Accepted Article

Journal of Frailty, Sarcopenia and Falls

Review Article

Identification and Evaluation of the Additional Effect of Cognitive Training in Balance Physiotherapy

Christos Nikitas[1], Dimitris Kikidis[1], Michalis Tsoukatos[1], Sofia Papadopoulou[1], Marousa Pavlou[2,3], Doris- Eva Bamiou[2,3]

[1] 1st Department of Otorhinolaryngology, Head and Neck Surgery, National and Kapodistrian University of Athens, Hippocrateion General Hospital, Athens, Greece;
[2]Ear Institute, University College London, London, UK;
[3]Department of Audiovestibular Medicine, Royal National ENT and Eastman Dental Hospitals, University College London Hospitals NHS Foundation Trust, London, UK

Abstract

This systematic review examines whether adding cognitive training to a multicomponent balance rehabilitation protocol provides additional benefits for older people with balance disorders who have no or mild cognitive impairment. A comprehensive search of electronic databases was conducted to identify eligible studies. The target population consists of community-dwelling older people at risk of falling and/or with a persistent history of imbalance, with an absence of or mild cognitive impairment. The GRADE system was used to assess the risk of bias. Sixteen RCTs were identified as eligible, integrating at least balance and cognitive training as modules of a multicomponent rehabilitation protocol. Strengthening exercises, endurance training, and advanced technology were also included. In almost all studies (except one), balance exercises were provided simultaneously with cognitive exercises. The recommended exercise dosage consisted of 40-60 minutes per session, performed 2-3 per week over a period of 12 weeks. Motor-cognitive training improved standing posture, gait speed, functional mobility, domains of cognitive function, and motor-cognitive performance. Duration of interventions was correlated with the level of clinical improvement. Specific methodological issues may limit the overall reliability and generalizability of the findings. Cognitive training provided additional benefits for posture, gait speed, functional mobility, and dual-task performance in older people with balance disorders by optimizing the allocation of attentional demands.

Keywords: Balance, Cognitive training, Intervention, Physiotherapy, Older people

Introduction

Postural control requires the rapid processing and integration of multiple afferent neural inputs from different sensory systems (visual, vestibular, somatosensory) within several neural networks in the brain to appropriately adapt human posture to both the environment and the planned tasks[1]. The need for the multifactorial organization of equilibrium stems from the fact that the human body cannot understand the laws governing the cosmos, and so through the integration and the reweighting of different stimuli, it constantly tries to maintain its postural and perceptual orientation in space, correcting the possible errors via reactive and anticipatory movement patterns[2].

Often, this process is semi-automatic[3], but in any human behavior that involves an additional skill beyond locomotion, the need to use a higher cognitive process is imperative[4]. Thus, in dual and/or multiple-task conditions, depending on the difficulty faced each time by the human body, the brain adjusts the allocation of cognitive resources, especially of

The authors have no conflict of interest.

***Corresponding author:** Christos Nikitas, PT, MSc, PhD, 1st Otorhinolaryngology and Head-Neck Surgery University Department, School of Medicine, National and Kapodistrian University of Athens, Vasilissis Sofias 114, Athens, 11527, Greece*

***E-mail:** xnikitas@hotmail.com*

***Edited by:** Dawn Skelton*

***Accepted** 8 January 2026*

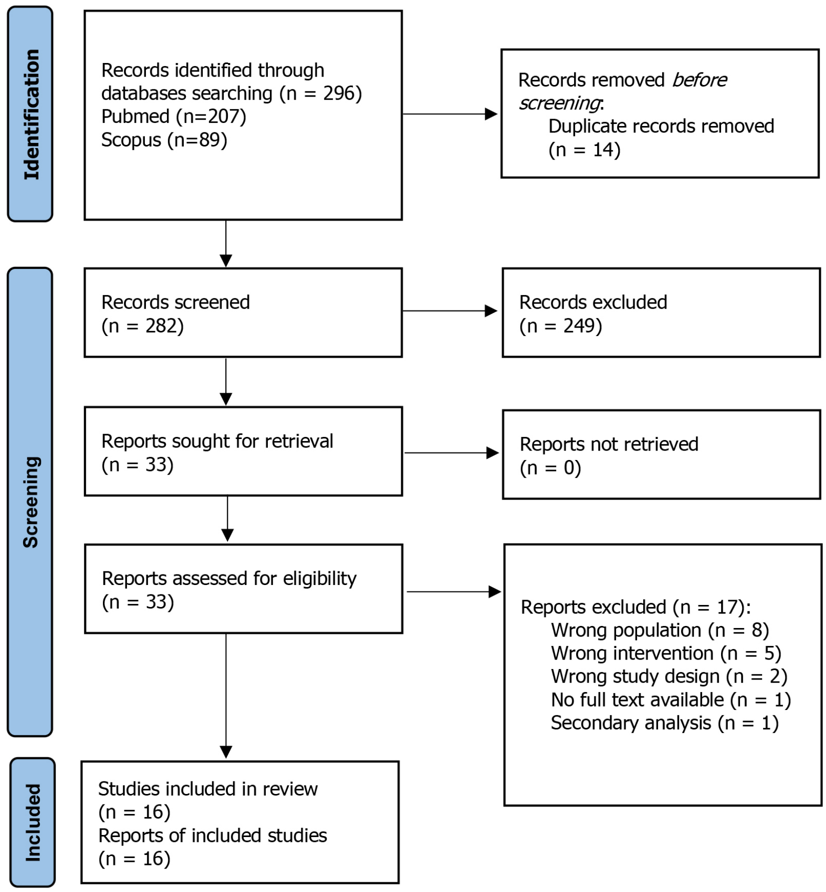

Figure 1. The CONSORT flowchart.

attention, so that the body is stabilized and then the latter tasks are carried out[5-6]. The alertness the body needs to prioritize tasks in the proper order is not always achieved, and this is a significant risk of losing balance and falling. Increased cognitive load during the dual-task condition impairs balance performance, further amplifying fall risk by disrupting the prioritization of cognitive and motor functions[7-9].

Balance disorders show an increasing lifetime prevalence over the last fifteen years and account for a significant proportion of emergency room visits[10]. There are a multitude of causes, including visual, somatosensory, cognitive, and vestibular pathologies[11]. The latter accounts for most cases of postural impairment in older people[12]. The vestibular system detects stance and motion and contributes to high cognitive processes such as self-motion perception[13], spatial navigation[14], and executive function[15]. Moreover, vestibular-mediated vestibular-ocular and vestibulospinal reflexes primarily contribute to postural control. Approximately. 80% of unexplained falls may be correlated to an undiagnosed vestibular pathology[12]. In addition, some cognitive functions, such as visuospatial ability, show deficits in both acute[16] and chronic vestibular disorders[17-18]. Although the process of symptomatic recovery after a vestibular lesion starts immediately, vestibular compensation usually carries a cognitive cost because of finite brain capacity[19].

Multicomponent rehabilitation protocols have been proposed as the gold standard for the rehabilitation of balance disorders[20-21] and for the rehabilitation of vestibular disorders in particular[22-24]. These protocols involve inputs that engage visual, vestibular, and somatosensory systems, with the primary goal of functional adaptation of the human body to the environment through sensory re-weighting. Cognitive training that aims to improve specific cognitive abilities has a strong evidence base and is included in clinical guidelines for both mild cognitive impairment and dementia[25-26]. The purpose of this systematic review is to investigate whether integrating cognitive training, as a distinct module within a multicomponent balance rehabilitation protocol, provides additional benefit for community-dwelling older people with balance disorders.

Materials and Methods

The systematic review was conducted according to PRISMA guidelines for systematic reviews in exercise medicine[27] and was registered with PROSPERO before the literature search (protocol number: CRD42023438216). The search strategy was developed in accordance with the recommendations outlined in the Cochrane Handbook for Systematic Reviews of Interventions[28]. Our literature search targeted Randomized Controlled Clinical Trials (RCTs) as eligible studies involving community-dwelling older people at risk of falls, able to walk, and/or a history of unsteadiness, disequilibrium, and dizziness, with an absence of or mild cognitive impairment (MCI). Concurrent balance rehabilitation protocol and cognitive training (including, but not limited to, cognitive training targeting specific cognitive functions and the use of e-health tools promoting cognitive function) was the primary type of intervention examined. RCTs in which cognitive training was one of the modules complementing the balance rehabilitation protocol (e.g., strength and/or flexibility exercises) were also included. All non-pharmacological interventions targeting postural control rehabilitation were included in the control group of the included studies. In the included studies, the primary outcome measures considered were balance assessment tools (static or dynamic). Secondary outcome measures included cognitive function assessment, as well as strength, endurance, and/or flexibility. Studies with a primary goal of evaluating cognitive training effects on cognitive function were excluded.

Search Syntax

The following electronic databases (PubMed, Scopus) were comprehensively searched by two reviewers for eligible English-language articles published within the last 10 years (since 2015). The search syntax for this scoping review was: ("balance physiotherapy" OR "vestibular rehabilitation") AND ("cognition" OR "cognitive training" OR cognitive training [Mesh Terms] OR "cognitive exercises").

Data Screening & Extraction

Data obtained from the search were reviewed independently by two authors (MT & SP). Duplicates or multiple reports of the same study were identified by first examining the titles and abstracts of the yielded studies and then their full texts. The results are presented in a flowchart including the reasons for exclusion. The number of publications and studies finally included in the final review was noted. The senior author resolved any disagreements. Two groups of two reviewers each screened full-text articles and independently produced a list of relevant data. Any ambiguities in data charting were discussed by the two authors in each group and resolved by the senior author. The search strategy and process flowchart are available in Figure 1.

Critical Appraisal

The Cochrane Risk of Bias tool was used to assess the quality of each study. The assessment included an analysis of potential sources of bias; each author in each group assigned a grade to each included study. Included studies were appraised for bias, inconsistency, indirectness, and imprecision following GRADE criteria[29]. Every study that presented the risk of bias, inconsistency, indirectness of evidence, and imprecision was evaluated according to the GRADE system[29]. This way, the risk of bias and the overall quality of the studies were classified as "very low", "low", "moderate", and "high". The senior author resolved any ambiguities.

Results

Study characteristics

In total, sixteen studies were identified as eligible. All studies recruited older people, seven studies recruited people over 60 years old[34-36,39,40,42,45] while eight studies recruited people over 65 years old[30,32,33,37,38,41,43,44], and one study recruited people over 70 years old[31]. Two studies recruited only male older people[38,41]. A total of 1006 participants were recruited across all studies (sample size range: 30 to 145 people). Participants were divided into two groups in most studies[30,32,35–37,40,42–45], three groups in three studies[31,34,48], and four groups in another three[33,39,41]. All included studies investigated the potential additional effect of cognitive training in balance rehabilitation. Seven of the included studies applied additional strengthening exercises to motor-cognitive exercises[30,31,37-39,40,42] while five used advanced technology[31,35,36,41,42]. Six studies involved only balance and cognitive training as modules for the rehabilitation program[32-34,43-45]. None of the studies specifically referred to a vestibular component targeting the vestibulo-ocular reflex in the exercise programme, nevertheless, two of them[33,38] incorporated an eye-hand coordination exercise, which involves vestibular processing. Two of the studies integrated endurance exercises into the therapeutic protocol[31,39]. All studies included a control group. The intervention duration varied from 4 to 24 weeks, with most studies involving more than 10 weeks of training[30-34,37,39,40,42,45]. The characteristics of all studies are presented in Table 1.

All studies used a variety of outcome measures, including objective measures of standing posture and locomotion, dynamic tests of postural control, self-reported questionnaires regarding disability or fear of falling, outcomes referring to strength, endurance, quality of life, cognitive function with a focus on spatial parameters, and dynamic balance tests assessing dual tasks and/or dual-task cost. A summary of the outcome measures included

Table 1. Characteristics of the included studies. RCT: Randomised Controlled Trial, DTC: Dual-Task Cost, SPPB: Short Physical Performance Battery, TUG: Timed Up and Go, TUG-Cog: Timed Up and Go – Gognitive, FES-I: Falls Efficacy Scale - International, SRT: Simple Reaction Time, TMT: Trail Making Test, GDS: Geriatric Depression Scale, ACE: Addenbrooke's Cognitive Examination, FAQ: Functional Activities Questionnaire, RT: Reaction Time, BEST: Balance Evaluation System Test, FGA: Functional Gait Assessment, MoCA: Montreal Cognitive Assessment, MST: Minutes Step Test, PBT: CTSIB: Clinical Test of Sensory Interaction on Balance, FR: Functional Reach, CST: Chair Stand Test, BBS: Berg Balance Scale, MWT: Minutes Walking Test, PPA: Physiological Profile Assessment, QoL: Quality of Life, Single Leg Stance Test, TST: Tandem Stance Test, STS: Sit to Stand Test, FRAQ: Falls Risk Awareness Questionnaire, MMSE: Mini-Mental State Examination, OLST: The One Leg Standing Test, PBT: Postural Balance Test.

Title (author, year)	Research Hypothesis	Inclusion Criteria	Sample size, N of participants, Female (n,%)	Mean age (+/- SD) for each group	Intervention characteristics for all groups	Exercise dosage (min/session and sessions/week)	Duration of intervention	Outcome Measures	Results	Comments
VanhetReve, 2014[30]	Strength-balance combined with cognitive training (SBC) improves physical and cognitive functioning compared to strength-balance (SB) training alone.	Autonomous living adults over 65 years old MMSE ≥ 22/30, Ability to walk 20 m, Free of rapidly progressive, acute or unstable chronic illness.	N:145 Control= 76 (52.30%) Intervention= 69 (49,25%)	Control= 81.9 ± 6.3 Intervention= 81.1 ± 8.3	Control (SB): resistance training and balance training Intervention (SBC): As in the SB group plus cognitive tasks (targeting in alertness, selective and divided attention)	Control= (40 min/ session; 2 sessions/ week) Intervention= (40 min/ session; 2 sessions/ week)	12 weeks	Balance outcomes: Gait parameters in four tasks were calculated using software (GAITRite) and (DTC): SPPB, TUG, FES-I, and fall rate. Cognitive outcomes: SRT, TMT-A and TMT-B, Divided attention	SBC significantly improved in DTC of gait parameters ($p < 0.05$), SRT ($p < 0.001$), TMT-B ($p < 0.001$), divided attention ($p < 0.001$), FES-I ($p < 0.001$), and fall rate ($p < 0.001$).	The simultaneous strength-balance-cognitive training positively affected DTC of gait variability and cognitive function parameters (divided attention).
Eggenberger, 2015[31]	Simultaneous cognitive–physical training compared to aerobic endurance creates additional enhancements in dual task gait and fitness, as well as a reduction in falls in older adults.	Seniors over 70 years old, Live independently or at residence facilities for the older people, Ability to walk at least 20 m, No diagnosed with Alzheimer's disease, No recent head injury, MMSE ≥ 22/30.	N: 70 Control (PHYS): 24 (64%) Intervention_1 (DANCE):24 (58.3%) Intervention_2 (MEMORY): 22 (72.7%)	Control: 80.8 ± 4.7 Intervention_1= 77.3 ± 6.3 Intervention_2= 78.5 ± 5.1	Control (PHYS): treadmill walking or running plus strength and balance exercise Intervention_1 (DANCE): virtual reality video game dancing plus strength and balance exercise Intervention_2 (MEMORY): treadmill walking with simultaneous verbal memory training plus strength and balance exercise	Control= (60 min/ session; 2 sessions/ week) Intervention_1= (60 min/session; 2 sessions/week) Intervention_2= (60 min/session; 2 sessions/week)	24 weeks	Balance outcomes: Gait parameters using software (GAITRite), SPPB, 6-MWT, FES-I, fall rate Cognitive outcomes= DTC Other outcomes= GDS	Intervention groups (DANCE/MEMORY) showed a significant advantage compared to control (PHYS) in the DTC of step time variability in fast walking ($P=0.044$). Decreased incidence of falls (-77%, $P<0.001$). Single-task fast walking, gait variability at preferred walking speed and SPPB decreased at follow-up (all $P<0.05$)	The simultaneous strength-balance-cognitive training improved DTC of gait variability and decreased falls rate.
Hagovska, 2016[32]	Cognitive training (CogniPlus) with dynamic balance training compared to balance training alone could improve postural control, cognitive functions and functional status but also could improve the and functional status in adults with mild cognitive deficit.	People aged 65-75 years old diagnosed with MCI, MMSE>23/30	N: 80 Control:40 (52%) Intervention: 40(45%)	Control= 65.9 ± 6.2 intervention= 68 ± 4.4	Control: Dynamic balance training Intervention: Dynamic balance training plus cognitive training (CogniPlus: targeting attention, working memory, long-term memory, executive functions, and visual-motor abilities).	Control: (30 min/ session; 7 sessions/ week) Intervention: (30 min/ session; 7 sessions/ week) + (10 min/ session; 2 sessions/ week)	10 weeks	Balance outcomes= BestTest Cognitive outcomes: ACE Other outcomes= FAQ	The intervention group improved in in the ACE and the BESTest $p<0.05$ and $p<0.0001$ respectively)	The separately balance-cognitive training improved postural control and cognitive function.

Table 1. *(Cont. from previous page).*

Title (author, year)	Research Hypothesis	Inclusion Criteria	Sample size, N of participants, Female (n,%)	Mean age (+/- SD) for each group	Intervention characteristics for all groups	Exercise dosage (min/session and sessions/week)	Duration of intervention	Outcome Measures	Results	Comments
Wongcharoen, 2017[33]	Home-based balance and dual task training compared to home-based single-task training could be more effective and demonstrate greater effectiveness.	Community-dwelling adults over 65 years old, Ability to walk at least 10 m normal score MMSE	N: 60 Intervention_1 (single task motor training):15 Intervention_2 (single task cognitive training):15 Intervention_3 (dual task motor-cognitive training:15 Intervention_4 (cognitive – cognitive training): 15 (% of female was not mentioned)	Intervention_1: 73.53 ± 5.94 Iintervention_1: 72.40 ± 6.30 Iintervention_2: 71.87 ± 4.57 Intervention_3: 74.73 ± 5.97	Intervention_1 (SM): single-task motor training- stance and gait activities, then stance and gait activities plus hand manipulation Intervention_1 (SC): single-task cognitive training-visuospatial skills, executive function, attention, and working memory. Intervention_2 (MC): dual-task motor-cognitive training-exercises as the SM group and simultaneously cognitive tasks as in the SC group Intervention_3: (CC) : dual-task cognitive–cognitive training-tasks as the SC group while practicing two of the cognitive tasks simultaneously	Intervention_1: (60 min/session; 3 sessions/week) intervention_2: (60 min/session; 3 sessions/week) intervention_3: (60 min/session; 3 sessions/week) intervention_4: (60 min/session; 3 sessions/week)	4 weeks	Balance outcomes: Center of Mass, Base of Support using equipment consisting of a 9-camera caption motion system Cognitive outcomes: gait parameters, for all walking tasks and rate of verbal response	SC and MC participants significantly improved (p<0.05) their center of mass to BoS distance (XcoM-BoS) distance and the gait speed under dual task narrow walking (narrow walking + verbal fluency). MC group significantly increased their stride length after training in single and dual task conditions (p = 0.001). Participants in all groups significantly increased their rates of verbal response in all testing conditions.	The simultaneous balance-cognitive training was superior to single-task motor training in improving balance performance under a dual-task condition. Interestingly ,the SC group improved performance under single- and dual-task conditions.
Jehu, 2017[34]	Balance, mobility and cognitive training (BMT + C) compared to balance and mobility training (BMT) could improve and maintain postural control 12 week follow-up.	Adults over 60 years old, No self-reported musculoskeletal, neurological or sensory deficits, Normal vision, MMSE ≥24/30	N: 39 Control= 13 (69.23%) Intervention_1(BMT): 12 (80%) Itervention_2 (BMT+C): 14 (64.29%)	Control: 66.3 ± 4.4 Intervention_1: 70.2 ± 3.2 Intervention_2: 68.7 ± 5.5	Control: keep their daily activities Intervention_1 (BMT): static and dynamic exercises on a variety of unstable objects Intervention_2:((BMT+C): BMT and cognitive tasks (targeting on working memory components)	Control: daily activities Intervention_1 (BMT): (60 min/session; 3 sessions/week) Intervention_2= (60 min/session; 3 sessions/week)	12 weeks	Balance outcomes: Postural parameters (area, velocity, entropy Center of Pressure displacement) on a force platform in six conditions. Cognitive outcomes: RT	There were no significant differences for all postural measures (p>0.05) after the training period in all groups. Statistically significant differences (p<0.05) for RT in both intervention groups (BMT, BMT+C) with respect to the baseline assessment and control group. The improvement for both intervention groups sustained in the 12 weeks follow-up assessment	The simultaneous balance and cognitive training offered improvement in RT in standing balance tasks.

Table 1. *(Cont. from previous page).*

Title (author, year)	Research Hypothesis	Inclusion Criteria	Sample size, N of participants, Female (n,%)	Mean age (+/- SD) for each group	Intervention characteristics for all groups	Exercise dosage (min/session and sessions/week)	Duration of intervention	Outcome Measures	Results	Comments
Gomes, 2018[35]	Serious games (Nintendo Wii Fit Plus -NWFP) compared to physical activity education improves postural control, cognition, mood, and fear of falling. NWFP's feasibility, acceptability and safety was also assessed.	Frail and pre-frail adults over 60 years old, Ability to walk independently and Perform physical exercises in the orthostatic position, Normal or corrected visual acuity, Good hearing acuity, No previous experience with the video game.	N: 30 Control: 15 (% of female not mentioned) Intervention_1 (NWFP):15 (% female not mentioned)	Control: 85 ± 6.19 Intervention= 83 ± 5.87	Control: booklet with information and illustrations outlining the benefits and risks of physical activity Intervention_1: NWFP games (Obstacle Course,Single Leg Extension, Basic Run,Torso Twist)	Control: (not mentioned) Intervention: (50 min/ session; 2 sessions/ week)	7 weeks	Balance outcomes= Mini-BESTest, FGA, FES-I Cognitive outcomes= MoCA Other outcomes: Feasibility, acceptability, safety,GDS	Significant improvement in the Mini-BESTest and Functional Gait Assessment in the intervention group vs control (p<0.05). NWFP was feasible, acceptable, and safe	Serious games use improved postural control and gait, but not cognition, mood, or fear of falling.
Bacha, 2018[36]	Serious games (Kinect Adventures Training Group-KATG) versus conventional physiotherapy (CPTG) on postural control gait, cardiorespiratory fitness, and cognition of community dwelling older people people. KATG's acceptability, adherence, and safety of the interventions was evaluated.	Older people aged between 60 and 80 years old, Capable of walking without assistance, Normal or corrected visual and auditory acuity, Without any decompensated disease	N:50 Control: 25 (83%) Intervention: 25 (65%)	Control= 65,5 (Q1:65.0 – Q371.75) Intervention= 71 (Q1:66.0 -Q3:74.50)	Control (CPTG): static and dynamic balance, endurance, muscle strength, motor coordination, muscle stretching exercises. Intervention (KATG): Xbox Kinect Adventures games, without interference from the physical therapist	Control:(60 min/ session; 2 sessions/ week) Intervention: (60 min/ session; 2 sessions/ week)	7 weeks	Balance outcomes:Mini-BESTest, FGA Cognitive outcomes: MoCA Other outcomes: acceptability, 6MST	Both interventions positively affected balance, cardiorespiratory fitness, and cognition of the older people (all p<0.0001)	Serious games improved balance, cognition, and fitness of the older people.
Laatar, 2018[37]	Balance-strength-cognitive training (PCG) compared to a balance training program (PG) improves postural control, functional performance and cognition in older adults.	Older adults, No serious visual impairments, No severe cardiac, pulmonary, metabolic or musculoskeletal disorders or neurological diseases	N:25 Control (PG):12 (% of female not mentioned) Intervention (PCG):13 (% of female not mentioned)	Control: 67.45 ± 2.38 Intervention: 66.29 ± 3.61	Control (PG): balance (vestibular), strength and sensory exercises Intervention (PCG): Combined balance-strength exercises while simultaneously performing cognitive tasks(counting, naming, memory, attention)	Control: (60 min/ session; 3 sessions/ week) Intervention: (60 min/ session; 3 sessions/ week)	24 weeks	Balance outcomes: Center o f Pressure, gait speed, TUG, FR Cognitive outcomes= SRT Other outcomes= CST	Gait speed was significantly higher in the PCG compared to the PG during post-intervention (p < 0.01) and follow-up (p< 0.05). CoP values were significantly (p < 0.01) lower in the PCG compared to the PG during post-intervention. Attention was improved (p < 0.001) during post-intervention for both groups.	The simultaneous strength-balance- cognitive training provided significant improvements in balance, cognitive parameters (attention) and strength. Long term positive effects for balance, gait speed and attention were not maintained 12 weeks post intervention.

Table 1. *(Cont. from previous page).*

Title (author, year)	Research Hypothesis	Inclusion Criteria	Sample size, N of participants, Female (n,%)	Mean age (+/- SD) for each group	Intervention characteristics for all groups	Exercise dosage (min/session and sessions/week)	Duration of intervention	Outcome Measures	Results	Comments
Norouzi, 201938	The simultaneous cognitive and resistance training (mCdtt) compared to simultaneous strength and balance training (mMdtt) improves Working Memory (WM) and Balance in older adults.	Male over the age of 65 years old, MMSE ≥24/30, Ability to stand upright, with no injuries of the lower extremities, Good physical activity status.	N:60 Control:20 (% female not mentioned) Intervention_1 (mMdtt): 20 (% female not mentioned) Intervention_2 (mCdtt): 20 (% female not mentioned)	Control: 68.10 ± 3.71 Intervention_1= 68.31 ± 4.12 Intervention_2= 68.51 ± 3.65	Control: maintain daily physical activity levels Intervention_1 (mMdtt): resistance training plus a motor skill training intervention_2 (mCdtt): resistance training plus twelve (12) cognitive tasks targeting working memory.	Control: (60 min/ session; 2 to 3 sessions/week) intervention_1: (60 min/session; 2 sessions/week) intervention_2: (not mentioned)	4 weeks	Balance outcomes:BBS Cognitive outcomes: Computer-based reaction time task for working memory (WM)	WM in mCdtt group was significantly higher compared to other groups ($p \leq .001$). Balance performance in mCdtt group increased significantly at post-intervention (8 weeks) and follow-up (12 weeks) compared to other groups ($p \leq .001$)	The simultaneous strength – cognitive training could improve balance and cognitive function parameters (working memory).
Lipardo, 2020[39]	Combined physical and cognitive training (PACT) leads to lower incidence of falls and reduced fall risk in older people with mild cognitive impairment (MCI) compared with cognitive training (CT) or physical training (PT) alone.	Adults over the age of 60 with mild cognitive impairment.	N:92 Control (WG): 23 (74%) Intervention_1 (PT) :23 (96%) Intervention_2 (CT): 23 (78%) Intervention_3 (PACT): 23 (70%)	Control: 68 ± 8.5 Intervention_1: 73 ± 7 Intervention_2: 68 ± 7.5 Intervention_3: 67 ± 8	Control (WG): maintain daily physical activity levels Intervention_1 (PT): physical training [balance (>1/3 of the program), strength, endurance, and flexibility] Intervention_2 (CT): cognitive training (paper-based cognitive exercises targeting on executive function, memory, attention, and orientation) Intervention_3 (PACT): combination of physical (same as PT) and cognitive training (targeting on executive function)	Control: (not mentioned) Intervention_1:(60-90 min/session; 3 sessions/week) Intervention_2:(60-90 min/session; 1 sessions/week) Intervention_3: (60-90 min/session; 3 sessions/week)	12 weeks	Balance outcomes: TUG, 10 -MWT, CST Cognitive outcomes: PPA	No significant difference among groups on fall rate and risks of falling. Significant improvement in functional mobility (TUG) for the PACT group (p=0.001) and the CT group (P=0.012) compared to WG at the follow up visit (36 weeks).	The simultaneous strength-balance-cognitive training improved gait speed in dual task training paradigm but no effect on falls.
Alves de Oliveira, 2020[40]	Unstable strength training without cognitive training (UST) compared to unstable strength training with cognitive training (C+UST) on functional performance, balance, fear of falling, and quality of life in older adults.	Older adults over 60 years old, No terminal or unstable illness, MMSE ≥22/30, No previous experience with strength exercise training in the last six months	N:49 Control (UST): 25 (88%) Intervention (C_UST): 25 (88%)	Control: 67.52 6.09 Intervention: 69.08 5.03	Control (UST): Strength exercises with the use of unstable devices Intervention (C+UST): UST exercises plus cognitive training targeting executive function, working memory, and language	Control: (60 min/ session; 3 sessions/ week) Intervention: (60 min/ session; 3 sessions/ week)	24 weeks	Balance outcomes: TUG, FES-I, BBS, Cognitive outcomes: TUG -Cog, DTC Other outcomes: sit-and-reach-test, handgrip strength, QoL, RT	C+UST group improved TUGcog performance and DTC at 12 (p = 0.021) and 24 weeks (p = 0.014). The UST group had better scores on the RT C+UST (p = 0.016). Both groups significantly improved BBS, QoL, and FES-I (p = 0.001)	The simultaneous strength-balance -cognitive training promoted greater gains in functional mobility Both interventions improved single-task functional mobility. Cognitive training provided additional dual-task functional performance gains.

Table 1. *(Cont. from previous page).*

Title (author, year)	Research Hypothesis	Inclusion Criteria	Sample size, N of participants, Female (n,%)	Mean age (+/- SD) for each group	Intervention characteristics for all groups	Exercise dosage (min/session and sessions/week)	Duration of intervention	Outcome Measures	Results	Comments
Sadeghi, 2021[41]	Balance training (BT), virtual reality balance training (VR), compared to combined exercise (MIX- BT+VR) provoke greater improvements in strength, balance, functional mobility and risk of falls.	Male over 65 years old, Ability to walk 10 m independently No experience with BT or VR in the past 6 months, No neurological, cognitive, orthopedic, cardiovascular complications.	N: 64 Control= 16 (% female not mentioned) Intervention_1 (BT)= 16 (% female not mentioned) intervention_2 (VR)= 16 (% female not mentioned) intervention_3 (MIX)= 16 (% female not mentioned)	Control= 72.2 ± 7.2 intervention_1= 70.4 ± 4.3 intervention_2= 74.1 ± 7.0 intervention_3= 70.5 ± 5.1	Control: maintain daily physical activity levels Intervention_1: BT: vestibular rehabilitation and weight shifting Intervention_2: VR: virtual reality balance training, using game consoles Intervention_3: MIX: combined BT and VR training	Control= (not mentioned) intervention_1= (40 min/session; 3 sessions/week) intervention_2= (40 min/session; 3 sessions/week) intervention_3= (40 min/session; 3 sessions/week)	8 weeks	Balance outcomes=SLST, TST,TUG,10MWT Other outcomes= isokinetic muscle strength	MIX group showed greater improvements compared to other groups for strength (p<0.05), balance (p<0.001), and functional mobility (p<0.001)	Balance training with serious games training improved strength, balance and functional mobility.
Moreira, 2021[42]	Serious games (EG) compared to traditional multicomponent (MG) physical exercise training program on perceptive-cognitive and physical functions of pre-frail older adults.	Pre-frail over 60 years old, Reduced cognitive capacity (MMSE), No neurologic disease or arrhythmia or use of orthosis.	N=66 Control (MG)= 34 (0%) Intervention (EG)= 32 (100)	Control= 70.76 ± 5.60 Intervention= 70.84 ± 4.53	Control (MG): warm-up,strengthening exercises, balance, cardiorespiratory exercises Intervention (EG): warm-up,strengthening exercises, balance, cardiorespiratory exercises combined with exergames (Kinect)	Control= (45 min/ session; 3 sessions/ week) Intervention=(45 min/ session; 3 sessions/ week)	12 weeks	Balance outcomes= FES-I, FRAQ, STS, TUG, 10MWT, MiniBestTest Cognitive outcomes= MMSE, TMT Other outcomes= isokinetic dynamic tests, handgrip strength	EG group showed better results in on cognition (MMSE, p<0.003), Balance (p<0,001), gait speed (p<0.01) and mobility (p=0.01). MG improved in physical function (Muscle power p<0.05). Both groups reduced fear of falling.	Falls- balance-cardiorespiratory training and serious games combined improved gait speed, balance, cognition and muscle power.
Yuzlu, 2022[43]	The consecutive dual-task balance training (CDTT) compared to integrated dual-task training (IDTT) improves balance, gait speed and fear of falling in older adults.	Adults over 65 years old, MOCA≥21/30, No balance problems caused by orthopedic or neurologic disorders.	N = 58 Control (IDDT)= 29 (79.3%) Intervention (CDTT)= 29 (82.8%)	Control= 85.3 ± 7.2 intervention= 82.9 ± 6.6	Control (IDDT): Balance exercises performed simultaneously with cognitive training targeting attention, memory, fluency, problem solving) Intervention (CDDT):Balance and cognitive training performed separately	Control= (60 min/ session; 2 sessions/ week) Intervention= (60 min/ session; 2 sessions/ week)	8 weeks	Balance outcomes= BBS, FES-I, 10MWT-DT, 10MWT-ST, TUG Cognitive outcomes=TUG-Cog	A statistically significant difference of group time interaction for the TUG-Cog and FES-I variables (all p < .001). The difference in the time effect in all scales except 10MWT-ST (all p < .001)	There were no significant differences between the simultaneous and separate balance-cognitive training on balance and gait speed in dual-task conditions.
Park, 2022[44]	Dual-task training (EG) compared to single-task training (CG) could show greater improvements in balance and executive function in older fallers.	Older adults over 65 years old, Falls in the last 6 months, MMSE ≥24/30	N=58 Control (CG)= 29 ((% female not mentioned Intervention (EG)= 29 (% female not mentioned	Control= 70.97 ± 2.78 intervention= 71.76 ± 3.14	Control (CG): balance training combined with hand manipulation. Intervention (EG): Dual-task training, balance tasks while simultaneusly conducting cognitive tasks	Control= (45 min/ session; 2 sessions/ week) Intervention= (45 min/ session; 2 sessions/ week)	6 weeks	Balance outcomes= OLST, TUG Cognitive outcomes= TMT-B	The EG showed a more significant improvement in the OLST, the TUG and the TMT-B (all p < 0.001) compared to the CG.	The simultaneously balance-cognitive training improved dynamic balance, and cognitive function parameter (executive function).

Table 1. *(Cont. from previous page).*

Title (author, year)	Research Hypothesis	Inclusion Criteria	Sample size, N of participants, Female (n,%)	Mean age (+/- SD) for each group	Intervention characteristics for all groups	Exercise dosage (min/session and sessions/week)	Duration of intervention	Outcome Measures	Results	Comments
Trombini-Souza, 2023[45]	Alternately single motor task to dual task or strictly simultaneously dual task would improve gait, balance, and cognitive function in community-dwelling older adults.	Adults aged 60-80 years old, BBS ≥ 52/56, MMSE ≥ 24/30, Ability to walk 60 m.	N=60 Control (SMT)= 26 (86.6%) Intervention (SDT)= 26 (86.6%)	Control= 66 ± 4 Intervention= 67 ± 5	Control: alternating motor tasks and dual tasks for all sessions Intervention: SMT and SDT interchangeably in stage 1 and strictly SDT in stage 2	Control=(60 min/ session; 2 sessions/ week) Intervention=(60 min/ session; 2 sessions/ week)	24 weeks	Balance outcomes=gait speed using a software (Gait Analyzer),TUG, TUG-Cog, PBT, SST,STS, FR, CTSIB Cognitive outcomes=Stroop test, DTC.,TMT-A and TMT-B	Both groups significantly improved in gait parameters, gait speed, DTC, postural control, and cognitive function parameters (executive function, attention).	Improvement in balance and cognition regardless of the protocol provided the balance-cognitive training. The gains were not maintained 24 weeks post intervention.

Table 2. Outcome measures included in the eligible studies. TUG: Timed Up and Go, DT: Dual Task, SPPB: Short Physical Performance Battey, BBS: Berg Balance Scale, BEST: Balance Evaluation Systems Test, FGA: Functional Gait Assessment, MWT: Minutes Walk Test, MoCA: Montreal Cognitive Assessment, MMSE: Mini-Mental State Examination, PPA: Physiological Profile Assessment, SRT: Simple Reaction Time., TMT: Trail Making Test, ACE: Addenbrooke's Cognitive Examination, GDS: Geriatric Depression Scale, FAQ: Functional Activities Questionnaire, RT: Reaction Time, WMP: Working Memory Performance. Outcomes.

Outcomes / Authors	Gait parameters	Posture parameters	TUG	Cognitive-Motor/ Gait DT	SPPB	FES-I	BBS	BESTest	miniBEST	FGA	Falls Rate	Endurance (3MWT, 6MWT, 6MST)	MoCA	MMSE	PPA	SRT	TMT-A	TMT-B	ACE	GDS	FAQ	RT	WMP	Strength
VanhetReve, 2014[30]	X		x	x	x	x					x					x	x	x						
Eggenberger, 2015[31]	X			x	x	x					x	x								x				
Hagovska, 2016[32]								x											x					
Wongcharoen, 2017[33]	X			x																				
Jehu, 2017[34]		x																				x		
Gomes, 2018[35]						x			x	x			x							x				
Bacha, 2018[36]									x	x			x											
Laatar, 2018[37]		x	x													x								x
Norouzi, 2019[38]							x																x	
Lipardo, 2020[39]			x									x			x									

Table 2. *(Cont. from previous page).*

Authors \ Outcomes	Gait parameters	Posture parameters	TUG	Cognitive-Motor/ Gait DT	SPPB	FES-I	BBS	BESTest	miniBEST	FGA	Falls Rate	Endurance (3MWT, 6MWT, 6MST)	MoCA	MMSE	PPA	SRT	TMT-A	TMT-B	ACE	GDS	FAQ	RT	WMP	Strength
Alves de Oliveira, 2020[40]			x	x		x	x									x								x
Sadeghi, 2021[41]		x	x																					x
Moreira, 2021[42]			x			x			x			x		x										x
Yuzlu, 2022[43]			x	x		x	x					x												
Park, 2022[44]		x	x															x						
Trombini-Souza, 2023[45]	x	x	x	x													x	x						

is provided in Table 2.

The most significant improvement across the nine included studies was observed in gait speed[30,31,33,37,39,42-45]. Seven included studies also reported improvement in gait dual-task cost[30,31,33,39,40,43,45]. For the included studies, only improvements in balance and cognitive training were reported for static postural control, functional mobility, measured by the Timed Up and Go (TUG) test, domains of cognitive function, and motor-cognitive performance, where they were assessed[32-34,43-45].

Quality Assessment

The quality rating for each study is presented in Figure 2. Most studies show a low risk of bias for the generation of allocation sequence and concealment[30-33,35-37,39,40,42,44-45] as well as for missing outcome data[31-33,35,37-41,43,45]. Unclear risk of bias is reported for the majority of included RCTs regarding the blinding of assessors[32-34,37,38,40-43,45].

Discussion

This systematic review aimed to investigate whether concurrent cognitive training provides additional clinical benefit to multicomponent balance rehabilitation protocols, specifically by improving static and dynamic balance outcome measures. Studies that included cognitive training as a rehabilitation component were included in the review. The promotion of multiple task retraining, including cognitive training, involves a broader range of coordination skills, mimicking the complexity of daily activities. The addition of cognitive tasks to multi-component balance rehabilitation interventions appears to yield statistically significant improvements in the outcome measures related to postural control, static or dynamic, including postural and gait parameters, gait speed, functional mobility, dual-task cost, and domains of cognitive function. Static posture parameters were improved in four included studies[37,41,44,45]. Gait speed in dual-task conditions improved in four studies, as measured by objective recordings from specialized accelerometers using specific software3[0,31,33,45]. Moreover, functional mobility, as measured by the TUG test, improved in nine studies[30,37,39-45]. Establishing a standardized test battery for dual-task assessment in people with balance disorders to reflect their real-life performance better is considered necessary[46].

Static balance is a fundamental component of postural control, providing baseline stability for human movement. In a recent systematic review, increased prefrontal cortex activation during dual-task balance tasks reflects compensatory neural

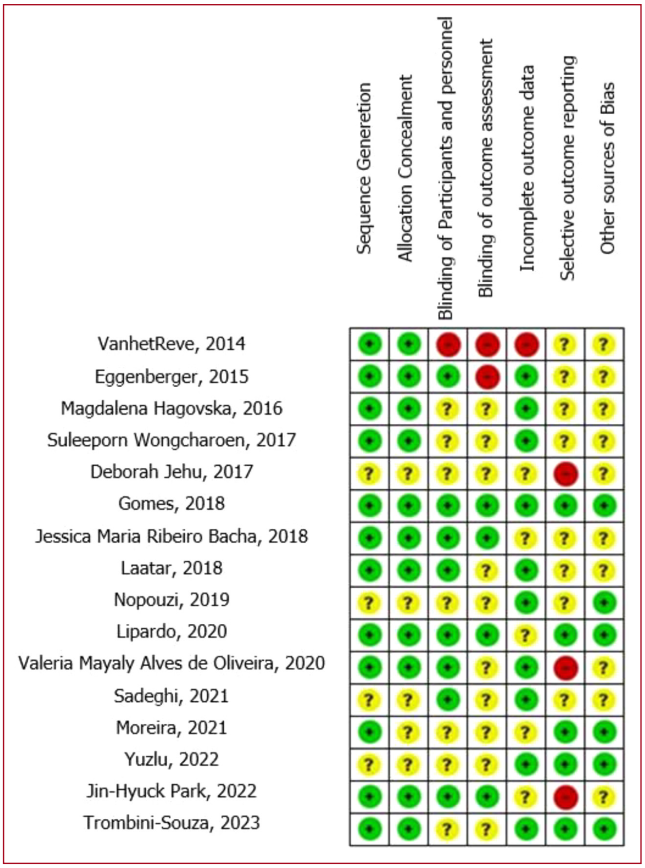

Figure 2. The risk of bias graph of the included studies.

recruitment, supporting the role of cognitive training in enhancing static balance through neuroplastic adaptation[47]. Primarily, targeting attention improvement could facilitate postural sway and sensory integration[41,44].

Gait speed is considered a reliable vital sign in older people with or without cognitive impairment[48-50]. A gait speed <0.6 m/s indicates mobility limitations in older people[51]. The clinical guidelines for falls assessment state a gait speed cut-off point of 0.8 m/s, for distinguishing older people at risk of falling[52]. In cases of balance disorders due to vestibular pathology, an increase in gait speed from 0.20 to 0.34 m/s is considered a minimally clinically significant difference in improving self-reported balance confidence[53]. On the contrary, a decline in gait speed of more than 0.1 m/s in community-dwelling older people is strongly associated with a high risk of falling[50]. In VanhetReve et al.'s study, velocity was statistically improved in the dual-task condition in both groups[30]. In the Eggenberger et al. study, although the sample consisted of healthy older people, there was a statistically significant improvement in walking speed from the pretest to the 6-month follow-up across all intervention groups[31]. Improvement in gait speed in dual task conditions was also reported in the motor-cognitive arm of the Wongcharoen et al. study[33]. Examining different types of dual-task training protocols, the improvement in gait speed, independent of the type of intervention, in dual task conditions improved by 0.013 mean change (95% CI: -0.038 to 0.064), after 24 weeks of intervention[45]. Unfortunately, in dual-task conditions, there is insufficient data to determine whether this difference has a significant clinical impact. Thus, we cannot easily generalize the results of these studies. A meta-analysis is essential.

The improvement reported in nine included studies in TUG performance reflects the enhancement of older people's capacity to integrate balance, gait, and executive function under time constraints[30,37,39-45]. Improved TUG performance following dual-task interventions indicates more efficient cognitive-motor coordination, which is critical for safely performing daily activities in dynamic, cognitively demanding environments, and contributes to greater functional autonomy. The most significant improvement reported in the included studies was up to 0.74 seconds[45].

The improvement in postural control, and especially in gait parameters, achieved by implementing motor-cognitive tasks in a balance rehabilitation program, is probably related to a more efficient allocation of attentional demands. Increased attention can disrupt sensory weighting, leading to maladaptive postural strategies and functional gait abnormalities[55]. Given that cognitive resources are integral to effective postural control, the age-related decline in sensory inputs requires an efficient attention to maintain stability during complex motor tasks[55]. Functional gait performance in older people is also related to variability in attention as part of executive function[56]. Motor-cognitive tasks as part of a rehabilitation program improve participants' ability to coordinate, control, and sustain attention across two or multiple tasks[30,32,33,37,39,45]. Sustained attention is established as a strong predictor of functional gait variability in people with unsteadiness due to vestibular disorders[18]. The automation and prioritization of different goals (motor and cognitive) may allow the central nervous system to improve its performance in balance and to better prioritize tasks[7]. This can also explain the implementation of strengthening exercises in the rehabilitation program, which were either occurred in a predetermined position or challenged participants' postural control, contributing to improvements in balance parameters[30,31,36–42]. On the other hand, the improvement in the fear of falling and the actual fall rate is unclear, as only one included study supports the reduction in the fall rate[31]. In contrast, one study reported no effect[39], and four included studies reported improvements in fear of falling, as measured by the FES-I questionnaire[30,40,42,43]. Motor and cognitive processes share overlapping neural networks that mainly involve cortical (prefrontal cortex, anterior cingulate cortex) and subcortical (basal ganglia, globus pallidus) structures[57]. Inclusion of fMRI in future studies could facilitate the decoding of neuroplasticity processes.

In all but one[32] of the included studies, balance and cognitive exercises are simultaneously provided. The different ways of delivering motor-cognitive exercises (simultaneously vs. separately) did not seem to contribute to the clinical effect reported after eight weeks of intervention, as supported by one included study[43]. Cognitive training exercises should aim to improve parameters involved in dynamic balance, such as attention, memory, reaction time, executive function, and visuospatial ability. Immersive environments can integrate the above training components into a single technical solution. All five studies incorporating virtual reality training improved the assessed postural parameters[31,35,36,41,42]. Even if none of the included studies specifically referred to a component targeting the vestibulo-ocular reflex in the exercise programme, two of them included a hand-eye coordination paradigm[33,38]. The additional effect of incorporating vestibular exercises in balance rehabilitation programs is well documented[58-60]. Future clinical studies should aim to incorporate more exercises that activate the vestibular system, particularly exercises that adapt the vestibulo-ocular reflex.

Three of the included studies[32,37,38] argue that motor-cognitive intervention can sometimes lead to a transfer effect, although considerable literature strongly disproves this[61-63]. There is a possibility that cognitive intervention is not targeted, and the assessment methods may not be the most appropriate for detecting this improvement. Interestingly, when the cognitive tasks were given in parallel[43] or included other exercise modules such as strengthening[36-40,42] or the use of technology[36,41], improvements in dynamic balance and functional mobility were reported. In the study by Librado[39], the group received only cognitive training, improved balance after 12 weeks of intervention and this effect was maintained after 36 weeks. This may suggest that attentional demands can be allocated when different goals are compromised, not just cognitive ones.

Regarding the implementation of balance exercises, the studies included a wide range of static and dynamic exercises in sitting, standing, and walking. One leg stance, standing on a foam surface, stepping over obstacles, tandem walking, walking backwards, and advanced walking (eight-shaped walking and walking on uneven surfaces) exercises were those that most commonly applied. The least used exercises involve weight transfer[36,41,4]3 and reaching-out exercises[34,39].

In the included studies, 45 - 60 minutes of exercise at least three times a week was the preferred dosage[33,34,37,39-42]. The maximum and minimum exercise session durations were 90 and 40 minutes, respectively, and the frequency was three times per week. In only one study was the exercise regimen provided daily[32]. The intervention duration also varied, with two studies lasting four weeks[33,38], one study lasting six weeks[44], two studies lasting seven weeks35, 36, two studies lasting eight weeks[41,43], one study lasting 10 weeks[32], four studies lasting 12 weeks[30,34,39,42], and four for 24 weeks[31,37,40,45]. However, evidence regarding long-term maintenance of improvements is conflicting. In the Lipardo and Tsang study[39], improvement was maintained for 36 weeks after 12 weeks of intervention, whereas Lattar et al.[37] reported that after 3 months, the effect was not maintained. The longer the intervention is followed, the better the coordination of tasks and the allocation of attention, which implies better performance on the outcome measures. In the de Oliveira study[40], it is noted that 24 weeks of intervention is ideal, as significantly greater improvements in functional mobility were reported. Additional gains in flexibility, quality of life, and fear of falling emerged or strengthened only in 24 weeks. Nevertheless, implementing a 24-week protocol presents several management challenges, including maintaining participant adherence throughout the duration and allocating time and resources effectively.

Despite the positive results, there are some methodological issues to highlight for future clinical studies, in addition to age and signs of cognitive decline. Firstly, the acceptance of an age limit for defining the older adult population is crucial, as researchers have used different age cutoffs. The same applies to the cognitive decline threshold. Inclusion criteria in eight out of sixteen studies used MMSE to indicate cognitive decline, but with different cut-off points[30-32,34,38,40,44,45]. Moreover, the MMSE is not as robust as the MoCA for detecting subtle mild cognitive deficit64. The adoption of common standards will allow better profiling and stratification of individuals. Secondly, differences in the training frequency and intervention duration limit comparability, as improvements could be driven by intensity rather than content. A recent study investigating the link between motor skills and cognitive performance indicates that this relationship is not only task-specific but also influenced by variability[65]. Therefore, future studies should adopt a more standardized protocol for intervention dosage to yield more robust results. This should also be applied to the type of cognitive exercises, as different neural networks and motor-cognitive interactions are likely activated[66]. The combined variability across existing clinical studies reduces the external validity of the results. At this point, clinicians cannot follow any clear instructions for implementing effective dual-task interventions, despite undoubtedly improved balance.

Conclusion

The systematic review aimed to investigate the additional benefit of incorporating cognitive tasks within multicomponent balance rehabilitation interventions for community-dwelling older people with postural impairment. Despite heterogeneity among studies, the evidence consistently indicates that integrating cognitive tasks enhances static postural control, gait speed, and functional mobility, and strengthens cognitive-motor coordination, which is essential for navigating complex environments. These findings support the inclusion of cognitive components as a standard module of balance interventions in this specific population.

Authors' Contributions

CN contributed to data extraction, risk of bias assessment, visualizations, and wrote the main document. DK designed the methodology, contributed to risk of bias assessment, reviewed, and edited the manuscript. MT and SP performed the literature screening, data extraction, risk of bias assessment and visualization. MP and BDE contributed to methodology, supervised the project, reviewed, and edited the manuscript. All authors reviewed and approved the final version.

Funding

This work was funded by the European Union's Horizon 2020 research and innovation program under (Grant No: 101057747).

References

1. Shumway-Cook A, Woollacott MH. Motor control: translating research into clinical practice. 4th ed. Philadelphia: Lippincott Williams & Wilkins; 2012.
2. Bronstein AM, Brandt T. Clinical disorders of balance, posture and gait. 2nd ed. London: CRC Press; 2004.
3. Dijkstra BW, Bekkers EMJ, Gilat M, de Rond V, Hardwick RM, Nieuwboer A. Functional neuroimaging of human postural control: A systematic review with meta-analysis. Neurosci Biobehav Rev. 2020 Aug;115:351-362. doi: 10.1016/j.neubiorev.2020.04.028. Epub 2020 May 11.
4. Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture. 2002 Aug;16(1):1-14.
5. Müller ML, Redfern MS, Jennings JR. Postural prioritization defines the interaction between a reaction time task and postural perturbations. Exp Brain Res. 2007 Dec;183(4):447-56.
6. Huxhold O, Li SC, Schmiedek F, Lindenberger U. Dual-tasking postural control: aging and the effects of cognitive demand in conjunction with focus of attention. Brain Res Bull. 2006 Apr 14;69(3):294-305.
7. Neider MB, Gaspar JG, McCarley JS, Crowell JA, Kaczmarski H, Kramer AF. Walking and talking: dual-task effects on street crossing behavior in older adults. Psychol Aging. 2011 Jun;26(2):260-8.
8. Nagamatsu LS, Voss M, Neider MB, Gaspar JG, Handy TC, Kramer AF, et al. Increased cognitive load leads to impaired mobility decisions in seniors at risk for falls. Psychol Aging. 2011 Jun;26(2):253-9.
9. Allali G, Launay CP, Blumen HM, Callisaya ML, De Cock AM, Kressig RW, et al. . Falls, Cognitive Impairment, and Gait Performance: Results From the GOOD Initiative. J Am Med Dir Assoc. 2017 Apr 1;18(4):335-40.
10. Mitchell MB, Bhattacharyya N. Balance Disorder Trends in US Adults 2008-2016: Epidemiology and Functional Impact. OTO Open. 2023 Jun 6;7(2):e58.
11. Wagner AR, Akinsola O, Chaudhari AMW, Bigelow KE, Merfeld DM. Measuring Vestibular Contributions to Age-Related Balance Impairment: A Review. Front Neurol. 2021 Feb 9;12:635305.
12. Pothula VB, Chew F, Lesser TH, Sharma AK. Falls and vestibular impairment. Clin Otolaryngol Allied Sci. 2004 Apr;29(2):179-82.
13. Britton Z, Arshad Q. Vestibular and Multi-Sensory Influences Upon Self-Motion Perception and the Consequences for Human Behavior. Front Neurol. 2019 Mar 7;10:63.
14. Yoder RM, Taube JS. The vestibular contribution to the head direction signal and navigation. Front Integr Neurosci. 2014 Apr 22;8:32.
15. Bigelow RT, Agrawal Y. Vestibular involvement in cognition: Visuospatial ability, attention, executive function, and memory. J Vestib Res. 2015;25(2):73-89.
16. Ayar DA, Kumral E, Celebisoy N. Cognitive functions in acute unilateral vestibular loss. J Neurol. 2020 Dec;267(Suppl 1):153-159.
17. Dordevic M, Sulzer S, Barche D, Dieterich M, Arens C, Müller NG. Chronic, Mild Vestibulopathy Leads to Deficits in Spatial Tasks that Rely on Vestibular Input While Leaving Other Cognitive Functions and Brain Volumes Intact. Life (Basel). 2021 Dec 9;11(12):1369.
18. Nikitas C, Kontogianni E, Papadopoulou S, Tsoukatos M, Kikidis D. Can vigilance predict the status of safe functional gait and risk of falls in patients with peripheral vestibular disorders? A cross-sectional study. J Neurol Sci. 2023 Feb 15;445:120547.
19. Redfern MS, Talkowski ME, Jennings JR, Furman JM. Cognitive influences in postural control of patients with unilateral vestibular loss. Gait Posture. 2004 Apr;19(2):105-14.
20. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al., World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020 Dec;54(24):1451-62.
21. Falls: Assessment and Prevention of Falls in Older People. London: National Institute for Health and Care Excellence (NICE); 2013 Jun.
22. Hall CD, Herdman SJ, Whitney SL, Cass SP, Clendaniel RA, Fife TD, et al. Vestibular Rehabilitation for Peripheral Vestibular Hypofunction: An Evidence-Based Clinical Practice Guideline: FROM THE AMERICAN PHYSICAL THERAPY ASSOCIATION NEUROLOGY SECTION. J Neurol Phys Ther. 2016 Apr;40(2):124-55.
23. Hillier SL, McDonnell M. Vestibular rehabilitation for unilateral peripheral vestibular dysfunction. Cochrane Database Syst Rev. 2011 Feb 16;(2):CD005397. doi: 10.1002/14651858.CD005397.pub3. Update in: Cochrane Database Syst Rev. 2015 Jan 13;1:CD005397.
24. McDonnell MN, Hillier SL. Vestibular rehabilitation for unilateral peripheral vestibular dysfunction. Cochrane Database Syst Rev. 2015 Jan 13;1(1):CD005397.
25. Bahar-Fuchs A, Martyr A, Goh AM, Sabates J, Clare L. Cognitive training for people with mild to moderate dementia. Cochrane Database Syst Rev. 2019 Mar 25;3(3):CD013069.
26. Petersen RC, Lopez O, Armstrong MJ, et al. Practice guideline update summary: Mild cognitive impairment: Report of the Guideline Development, Dissemination, and Implementation Subcommittee of the American Academy of Neurology. Neurology. 2018;90(3):126-35.
27. Ardern CL, Büttner F, Andrade R, Weir A, Ashe MC, Holden S, et al. Implementing the 27 PRISMA 2020 Statement items for systematic reviews in the sport and exercise medicine, musculoskeletal rehabilitation and sports science fields: the PERSiST (implementing Prisma in Exercise, Rehabilitation, Sport medicine and SporTs science) guidance. Br J Sports Med. 2022 Feb;56(4):175-95.
28. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, et

al. Cochrane handbook for systematic reviews of interventions. 2nd ed. Chichester (UK): The Cochrane Collaboration; 2019.
29. Guyatt G, Oxman AD, Akl EA, Kunz R, Vist G, Brozek J, et al. GRADE guidelines: 1. Introduction-GRADE evidence profiles and summary of findings tables. J Clin Epidemiol. 2011 Apr;64(4):383-94. doi: 10.1016/j.jclinepi.2010.04.026. Epub 2010 Dec 31.
30. van het Reve E, de Bruin ED. Strength-balance supplemented with computerized cognitive training to improve dual task gait and divided attention in older adults: a multicenter randomized-controlled trial. BMC Geriatr. 2014 Dec 15;14:134.
31. Eggenberger P, Theill N, Holenstein S, Schumacher V, de Bruin ED. Multicomponent physical exercise with simultaneous cognitive training to enhance dual-task walking of older adults: a secondary analysis of a 6-month randomized controlled trial with 1-year follow-up. Clin Interv Aging. 2015 Oct 28;10:1711-32.
32. Hagovská M, Takáč P, Dzvoník O. Effect of a combining cognitive and balanced training on the cognitive, postural and functional status of seniors with a mild cognitive deficit in a randomized, controlled trial. Eur J Phys Rehabil Med. 2016 Feb;52(1):101-9.
33. Wongcharoen S, Sungkarat S, Munkhetvit P, Lugade V, Silsupadol P. Home-based interventions improve trained, but not novel, dual-task balance performance in older adults: A randomized controlled trial. Gait Posture. 2017 Feb;52:147-52.
34. Jehu D, Paquet N, Lajoie Y. Balance and mobility training with or without concurrent cognitive training does not improve posture, but improves reaction time in healthy older adults. Gait Posture. 2017 Feb;52:227-32.
35. Gomes GCV, Simões MDS, Lin SM, et al. Feasibility, safety, acceptability, and functional outcomes of playing Nintendo Wii Fit PlusTM for frail older adults: A randomized feasibility clinical trial. Maturitas. 2018;118:20-28. doi:10.1016/j.maturitas.2018.10.002 .
36. Bacha JMR, Gomes GCV, de Freitas TB, Viveiro LAP, da Silva KG, Bueno GC, et al. Effects of Kinect Adventures Games Versus Conventional Physical Therapy on Postural Control in Elderly People: A Randomized Controlled Trial. Games Health J. 2018 Feb;7(1):24-36.
37. Laatar R, Kachouri H, Borji R, Rebai H, Sahli S. Combined physical-cognitive training enhances postural performances during daily life tasks in older adults. Exp Gerontol. 2018 Jul 1;107:91-7.
38. Norouzi E, Vaezmosavi M, Gerber M, Pühse U, Brand S. Dual-task training on cognition and resistance training improved both balance and working memory in older people. Phys Sportsmed. 2019 Nov;47(4):471-78.
39. Lipardo DS, Tsang WW. Effects of combined physical and cognitive training on fall prevention and risk reduction in older persons with mild cognitive impairment: a randomized controlled study. Clin Rehabil. 2020 Jun;34(6):773-782.
40. de Oliveira VMA, Pirauá ALT, Cavalcante BR, Beltrão NB, de Farias WM, Pitangui ACR, et al Additional Functional Performance Gains After 24-Week Unstable Strength Training With Cognitive Training in Community-Dwelling Healthy Older Adults: A Randomized Trial. J Aging Phys Act. 2021 Jun 1;29(3):412-22.
41. Sadeghi H, Jehu DA, Daneshjoo A, Shakoor E, Razeghi M, Amani A, et al. Effects of 8 Weeks of Balance Training, Virtual Reality Training, and Combined Exercise on Lower Limb Muscle Strength, Balance, and Functional Mobility Among Older Men: A Randomized Controlled Trial. Sports Health. 2021 Nov-Dec;13(6):606-12.
42. Moreira NB, Rodacki ALF, Costa SN, Pitta A, Bento PCB. Perceptive-Cognitive and Physical Function in Prefrail Older Adults: Exergaming Versus Traditional Multicomponent Training. Rejuvenation Res. 2021 Feb;24(1):28-36.
43. Yuzlu V, Oguz S, Timurtas E, Aykutoglu E, Polat MG. The Effect of 2 Different Dual-Task Balance Training Methods on Balance and Gait in Older Adults: A Randomized Controlled Trial. Phys Ther. 2022 Mar 1;102(3):pzab298.
44. Park JH. Is Dual-Task Training Clinically Beneficial to Improve Balance and Executive Function in Community-Dwelling Older Adults with a History of Falls? Int J Environ Res Public Health. 2022 Aug 17;19(16):10198.
45. Trombini-Souza F, de Moura VTG, da Silva LWN, Leal IDS, Nascimento CA, Silva PST, et al. Effects of two different dual-task training protocols on gait, balance, and cognitive function in community-dwelling older adults: a 24-week randomized controlled trial. PeerJ. 2023 Apr 21;11:e15030.
46. Danneels M, Van Hecke R, Keppler H, Degeest S, Cambier D, van de Berg R, et al. Psychometric Properties of Cognitive-Motor Dual-Task Studies With the Aim of Developing a Test Protocol for Persons With Vestibular Disorders: A Systematic Review. Ear Hear. 2020 Jan/Feb;41(1):3-16.
47. Kahya M, Moon S, Ranchet M, Vukas RR, Lyons KE, Pahwa R, et al. Brain activity during dual task gait and balance in aging and age-related neurodegenerative conditions: A systematic review. Exp Gerontol. 2019 Dec;128:110756.
48. Middleton A, Fritz SL, Lusardi M. Walking speed: the functional vital sign. J Aging Phys Act. 2015 Apr;23(2):314-22.
49. Hoogendijk EO, Rijnhart JJM, Skoog J, Robitaille A, van den Hout A, Ferrucci L, et al. Gait speed as predictor of transition into cognitive impairment: Findings from three longitudinal studies on aging. Exp Gerontol. 2020 Jan;129:110783.
50. Adam CE, Fitzpatrick AL, Leary CS, Hajat A, Ilango SD, Park C, et al. Change in gait speed and fall risk among community-dwelling older adults with and without mild cognitive impairment: a retrospective cohort analysis. BMC Geriatr. 2023 May 25;23(1):328.
51. Cawthon PM, Patel SM, Kritchevsky SB, Newman AB, Santanasto A, Kiel DP, et al. What Cut-Point in Gait Speed Best Discriminates Community-Dwelling Older Adults With Mobility Complaints From Those Without? A Pooled Analysis From the Sarcopenia Definitions and Outcomes Consortium. J Gerontol A Biol Sci Med Sci. 2021 Sep 13;76(10):e321-e327.
52. Montero-Odasso M, van der Velde N, Martin FC, Petrovic M, Tan MP, Ryg J, et al. . World guidelines for falls prevention and management for older adults: a global initiative. Age Ageing. 2023 Oct 2;52(10):afad199.
53. Thorman IB, Loyd BJ, Clendaniel RA, Dibble LE, Schubert MC. The minimal clinically important difference for gait speed in significant unilateral vestibular hypofunction after vestibular rehabilitation. J Otol. 2023 Jan;18(1):15-20.
54. Perez DL, Edwards MJ, Nielsen G, Kozlowska K, Hallett M, LaFrance WC Jr. Decade of progress in motor functional neurological disorder: continuing the momentum. J Neurol Neurosurg Psychiatry. 2021 Mar 15:jnnp-2020-323953.
55. Tard C, Dujardin K, Girard A, Debaughrien M, Derambure P, Defebvre L, et al. How does visuospatial attention modulate motor preparation during gait initiation? Exp Brain Res. 2016 Jan;234(1):39-50.
56. Persad CC, Giordani B, Chen HC, Ashton-Miller JA, Alexander NB, Wilson CS, et al. Neuropsychological predictors of complex obstacle avoidance in healthy older adults. J Gerontol B Psychol Sci Soc Sci. 1995 Sep;50(5):P272-7.
57. Marusic U, Verghese J, Mahoney JR. Cognitive-Based Interventions to Improve Mobility: A Systematic Review and Meta-analysis. J Am Med Dir Assoc. 2018 Jun;19(6):484-491.e3.
58. Skelton D, Dinan S, Campbell M, Rutherford O. Tailored group

exercise (Falls Management Exercise -- FaME) reduces falls in community-dwelling older frequent fallers (an RCT). Age Ageing. 2005 Nov;34(6):636-9.

59. Kristinsdottir EK, Baldursdottir B. Effect of multi-sensory balance training for unsteady elderly people: pilot study of the "Reykjavik model". Disabil Rehabil. 2014;36(14):1211-8.
60. Liston MB, Alushi L, Bamiou DE, Martin FC, Hopper A, Pavlou M. Feasibility and effect of supplementing a modified OTAGO intervention with multisensory balance exercises in older people who fall: a pilot randomized controlled trial. Clin Rehabil. 2014 Aug;28(8):784-93.
61. Silsupadol P, Lugade V, Shumway-Cook A, van Donkelaar P, Chou LS, Mayr U, et al. Training-related changes in dual-task walking performance of elderly persons with balance impairment: a double-blind, randomized controlled trial. Gait Posture. 2009 Jun;29(4):634-9.
62. Halvarsson A, Franzén E, Farén E, Olsson E, Oddsson L, Ståhle A. Long-term effects of new progressive group balance training for elderly people with increased risk of falling - a randomized controlled trial. Clin Rehabil. 2013 May;27(5):450-8.
63. Hiyamizu M, Morioka S, Shomoto K, Shimada T. Effects of dual task balance training on dual task performance in elderly people: a randomized controlled trial. Clin Rehabil. 2012 Jan;26(1):58-67.
64. Trzepacz PT, Hochstetler H, Wang S, Walker B, Saykin AJ; Alzheimer's Disease Neuroimaging Initiative. Relationship between the Montreal Cognitive Assessment and Mini-mental State Examination for assessment of mild cognitive impairment in older adults. BMC Geriatr. 2015 Sep 7;15:107.
65. Stuhr C, Hughes CM, Stöckel T. Task-specific and variability-driven activation of cognitive control processes during motor performance. Sci Rep. 2018;8:10811.
66. Adamovich T, Ismatullina V, Chipeeva N, Zakharov I, Feklicheva I, Malykh S. Task-specific topology of brain networks supporting working memory and inhibition. Hum Brain Mapp. 2024 Sep;45(13):e70024.