,441	-0,016	-2,110	0,035								

Fig. 4. Forest plot showing the effect of dual-task training on balance when compared to different intervention.

balance were reviewed, four of which were analyzed. One study has been excluded from the analysis because of its limited number of training sessions and poor correlation with the other studies in the sample (Li et al., 2010). One study with a high risk of bias, caused by insufficient blinding, was excluded (Norouzi et al., 2019) As a result of the power analysis of the studies used in the comparison of the DTT group and non-intervention, the result was 99.89 % in the fixed-effect model and 99.92% in the random-effects model. In these studies, the duration of DTT varied between 18 sessions and 48 sessions. Although no statistical difference was observed in one study, a difference in favor of DT was found in three studies.

The results of the meta-analysis showed that DTT had a significant effect on balance in older adults compared to the non-intervention group (SMD: −0.691 [95 % CI −1.153, −0.229] $p = 0.003$, I^2=78.74) (Fig. 5). The funnel plot indicated a suggestion of publication bias (Supplemental Figure S2). Egger's regression intercept test indicated possible publication bias ($p = 0.012$). A sensitivity analysis was performed by excluding the one study (Yamada, Aoyama, Hikita et al., 2011) with the larger effect size. The results of this analysis showed that DTT still had a significant clinical impact on balance compared to the non-intervention group (SMD: −0.430 [95 % CI −0.692, −0.167] $p = 0.001$, I^2=0.000) (Fig. 6). The funnel plot shown in Supplemental Figure S3 and Egger's regression intercept test demonstrated no evidence of publication bias ($p = 0.385$). Result of meta-regression analysis showed that participant sex distribution (male/female) did not affect the balance between the groups (β=2,51; 95% CI −3,99 to 9,01; $p = 0.637$; R^2=0.00).

Model	Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
		Statistics for each study						
	Brustio,2018,Comparison 2(TUG)	-0,679	0,322	0,104	-1,311	-0,048	-2,110	0,035
	Sedaghati,2022 (TUG)	-0,562	0,385	0,149	-1,318	0,193	-1,459	0,145
	Javadpour,2022,Comparison 2 (TUG)	-0,179	0,295	0,087	-0,758	0,400	-0,606	0,544
	Yamada,2011b (TUG)	0,096	0,218	0,048	-0,332	0,524	0,438	0,662
	Sedaghati,2022 (TUG-D)	-0,388	0,382	0,146	-1,136	0,360	-1,017	0,309
	Sedaghati,2022 (BBS)	-2,390	0,495	0,245	-3,360	-1,420	-4,830	0,000
	Javadpour,2022,Comparison 2 (ABC)	-0,238	0,296	0,088	-0,818	0,342	-0,806	0,420
	Javadpour,2022,Comparison 2 (FAB)	-1,755	0,347	0,120	-2,435	-1,075	-5,057	0,000
	Brustio,2018,Comparison 2(FSST)	-0,639	0,321	0,103	-1,269	-0,010	-1,991	0,046
Random		-0,691	0,236	0,056	-1,153	-0,229	-2,932	0,003

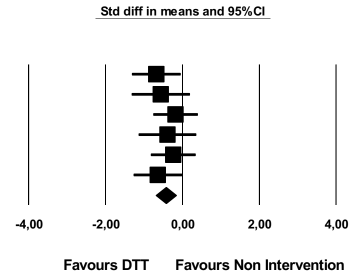


Meta Analysis

Model	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
Model		Effect size and 95% confidence interval					Test of null (2-Tail)		Heterogeneity				Tau-squared			
Fixed	9	-0,519	0,106	0,011	-0,727	-0,312	-4,904	0,000	37,636	8	0,000	78,744	0,384	0,256	0,065	0,620
Random effects	9	-0,691	0,236	0,056	-1,153	-0,229	-2,932	0,003								

Fig. 5. Forest plot showing the effect of dual-task training on balance when compared to non-intervention.

Model	Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Brustio,2018,Comparison 2(TUG)	-0,679	0,322	0,104	-1,311	-0,048	-2,110	0,035
	Sedaghati,2022 (TUG)	-0,562	0,385	0,149	-1,318	0,193	-1,459	0,145
	Javadpour,2022,Comparison 2 (TUG)	-0,179	0,295	0,087	-0,758	0,400	-0,606	0,544
	Sedaghati,2022 (TUG-D)	-0,388	0,382	0,146	-1,136	0,360	-1,017	0,309
	Javadpour,2022,Comparison 2 (ABC)	-0,238	0,296	0,088	-0,818	0,342	-0,806	0,420
	Brustio,2018,Comparison 2(FSST)	-0,639	0,321	0,103	-1,269	-0,010	-1,991	0,046
Fixed		-0,430	0,134	0,018	-0,692	-0,167	-3,210	0,001



Meta Analysis

Model	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
	Effect size and 95% confidence interval						Test of null (2-Tail)		Heterogeneity				Tau-squared			
Fixed	6	-0,430	0,134	0,018	-0,692	-0,167	-3,210	0,001	2,295	5	0,807	0,000	0,000	0,069	0,005	0,000
Random effects	6	-0,430	0,134	0,018	-0,692	-0,167	-3,210	0,001								

Fig. 6. Sensitivity analysis forest plots showing the effect of dual-task training on balance when compared to non-intervention.

4. Discussion

This systematic review and meta-analysis represents the first study to investigate the impact of DTT on balance in healthy older individuals. Four studies comparing the effects of DTT and no intervention on balance were included in the analysis. The outputs of this meta-analysis showed that DTT had a significant beneficial effect on balance in healthy older adults compared to the non-intervention control group. Nine studies were analysed that compared the effects of DTT and different interventions on balance. Based on the findings of the meta-analysis, DTT also demonstrated a significant positive effect on balance in healthy older adults compared to other interventions, including traditional physiotherapy, stretching, balance exercises, walking, and multi-component exercises.

Our findings demonstrate that DTT has a notable positive impact on balance in healthy older individuals when compared to those who did not receive any intervention. This is a predictable result, as all included studies used at least one task as a motor task. Performing concurrently two independent tasks with distinct goals is defined as DT. Therefore, performing two cognitive tasks simultaneously is also referred to as DT (McIsaac et al., 2015). However, this type of DT is rarely used in DT studies. This is consistent with our analysis, which found that only two studies used motor-motor DTT, while the rest utilized cognitive-motor training with motor tasks such as gait and balance exercises (Kelly et al., 2012). Physical exercise programs, particularly specialized programs such as gait or balance training, have been shown to have beneficial effects on balance performance in older adults, as supported by existing literature (De Labra et al., 2015). More specialized exercise programs, such as gait or balance training, also have positive effects on balance performance of older adults (Lesinski et al., 2015; Zhang, Low, Gwynn et al., 2019). Thus, our findings align with prior reports on the effects of DTT versus non-intervention.

Another potential factor that may explain why DTT has a greater positive impact on the balance of older adults than non-intervention is the role of cognitive functions. Studies that utilized cognitive-motor DTT had a cognitive task included, and thus had a cognitive training element. Cognitive functions, particularly executive functions, are associated with postural control in older adults (Liu-Ambrose et al., 2008). Executive functions are essential for screening and processing both internal and external stimuli, setting goals, resolving problems, and carrying out behaviors required to meet environmental demands (Voos et al., 2011). These components are also necessary for maintaining functional balance and mobility (Ble et al., 2005; Liu-Ambrose et al., 2008; Voos et al., 2011). Deficits in executive functions are linked to balance issues in older adults with a correspondingly increased risk of falls (Zhang, Low, Schwenk et al., 2019). Previous research has found that cognitive training has beneficial effects on the executive functions of older adults (Nguyen et al., 2019). Additionally, cognitive training has been shown to have positive effects on balance performance in older adults (Smith-Ray et al., 2015). Therefore, it can be concluded that the cognitive training components of DTT in the included studies alone contribute to the enhancement of balance.

We observed that DTT yielded significantly better results in enhancing balance in healthy older adults when compared to conventional physiotherapy, stretching, balance, walking, and multicomponent exercises. Although previous meta-analyses investigating the effects of DTT on balance in neurological diseases such as multiple sclerosis (Martino Cinnera et al., 2021), Parkinson's disease (Du et al., 2022; Li et al., 2020) and stroke (He et al., 2018; Zhang et al., 2022) have reported that DTT is more effective in enhancing balance than other interventions, to our knowledge, no meta-analyses have examined the effects of DTT on balance in healthy older adults.

Rehabilitation programs aimed at enhancing balance and mitigating the likelihood of falls are often recommended for older individuals. Most of these programs include balance training in single task conditions (Silsupadol et al., 2006). To increase the challenge in balance training, older adults are asked to perform balance tasks with reduced sensory input or unstable surface (American Physical Therapy, 2001). One alternative to increase the level of difficulty is to execute the balance task while simultaneously performing a secondary task, also known as a dual-task condition (Silsupadol et al., 2006). As can be seen, in general, DTT is already a method used to provide more challenging balance training compared to single-task training. Therefore, a more challenging training is likely to yield superior effects. Cognitive functions may again be a possible explanation for these superior effects in older adults. Earlier studies have demonstrated that in the process of natural aging, increased attentional resources are required for maintaining postural stability during balance-related tasks (Lajoie et al., 1996). However, attention capacity declines with aging, as do other cognitive functions such as executive functions (Persson et al., 2006). There is also evidence that cognitive functions are related with balance ability (Leandri et al., 2015). Hence, it is reasonable to anticipate that interventions that enhance cognitive functions will also result in enhancements in balance performance. It has been demonstrated that DTT enhances cognitive functions like attention and executive functions in older adults (Morita et al., 2018). As a result, the improvements in cognitive functions through DTT can be considered as one of the factors leading to the superior effects of DTT on balance ability in older adults compared to other interventions.

The duration of the training included in the meta-analysis sessions varies between 20 min and 60 min. Total training sessions also varies between 12 and 60 sessions. Therefore, due to this variability, we cannot provide indication about the recommended training duration for DTT. However, durations of each individual session of DTT and other training methods compared were similar in included studies. Therefore, it can be concluded that the effectiveness of DTT does not depend on the duration of treatment session.

The primary advantage of this systematic review is that, to the best of our knowledge, it is the initial meta-analysis and systematic review to investigate the impact of DTT on balance in older adults. Additionally, we followed the PRISMA guidelines for our systematic review. One strength of our study is the comprehensive review of the grey literature. Finally, we evaluated the risk of bias of the included studies more strictly using the Cochrane Risk of Bias Assessment Tool.

There were five limitations with this systematic review and meta-analysis. First, in the power analysis of the studies used to compare the DTT group with the different intervention, the result was low in the random effects model. Moderate heterogeneity was assumed as the reason for this. Some of the studies included in our analysis had small sample sizes, which could increase the risk of type-II errors. Second, we did not conduct a subgroup analysis on different types of dual-tasks, such as motor-motor and cognitive-motor tasks. Therefore, it remains unclear if there are differences in the effectiveness of different types of DT on balance in older adults. Third, except for one study, no follow-up was conducted in the included studies. Therefore, it is not possible to conclude that improvements in balance with DTT are sustained over time. Fourth, a considerable number of studies included in the research did not utilize sufficient randomization and allocation concealment methods or appropriate blinding techniques. There were multiple sources of bias among the studies included, leading to uncertainty in the interpretation of the results. Fifth, only studies conducted in English and Turkish were included, introducing potential bias due to the exclusion of studies in other languages.

5. Conclusion

Our meta-analysis demonstrates that DTT interventions are effective in improving balance among healthy older adults when compared to not receiving any intervention. This positive effect persists even when compared to other interventions such as conventional physiotherapy, stretching, balance, walking and multicomponent exercises. These findings may serve as a valuable resource for clinicians in integrating DTT into their rehabilitation protocols for older adults, with the aim of enhancing balance skills in a safe and efficient manner. Thus, the goal of functional independence and reduced risk of falling can be achieved.

Funding

The authors did not receive support from any organization for the submitted work.

CRediT authorship contribution statement

Seda Ercan Yildiz: Conceptualization, Investigation, Methodology, Writing – original draft. **Oznur Fidan:** Conceptualization, Investigation, Methodology, Writing – original draft. **Cagrı Gulsen:** Investigation, Writing – original draft. **Ertugrul Colak:** Formal analysis, Writing – original draft, Writing – review & editing, Supervision. **Gulsum Aydan Genc:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors have no conflicts. The authors have no relevant financial or non-financial interests to disclose.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.archger.2024.105368.

References

Agmon, M., Belza, B., Nguyen, H. Q., Logsdon, R. G., & Kelly, V. E. (2014). A systematic review of interventions conducted in clinical or community settings to improve dual-task postural control in older adults. *Clinical Interventions in Aging*, 477–492.

American Physical Therapy, A.. (2001). Guide to physical therapist practice. second edition. American Physical Therapy Association. *Physical Therapy, 81*(1), 9–746. https://www.ncbi.nlm.nih.gov/pubmed/11175682.

Anton, S. D., Woods, A. J., Ashizawa, T., Barb, D., Buford, T. W., Carter, C. S., et al. (2015). Successful aging: Advancing the science of physical independence in older adults. *Ageing Research Reviews, 24*(Pt B), 304–327. https://doi.org/10.1016/j.arr.2015.09.005

Balci, L. A., Sogukkanli, K., Burcu, S., & Hanoglu, L. (2022). Effects of single-task, dual-task and successive physical-cognitive training on fall risk and balance performance in older adults: A randomized trial. *Journal of Exercise Therapy and Rehabilitation, 9*(1), 1–11.

Bennie, S., Bruner, K., Dizon, A., Fritz, H., Goodman, B., & Peterson, S. (2003). Measurements of balance: Comparison of the "timed up and go" test and functional reach test with the berg balance scale. *Journal of Physical Therapy Science, 15*(2), 93–97.

Ble, A., Volpato, S., Zuliani, G., Guralnik, J. M., Bandinelli, S., Lauretani, F., et al. (2005). Executive function correlates with walking speed in older persons: The InCHIANTI study. *Journal of the American Geriatrics Society, 53*(3), 410–415.

Boisgontier, M. P., Beets, I. A., Duysens, J., Nieuwboer, A., Krampe, R. T., & Swinnen, S. P. (2013). Age-related differences in attentional cost associated with postural dual tasks: Increased recruitment of generic cognitive resources in older adults. *Neuroscience & Biobehavioral Reviews, 37*(8), 1824–1837.

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2021). *Introduction to meta-analysis*. John Wiley & Sons.

Braver, T. S., & Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neuroscience & Biobehavioral Reviews, 26*(7), 809–817.

Brustio, P. R., Magistro, D., Rabaglietti, E., & Liubicich, M. E. (2017). Age-related differences in dual task performance: A cross-sectional study on women. *Geriatrics & Gerontology International, 17*(2), 315–321.

Brustio, P. R., Rabaglietti, E., Formica, S., & Liubicich, M. E. (2018). Dual-task training in older adults: The effect of additional motor tasks on mobility performance. *Archives of Gerontology and Geriatrics, 75*, 119–124. https://doi.org/10.1016/j.archger.2017.12.003

De Freitas, T. B., Leite, P. H. W., & Doná, F. (2018). The effects of dual task gait and balance training in Parkinson's disease: A systematic review. *Physiotherapy Theory and Practice*.

De Labra, C., Guimaraes-Pinheiro, C., Maseda, A., Lorenzo, T., & Millán-Calenti, J. C. (2015). Effects of physical exercise interventions in frail older adults: A systematic review of randomized controlled trials. *BMC Geriatrics, 15*, 1–16.

Du, Y. H., Ma, J., Hu, J. Y., Zhu, L., Wang, L. Y., Yang, R. Y., et al. (2022). Effects of dual-task training on gait and motor ability in patients with Parkinson's disease: A systematic review and meta-analysis. *Clinical Rehabilitation*. , Article 2692155221146085. https://doi.org/10.1177/02692155221146085

Egger, M., Davey Smith, G., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *British Medical Journal, 315*(7109), 629–634. https://doi.org/10.1136/bmj.315.7109.629

Gallou-Guyot, M., Mandigout, S., Bherer, L., & Perrochon, A. (2020). Effects of exergames and cognitive-motor dual-task training on cognitive, physical and dual-task functions in cognitively healthy older adults: An overview. *Ageing Research Reviews, 63*, Article 101135. https://doi.org/10.1016/j.arr.2020.101135

Gregory, M. A., Gill, D. P., Zou, G., Liu-Ambrose, T., Shigematsu, R., Fitzgerald, C., et al. (2016). Group-based exercise combined with dual-task training improves gait but not vascular health in active older adults without dementia. *Archives of Gerontology and Geriatrics, 63*, 18–27.

Guirguis-Blake, J. M., Michael, Y. L., Perdue, L. A., Coppola, E. L., & Beil, T. L. (2018). Interventions to prevent falls in older adults: Updated evidence report and systematic review for the US preventive services task force. *The Journal of the American Medical Association, 319*(16), 1705–1716. https://doi.org/10.1001/jama.2017.21962

He, Y., Yang, L., Zhou, J., Yao, L., & Pang, M. Y. C. (2018). Dual-task training effects on motor and cognitive functional abilities in individuals with stroke: A systematic review. *Clinical Rehabilitation, 32*(7), 865–877. https://doi.org/10.1177/0269215518758482

Higgins, J. P., Altman, D. G., Gøtzsche, P. C., Jüni, P., Moher, D., Oxman, A. D., et al. (2011). The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *British Medical Journal, 343*.

Higgins, J. P., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine, 21*(11), 1539–1558. https://doi.org/10.1002/sim.1186

Hiyamizu, M., Morioka, S., Shomoto, K., & Shimada, T. (2012). Effects of dual task balance training on dual task performance in elderly people: A randomized controlled trial. *Clinical Rehabilitation, 26*(1), 58–67. https://doi.org/10.1177/0269215510394222

Javadpour, S., Sinaei, E., Salehi, R., Zahednejad, S., & Motealleh, A. (2022). Comparing the effects of single-task versus dual-task balance training on gait smoothness and functional balance in community-dwelling older adults: A randomized controlled trial. *Journal of Aging and Physical Activity, 30*(2), 308–315. https://doi.org/10.1123/japa.2020-0523

Kelly, V. E., Eusterbrock, A. J., & Shumway-Cook, A. (2012). A review of dual-task walking deficits in people with Parkinson's disease: Motor and cognitive contributions, mechanisms, and clinical implications. *Parkinson's Disease, 2012*.

Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1996). Upright standing and gait: Are there changes in attentional requirements related to normal aging? *Experimental Aging Research, 22*(2), 185–198. https://doi.org/10.1080/03610739608254006

Leandri, M., Campbell, J., Molfetta, L., Barbera, C., & Tabaton, M. (2015). Relationship between balance and cognitive performance in older people. *Journal of Alzheimer's Disease, 45*(3), 705–707. https://doi.org/10.3233/Jad-142883

Lesinski, M., Hortobágyi, T., Muehlbauer, T., Gollhofer, A., & Granacher, U. (2015). Effects of balance training on balance performance in healthy older adults: A systematic review and meta-analysis. *Sports Medicine, 45*, 1721–1738.

Li, K. Z., Roudaia, E., Lussier, M., Bherer, L., Leroux, A., & McKinley, P. A. (2010). Benefits of cognitive dual-task training on balance performance in healthy older adults. *The Journals of Gerontology Series A: Biological Sciences, 65*(12), 1344–1352. https://doi.org/10.1093/gerona/glq151

Li, Z., Wang, T., Liu, H., Jiang, Y., Wang, Z., & Zhuang, J. (2020). Dual-task training on gait, motor symptoms, and balance in patients with Parkinson's disease: A systematic review and meta-analysis. *Clinical Rehabilitation, 34*(11), 1355–1367. https://doi.org/10.1177/0269215520941142

Liu-Ambrose, T. Y., Ashe, M. C., Graf, P., Beattie, B. L., & Khan, K. M. (2008). Increased risk of falling in older community-dwelling women with mild cognitive impairment. *Physical Therapy, 88*(12), 1482–1491.

MacPherson, S. E. (2018). Definition: Dual-tasking and multitasking. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*.

Martino Cinnera, A., Bisirri, A., Leone, E., Morone, G., & Gaeta, A. (2021). Effect of dual-task training on balance in patients with multiple sclerosis: A systematic review and meta-analysis. *Clinical Rehabilitation, 35*(10), 1399–1412.

McIsaac, T. L., Lamberg, E. M., & Muratori, L. M. (2015). Building a framework for a dual task taxonomy. *BioMed Research International, 2015*.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Annals of Internal Medicine, 151*(4), 264–269.

Morelli, N., & Morelli, H. (2021). Dual task training effects on gait and balance outcomes in multiple sclerosis: A systematic review. *Multiple Sclerosis and Related Disorders, 49*, Article 102794.

Morita, E., Yokoyama, H., Imai, D., Takeda, R., Ota, A., Kawai, E., et al. (2018). Effects of 2-year cognitive-motor dual-task training on cognitive function and motor ability in healthy elderly people: A pilot study. *Brain Sciences, 8*(5). https://doi.org/10.3390/brainsci8050086

Nguyen, L., Murphy, K., & Andrews, G. (2019). Immediate and long-term efficacy of executive functions cognitive training in older adults: A systematic review and meta-analysis. *Psychological Bulletin, 145*(7), 698.

Nieborowska, V., Lau, S. T., Campos, J., Pichora-Fuller, M. K., Novak, A., & Li, K. Z. (2018). Effects of age on dual-task walking while listening. *Journal of Motor Behavior, 51*(4), 416–427. https://doi.org/10.1080/00222895.2018.1498318

Nightingale, C. J., Mitchell, S. N., & Butterfield, S. A. (2019). Validation of the timed up and go test for assessing balance variables in adults aged 65 and older. *Journal of Aging and Physical Activity, 27*(2), 230–233.

Norouzi, E., Vaezmosavi, M., Gerber, M., Puhse, U., & Brand, S. (2019). Dual-task training on cognition and resistance training improved both balance and working memory in older people. *Physician and Sports Medicine, 47*(4), 471–478. https://doi.org/10.1080/00913847.2019.1623996

Pantoja-Cardoso, A., Aragão-Santos, J. C., Santos, P.d. J., Dos-Santos, A. C., Silva, S. R., Lima, N. B. C., et al. (2023). Functional training and dual-task training improve the executive function of older women. *Geriatrics, 8*(5), 83.

Park, J. H. (2022). Is dual-task training clinically beneficial to improve balance and executive function in community-dwelling older adults with a history of falls? *International Journal of Environmental Research and Public Health, 19*(16), 10198.

Pereira Oliva, H. N., Mansur Machado, F. S., Rodrigues, V. D., Leao, L. L., & Monteiro-Junior, R. S (2020). The effect of dual-task training on cognition of people with different clinical conditions: An overview of systematic reviews. *IBRO Reports, 9*, 24–31. https://doi.org/10.1016/j.ibror.2020.06.005

Persson, J., Nyberg, L., Lind, J., Larsson, A., Nilsson, L. G., Ingvar, M., et al. (2006). Structure-function correlates of cognitive decline in aging. *Cerebral Cortex, 16*(7), 907–915. https://doi.org/10.1093/cercor/bhj036

Pham, T. (2023). *Master thesis* [. California State University, Long Beach.

Plummer-D'Amato, P., Cohen, Z., Daee, N. A., Lawson, S. E., Lizotte, M. R., & Padilla, A. (2012). Effects of once weekly dual-task training in older adults: A pilot randomized controlled trial. *Geriatrics & Gerontology International, 12*(4), 622–629. https://doi.org/10.1111/j.1447-0594.2011.00825.x

Plummer, P., & Iyigün, G. (2018). Effects of physical exercise interventions on dual–task gait speed following stroke: A systematic review and meta–analysis. *Archives of Physical Medicine and Rehabilitation, 99*(12), 2548–2560.

Podsiadlo, D., & Richardson, S. (1991). The timed up & go": A test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society, 39*(2), 142–148.

Poyraz, T. (2017). *Master thesis* [. Istanbul Medipol Universitesi Saglık Bilimleri Enstitusu.

Rajalaxmi, V., Arthi, J., Kumar, G. M., Muthukumaran, N., Balathandayutham, K., Saraswathi, K., et al. (2022). Effects of dual task training versus PNF pattern on balance and cognition in geriatric population. *International Journal of Life Science and Pharma Research, 12*(4), L1–L7. https://doi.org/10.22376/ijpbs/lpr.2022.12.4.L1-7

Rezola-Pardo, C., Arrieta, H., Gil, S. M., Zarrazquin, I., Yanguas, J. J., López, M. A., et al. (2019). Comparison between multicomponent and simultaneous dual-task exercise interventions in long-term nursing home residents: The ageing on dual-task randomized controlled study. *Age and Ageing, 48*(6), 817–823.

Sedaghati, P., Goudarzian, M., Ahmadabadi, S., & Tabatabai-Asl, S. M. (2022). The impact of a multicomponent-functional training with postural correction on functional balance in the elderly with a history of falling. *Journal of Experimental Orthopaedics, 9*(1), 23. https://doi.org/10.1186/s40634-022-00459-x

Shu, Y., Bi, M. M., Zhou, T. T., Liu, L., & Zhang, C. (2022). Effect of dual-task training on gait and balance in stroke patients: An updated meta-analysis. *American Journal of Physical Medicine & Rehabilitation, 101*(12), 1148–1155.

Sibley, K. M., Straus, S. E., Inness, E. L., Salbach, N. M., & Jaglal, S. B. (2011). Balance assessment practices and use of standardized balance measures among Ontario physical therapists. *Physical Therapy, 91*(11), 1583–1591.

Silsupadol, P., Siu, K. C., Shumway-Cook, A., & Woollacott, M. H. (2006). Training of balance under single- and dual-task conditions in older adults with balance impairment. *Physical Therapy, 86*(2), 269–281. https://www.ncbi.nlm.nih.gov/pubmed/16445340.

Smith-Ray, R. L., Hughes, S. L., Prohaska, T. R., Little, D. M., Jurivich, D. A., & Hedeker, D. (2015). Impact of cognitive training on balance and gait in older adults. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 70*(3), 357–366.

Voos, M. C., Custódio, E. B., & Malaquias, J., Jr. (2011). Relationship of executive function and educational status with functional balance in older adults. *Journal of Geriatric Physical Therapy, 34*(1), 11–18.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin, 120*(2), 272.

Wollesen, B., Voelcker-Rehage, C., Regenbrecht, T., & Mattes, K. (2016). Influence of a visual-verbal Stroop test on standing and walking performance of older adults. *Neuroscience, 318*, 166–177. https://doi.org/10.1016/j.neuroscience.2016.01.031

Wollesen, B., Wildbredt, A., van Schooten, K. S., Lim, M. L., & Delbaere, K. (2020). The effects of cognitive-motor training interventions on executive functions in older people: A systematic review and meta-analysis. *European Review of Aging and Physical Activity, 17*, 9. https://doi.org/10.1186/s11556-020-00240-y

Yamada, M., Aoyama, T., Hikita, Y., Takamura, M., Tanaka, Y., Kajiwara, Y., et al. (2011a). Effects of a DVD-based seated dual-task stepping exercise on the fall risk factors among community-dwelling elderly adults. *Telemedicine and E-Health, 17*(10), 768–772. https://doi.org/10.1089/tmj.2011.0054

Yamada, M., Aoyama, T., Tanaka, B., Nagai, K., & Ichihashi, N. (2011b). Seated stepping exercise in a dual-task condition improves ambulatory function with a secondary task: A randomized controlled trial. *Aging Clinical and Experimental Research, 23* (5–6), 386–392. https://doi.org/10.1007/BF03337763

Zhang, W., Low, L. F., Gwynn, J. D., & Clemson, L. (2019a). Interventions to improve gait in older adults with cognitive impairment: A systematic review. *Journal of the American Geriatrics Society, 67*(2), 381–391.

Zhang, W., Low, L. F., Schwenk, M., Mills, N., Gwynn, J. D., & Clemson, L. (2019b). Review of gait, cognition, and fall risks with implications for fall prevention in older adults with dementia. *Dementia and Geriatric Cognitive Disorders, 48*(1–2), 17–29.

Zhang, X., Xu, F., Shi, H., Liu, R., & Wan, X. (2022). Effects of dual-task training on gait and balance in stroke patients: A meta-analysis. *Clinical Rehabilitation, 36*(9), 1186–1198.