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Effects of Combining Physical and Cognitive Training on Older Adults' Physical Performance and Functional Abilities: A Systematic Review

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ABSTRACT

Background: The combination of physical and cognitive training effectively enhances the physical function of the elderly by preventing and reducing the incidence of falls as well as increasing independence in daily activities. However, the optimal combination of strategies to achieve the best physical performance and functional capacity in healthy elderly is still being explored. **Objective:** This study aimed to explore effective combinations to improve physical function. **Methods:** A comprehensive database search was done through Web of Science, Medline, Embase and PubMed, and was supplemented with Google scholar since September 2022. Titles and abstracts were used to search for keywords, and data were extracted using the Participants; Interventions; Comparisons, and Outcomes (PICO). **Results:** The 23 included studies recruited subjects aged 65 and older, comprising 872 females and 497 males, while some research did not identify the gender of 216 participants. Among the included studies, 16 were of high quality while 7 were of low quality. Ten studies showed a significant improvement in gait among older adults who underwent combined physical-cognitive training, while two studies found no positive effect on dual-task gait performance. All five studies showed a significant improvement in strength. Out of the four studies conducted, only one showed no improvement in endurance. All five studies showed improved mobility, while only one study found no effect on agility. However, eight out of the eleven papers showed a significant improvement in balance for older adults who underwent combined cognitive and physical training. The three papers that effectively reduced the fear of falling were also significant. Two studies showed that those who received combined training exhibited a significantly better quality of life compared to those who did not. **Conclusion:** Combined motor-cognitive training is an advanced, feasible and effective method that can promote the improvement of gait, balance and overall health in the elderly. This type of training has a more significant impact on the elderly's fall response compared to general physical or cognitive training. Additionally, it contributes to promoting functional independence.

Key words: Combined Intervention, Dual-task Exercise, Cognitive Training, Physical Exercise, Older Adults, Physical Function

INTRODUCTION

Aging leads to the deterioration of various physical manifestations, resulting in impaired physical function and an increased risk of falls (Carvalho et al., 2020). This decline in these physical manifestations will continue as the population continues to age (Cheng et al., 2021). It is estimated that one out of every four individuals over the age of 65 is susceptible to experiencing a fall each year (Jia et al., 2019; Gale et al., 2016). Falls are responsible for significant injuries in 20% to 30% of cases (Gill et al., 2016). The World Health Organization (WHO) reported that falls are the second most common cause of accidental death, with the largest number of falls occurring among individuals aged 60 and above (World Health Organization, 2021).

The most common causes of falling are age-related declines in physical and cognitive function (Ambrose et al., 2013). Several factors contribute to a reduction in physical function, including difficulties with walking and balance, decreased strength in the upper and lower extremities, as well as vision and proprioception issues (Lord et al., 2003). Additionally, cognitive function, which encompasses processing attention, speed, visuospatial ability, memory, and executive function, is closely related to increased risk of falling (Yang & Hsu, 2010), especially among older adults (Montero et al., 2014). The complex and multiple tasks involved in the dai-

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ly lives of the elderly further increase their risk of falling (Plummer et al., 2016).

Current studies indicate that exercise interventions can prevent falls in the elderly and reduce fall rates, particularly programs that target balance improvement and provide adequate intensity (Sherrington et al., 2017). It is evident from research that cognition plays a crucial role in maintaining gait control and stability (Wang et al., 2021). As a result, researchers are placing increased emphasis on motor-cognitive combination training as a means to reduce the fall risk among the elderly and improve their quality of life.

Studies have demonstrated that motor-cognitive training improves gait function, fall risk, balance and agility in older adults (Viana et al., 2021; Chen et al., 2021; Molina & Ricci, 2014). Motor games and physical exercise have shown to improve balance control and overall muscular strength, reducing the risk of falls in healthy elderly (Peng et al., 2020; Piotrowska et al., 2020). Previous meta-analyses have provided evidence that motor-cognitive therapy is more effective than single exercises in improving physical performance and functional ability in the elderly (Gavelin et al., 2021; Karssemeijer et al., 2017). Additionally, experiments have demonstrated that multicomponent exercises can significantly enhance mobility and functional exercise capacity in the elderly (Haripriya et al., 2018; Jadczak et al., 2018). While many meta-analyses focus on the cognitive function effects of combined training, comparative studies that investigate different training combinations are still ongoing. Cognitive training has been found to enhance balance under various task conditions (Wongcharoen et al., 2017). Physical function is influenced by both single-task multicomponent and single-task cognitive training, but the optimal combination of motor-cognitive task loads to obtain the most significant intervention impact remains unknown.

Current research has demonstrated that both contemporaneous and sequential exercise training have equivalent or superior physical effects compared to other control groups (Gavelin et al., 2021). However, it is important to note that different combinations of training can lead to varying outcomes, and the benefits of training are influenced by factors such as the duration, intensity, and frequency of exercise. Therefore, this study aimed to explore effective combinations of training methods to improve physical function.

MATERIAL & METHODS

Registration and Ethics

This article was registered on PROSPERO (CRD42022362939) and was conducted according to PRISMA guidelines. Since this systematic review used published data, no ethics board approval was required.

Identification and Selection of Studies

The eligible studies were identified by conducting searches through Web of Science, PubMed, Medline, and Embase databases from their inception until 17 September 2022 using keywords such as “Dual task”, “Dual task training”, “Exercises”, “Training”, “Physical Training”, “Physical activity”, “Cognitive train”, “Strength”, “Balance”, “Mobility”, “Endurance”, “Performance”, “Functional abilities”, “Gait”, “Flexibility”, “Activities of daily living”, “Old people”, “Elders”, and “Geriatric”. The studies included in the review were restricted to the English language and peer-reviewed publications that focused on simultaneous (concurrent cognitive and motor training) or sequential (sequential cognitive and motor training) combined training. The references of the systematic reviews found in the database were manually searched. Articles and published randomized controlled trials related to motor-cognitive training and its effects on physical performance and functional capacity in the elderly were sought. The retrieved literature was imported into Zotero to remove all duplicates. Two independent reviewers (XY and GQ) conducted the initial screening, and then retrieved and evaluated the full texts of the included literature. Data extraction included information such as authors and year of publication, participant characteristics (number, gender, age and cognitive status), intervention characteristics (intervention type, week, frequency and duration), and primary outcomes. Any disagreements were resolved by third-party reviewers (KT and RO).

Eligibility Criteria

The inclusion criteria for the articles were based on the PICOS (Population, Intervention, Comparison, Outcome and Study Design), which is outlined in Table 1. Only peer-reviewed studies published in English and for which the full text was accessible were included in this paper.

Quality Assessment

This review evaluated the methodological quality of the trials and the quality of the selected articles based on the PEDro (de Morton et al., 2009). This scale assesses 11 elements using eight internal validity criteria, including random/concealed allocation, baseline similarity, blinding, important outcome measures and intention-to-treat analysis, along with two statistical reporting criteria and one external validity criterion. The first item on the scale, which was eligibility criteria, was excluded from the overall score as it did not influence the internal validity or statistical validity of the study. f the aforementioned conditions were met, a score of 1 point was assigned; otherwise, a score of 0 points was given. This study involved two independent raters to assess the methodological quality in the PEDro database, with a third rater available to resolve any disagreements. A PEDro score below 5 was considered low methodological quality, while a score of 5 or above was considered high-quality studies (Maher et al., 2003).

Data Syntheses and Analysis

This review employed the best evidence synthesis approach to measure the strength of the evidence. The evaluation structure considered the quantity of studies, the methodology quality of the research, and the consistency of

Table 1. Eligibility criteria according to the PICOS conditions

	Inclusion Criteria	Exclusion Criteria
Population	Healthy older adults (male and female, age ≥65). Participants were cognitively and physically healthy without any chronic disease, physical activity impairment, history of falls in the last six months, or the need for assisted living facilities.	Older adults with cognitive and physical impairments. Older adults aged <65. Seniors underwent other training courses.
Intervention	Combined physical and cognitive training (simultaneous training, sequential training or exergaming). No restriction was placed on the frequency, methods, duration of exercises, and measurement tools.	Interventions other than combined physical and cognitive training (psychological, dietary and pharmacological interventions) or in unsupervised training.
Comparison	Cognitive training, physical training, sham intervention or a passive control group.	Psychological, dietary, pharmacological interventions or unsupervised interventions.
Outcome	The results included at least one measurement related to physical function (strength, balance, mobility, endurance, gait, flexibility, fall or activities of daily living)	Measurements that do not correspond to physical function.
Study design	Randomized controlled trial.	No-randomized and non-controlled studies.

the findings across all evidence. The following categories were used: 1) strong evidence that included more than two high-quality studies that consistently reported significant results; 2) moderate evidence that encompassed situations where there was consistency between the results of one high-quality study and more than one low-quality study, or when several low-quality studies provided consistent findings; 3) limited evidence which was applied when findings were available from only one study or when there were two or more inconsistent study results; 4) conflicting evidence that was assigned when there were inconsistent outcomes across more than two studies; and 5) no evidence that was assigned when there was a lack of case-control studies (Burns et al., 2011).

RESULTS

Study Selection

A preliminary search of the databases yielded 408 results: PubMed (n = 94), Web of Science (n = 132), Medline (n = 133), Embase (n = 19), Google scholar (n = 7) and Reference (n = 8). Duplicate articles were removed, leaving 253 articles. Titles and abstracts were used to exclude ineligible literature, resulting in 101 relevant articles that were further evaluated for eligibility. After a thorough reading of these 101 articles, 78 articles were excluded for various reasons, including the absence of outcome items (n = 32) and the absence of a combination of cognitive or physical interventions (n = 46). Finally, the remaining 23 articles, which met the inclusion criteria, were included in the analysis (Figure 1).

Methodical Quality

7 studies scored less than 5 on the PEDro scale, while 16 studies scored 5 or above, indicating a mixed quality of studies with a higher proportion of high-quality studies. There was no correlation observed between publication year and quality as the lowest-quality study was published in 2016, while the highest-quality studies were published from 2018 and 2021 respectively (Table 1). The criteria that were met by most of the included literature were eligibility criteria (n = 23), random allocation (n = 21), group similarities at baseline (n = 23), between-group comparisons (n = 23), reporting point estimate and measures of variability (n = 22). In terms of blinding, one study satisfied the criteria for blind subjects (n = 4) and one study satisfied the criteria for blind therapists (n = 1). Five studies met the criteria for blind raters, while concealed allocation was reported in nine studies, and intention-to-treat analysis was conducted in five studies (refer to Table 2).

Description of Studies

The characteristics of the included studies are presented in Table 3. Analyses of all studies (n = 23) focused on investigating the outcomes of physical performance and functional capacity in elderly subjects.

Participants

The total sample size of the included studies in this review was 1,585 cognitively healthy elderly individuals. The individual sample sizes ranged from 20 to 314 subjects, with a breakdown of 872 females, 497 males and 216 subjects where gender was not specified. The age range of the subjects in the study varied from 66.9 to 86.2 years.

Interventions

This study used a combination of motor-cognitive training by utilising various techniques and interventions. The duration of the training programs was relatively long, and the frequency of sessions was high. Ten studies were conducted using a simultaneous approach by combining both cognitive and physical training in the interventions. Six studies focused on sequential training, where either cognitive or physical training was conducted alone. Additionally, eight studies incorporated exergaming interventions. One study included both exergames and simultaneous training interventions (Eggenberger

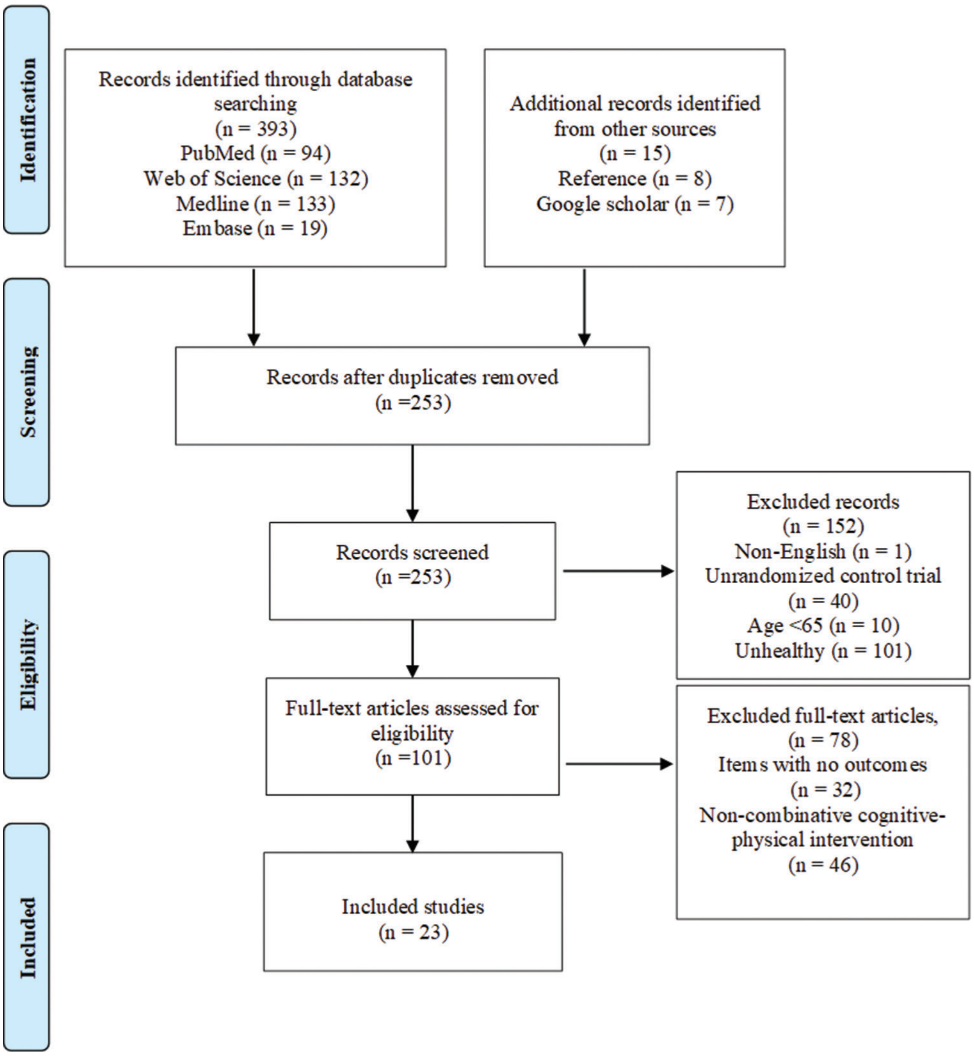

Figure 1. Prisma flow chart of the systematic review

et al., 2015), and three studies encompassed four sequential training interventions (Desjardins-Crepeau et al., 2016; Pothier et al., 2017; Fraser et al., 2017). Nineteen studies used active treatment measures, involving either physical or cognitive training. Four studies included an untreated control group (n = 3) and a sham treatment (n = 1). The treatment cycles ranged from 4 to 48 weeks, with 1 to 5 weekly intervention sessions lasting between 30 and 80 minutes.

Outcomes

The classification of this study was based on the effects of motor-cognitive training on physical performance and functional capacity in the elderly. All authors independently classified the papers according to the corresponding study sections. Disagreements among the authors were resolved through discussion.

Combined Training in Older Adults: Effects on Physical Performance and Functional Capacity

Combined motor-cognitive training was found to enhance physical performance and functional capacity to varying degrees in healthy elderly individuals compared with control groups. The most critical findings are summarized in Table 3.

Effect of Combined Training on Gait

Twelve studies assessed gait in elderly (Pichierri et al., 2012; Van et al., 2014; Eggenberger et al., 2015; Falbo et al., 2016; Schatten et al., 2016; Fraser et al., 2017; Pothier et al., 2017; Bacha et al., 2018; Kao et al., 2018; Raichlen et al., 2020; Adcock et al., 2020; Sipila et al., 2021). Meanwhile, gait measurement methods included GAITRite Electronic Walkway (Pichierri et al., 2012; Van et al., 2014; Eggenberger et al., 2015; Pothier et al., 2017), Functional Gait Assessment (Bacha et al., 2018; Kao et al., 2018), Wearable Physiology (Schatten et al., 2016; Adcock et al., 2020), Wearable Accelerometers (Raichlen et al., 2020), Photocell System (Falbo et al., 2016; Sipila et al., 2021), and Matscan floor mat (Fraser et al., 2017).

The results of the study demonstrated that a combination of cognitive and multicomponent physical training, which was supported by studies conducted by Falbo et al. (2016), Fraser et al. (2017) and Kao et al. (2018), showed moderate evidence of producing a significant impact on gait. Addition-

Table 2. Summary of quality assessment scores using PEDRO

Author and year	Eligibility criteria	Random allocation	Concealed allocation	Group similar at baseline	Blind subject	Blind therapist	Blind assessor	Follow-up	Intention to treat analysis	Between-group comparisons	Point measure and variability	PEDro score
Pichierri et al. (2012)	1	1	0	1	0	0	0	0	1	1	1	5
Van et al. (2014)	1	1	1	1	0	0	0	0	1	1	1	6
Kitazawa et al. (2015)	1	1	0	1	0	0	0	1	0	1	1	5
Eggenberger et al. (2015)	1	1	0	1	1	0	0	0	0	1	1	5
Falbo et al. (2016)	1	1	0	1	0	0	0	0	0	1	1	4
Schattin et al. (2016)	1	1	1	1	1	0	0	0	0	1	1	6
Desjardins-Crepeau et al. (2016)	1	1	0	1	0	0	0	0	0	1	1	4
Fraser et al. (2017)	1	1	0	1	0	0	0	0	0	1	1	4
Wongcharoen et al. (2017)	1	1	1	1	0	0	0	1	0	1	1	6
Pothier et al. (2017)	1	1	0	1	0	0	0	0	0	1	1	4
Htut et al. (2018)	1	1	0	1	0	0	1	1	0	1	1	6
Bacha et al. (2018)	1	1	1	1	0	0	1	1	0	1	1	7
Laatar et al. (2018)	1	1	0	1	0	0	0	0	0	1	1	4
Kao et al. (2018)	1	1	1	1	1	1	1	1	0	1	0	8
Norouzi et al. (2019)	1	1	0	1	0	0	0	1	0	1	1	5
Raichlen et al. (2020)	1	1	1	1	1	0	0	0	0	1	1	6
Adcock et al. (2020)	1	1	1	1	0	0	0	0	0	1	1	5
Li et al. (2020)	1	1	0	1	0	0	0	1	0	1	1	5
Jardim et al. (2021)	1	0	0	1	0	0	0	0	1	1	1	4
Hwang et al. (2021)	1	0	0	1	0	0	0	1	0	1	1	4
de Oliveira et al. (2021)	1	1	1	1	0	0	1	1	1	1	1	8
Párraga-Montilla et al. (2021)	1	1	1	1	0	0	0	1	0	1	1	6
Sipila et al. (2021)	1	1	0	1	0	0	1	1	1	1	1	7
Total	23	21	9	23	4	1	5	11	5	23	22	

Table 3. Overview of the included studies (n=23)

References	Participants and sex	Age	MMSE or MoCA	Cognitive intervention component	Physical intervention component	Combination method	Comparison group (s)	Intervention (Week/ frequency/min)	Outcomes
Pichierri et al. (2012)	N=22 F=18 M=4	86.25	27.1	Video game dancing	Strength and balance	Sequential	PE: Strength and balance	12/2/55 (PE: 40)	Dual-task fast walking (gait velocity↑, double support time↑, and step length↑); fall↔
Van et al. (2014)	N=151 F=70 M=81	81.5	27.65	Cognitive computer lesson	Strength and balance	Sequential	PE: Strength and balance	12/5 (PE: 2)/50 (PE: 40)	Dual-task walking (preferred speed↑, velocity↑, step time↑, step length↑, and fast speed↑); fear of fall↓; fall rate↓
Kitazawa et al. (2015)	N=60 F=33 M=27	76.4	NR	Dual-task net-step exercise	Net-step exercise	Simultaneous	No training	8/1/60	Timed up and go↑
Eggenberer et al. (2015)	N=71 F=46 M=25	78.9	28.23	Group 1: Video game dancing Group 2: Verbal memory training	Group 1: Video game dancing Group 2: Treadmill walking	Group 1: Exergaming Group 2: Simultaneous	PE: Treadmill walking	26/2/60	Group 1: Dual-task fast walking↑, step time↓, gait↑, functional fitness↑, and fall frequency↓Group 2: Dual-task walking (gait variability↓and preferred walking speed↓)
Falbo et al. (2016)	N=36 F=32 M=4	72.6	NR	Cognitive tasks during exercise	Coordination, balance, strength, agility, stretch	Simultaneous	PE: Coordination, balance, strength, agility, stretch	12/2/60	Gait performance↑
Schattin et al. (2016)	N=27 F=12 M=15	80	28.7	Group 1: Video game dancing	Group 1: Video game dancing	Exergaming	PE: Balance training	8/3/30	Group 1: Dual-task gait parameters↑PE: Single task gait parameters↑
Desjardins-Crepeau et al. (2016)	N=76 F=53 M=23	72.4	28.89	Group 1: Computerized dual-task training	Group 1: Aerobic and resistance	Sequential	Group 2: Computer lesson+Stretch Group 3: Computerized dual task+Stretch Group 4: Computer lesson+Aerobic	12/3/60	Functional mobility↑, 6-MWT↑, PPT↑, chair stand test (physical training×time) ↑, (physical training×cognitive training×time) ↔

(*Contd...*)

Table 3. (*Continued*)

References	Participants and sex	Age	MMSE or MoCA	Cognitive intervention component	Physical intervention component	Combination method	Comparison group (s)	Intervention (Week/ frequency/min)	Outcomes
Fraser et al. (2017)	N=72 F=51 M=21	71.45	28.81	Group 1: N-back task	Group 1: Aerobic training	Sequential	Group 2: Computer lessons+Stretch Group 3: Computer lessons+Aerobic Group 4: N-back task+Stretch	12/3/60	Walking speed↑and single and dual-task balance↑
Wongcharoen et al. (2017)	N=60	73.13	28.53	Group 1: Cognitive tasks during exercise	Group 1: Balance	Group 1: Simultaneous	PE: Balance CT: Cognitive Tasks DTCT: Perform two cognitive tasks simultaneously	4/3/60	Group 1: Dual-task balance performance↑CT: Single/dual-task balance performance↑
Pothier et al. (2017)	N=90 F=64 M=26	72.15	28.78	Group 1: Computerized dual-task training	Group 1: Aerobic and resistance	Sequential	Group 2: Stretch +computer dual-task training Group 3: Aerobic+resistance +computer lesson Group 4: Stretch +computer lesson	12/2/60	Group 1, Group 2, and Group 3: Spontaneous walking speed↑
Htut et al. (2018)	N=84 F=37 M=47	75.8	25.2	Group 1: X-box 360 games	Group 1: X-box 360 games	Group 1: Exergaming	PE: Strength and balance CT: Cognitive games	8/3/30	PE: Timed up and go↑, 5-time sit-to-stand↑, and Borg category ratio scale↑CT: Timed up and go test↑and satisfaction↑Group 1: Fall Efficacy Scale International↑, Borg category ratio scale↑, and satisfaction↑
Bacha et al. (2018)	N=46 F=34 M=12	68	23	Group 1: Kinect adventure games	Group 1: Kinect adventure games	Exergaming	PE: Balance and strength	7/2/60	Group 1, PE: Postural control↑, gait↑, and cardiorespiratory fitness↑

(*Contd...*)

Table 3. (*Continued*)

References	Participants and sex	Age	MMSE or MoCA	Cognitive intervention component	Physical intervention component	Combination method	Comparison group (s)	Intervention (Week/ frequency/min)	Outcomes
Laatar et al. (2018)	N=24	66.9	NR	Group 1: Cognitive tasks during exercise	Group 1: Balance and strength	Group 1: Simultaneous	PE: Balance and strength	24/3/60	Group 1: Balance↑, 30-second chair stand test↑, timed up and go test↑, gait speed↑, and performance in daily tasks↑PE: Balance↑and physical functions↑
Kao et al. (2018)	N=62 F=55 M=7	72.92	27.5	Interactive cognitive training	Coordination, strength, aerobic, stepping, and balance training	Simultaneous	CT: Computer cognitive training	8/3/30	Stride length↑, leg exhibited↑, functional gait assessment↑, balance performance↑
Norouzi et al. (2019)	N=60	68.31	26.3	Group 1: Cognitive tasks during exercise	Group 1: Resistance	Group 1: Simultaneous	PE: Resistance training+motor skill training CT: Group discussions	4/3 (CT: 2-3)/60-80 (CT: 60)	Group 1: Balance (significant Time×Group interaction) ↑
Raichlen et al. (2020)	N=74 F=47 M=27	67.85	29.07	Group 1: Cognitive tasks during exercise	Group 1: Recumbent bicycle	Group 1: Simultaneous	CG: Video watching CT: Cognitive tasks PE: recumbent bicycle	12/3/30	Group 1: Dual-task gait↔
Adcock et al. (2020)	N=31 F=16 M=15	73.9	29.05	Step-based cognitive exercises	Tai Chi, dancing, step training	Exergaming	General daily activities	16/3/30	Dual-task gait parameters (walking speed↑, stride length↑, and cycle duration↑), 30-second chair stand test↑, balance↔, and endurance↔
Li et al. (2020)	N=20 F=13 M=7	73.1	NR	Video game	Video game	Exergaming	No training	4/3/45	Balance↑
Jardim et al. (2021)	N=72	≥60	NR	Multiple sensory stimulations	Aerobic, strength	Exergaming	Health Education	24/2/75	Functional mobility↑, cardiorespiratory fitness↑, lower limbs strength↑, agility↑, quality of life↑, and dual-task performance↑

(*Contd*...)

Table 3. (*Continued*)

References	Participants and sex	Age	MMSE or MoCA	Cognitive intervention component	Physical intervention component	Combination method	Comparison group (s)	Intervention (Week/ frequency/min)	Outcomes
Hwang et al. (2021)	N=18 F=9 M=9	69.65	25.9	Virtual reality-based cognitive training	Walking, balance	Exergaming	CT: Desktop cognitive activities	6/3/30	10-MWT↑
De Oliveira et al. (2021)	N=72 F=51 M=21	71.45	28.81	Cognitive tasks during exercises	Unstable strength training	Simultaneous	PE: Unstable strength training	24/3/60	Single-task timed up and go↑, dual-task timed up and go↑, and mobility↑
Párraga-Montilla et al. (2021)	N=43 F=43	80.86	NR	Group 1: Motor games	Group 1: Motor tasks with cognitive input	Group 1: Simultaneous	CG: NT CT: Cognitive training PE: Aerobic, strength, motor aptitude	8/5/60	Group 1, CT, PE: Handgrip strength↑PE: 2-MST↑
Sipila et al. (2021)	N=314 F=188 M=126	74.45	27.65	Computer training	Walking and balance, resistance and balance, home exercises, aerobic training	Sequential	PE: Walking and balance, resistance and balance, home exercises, aerobic training	48/4/80 (PE: 60)	gait speed↔, walking distance↔, dual-task cost↔

Abbreviations and symbols: N=number; F=female; M=male; CG, control group; NT, no training; MMSE, Mini-Mental State Examination; MoCA, Montreal Cognitive Assessment; NR, no reference; DTCT, dual-task cognitive training; CT, cognitive training; PE, physical exercise; 2-MST,2-minute Step Test; 6-MWT, 6-meter Walk Test; 10-MWT, 10-meter Walk Test; PPT, Physical Performance Test; ↓, significantly reduced after training; ↑, significant increase after training; ↔, no significant change after training; +, exercises combinations.

ally, strong evidence was found for the positive effects of exergaming, which was demonstrated by studies conducted by Schattin et al. (2016), Bacha et al. (2018) and Adcock et al. (2020), on gait improvement. Limited evidence suggested that dance video game combined with balance and strength training (Pichierri et al., 2012), computer lessons combined with balance and strength training (Van et al., 2014), cognition and aerobic training (Eggenberer et al., 2015), and combined computer-based lessons with aerobic and strength training (Pothier et al., 2017) had a significant impact on gait as well. However, limited evidence also indicated no differences in dual-task gait with the combination of multicomponent cognitive training and recumbent bicycle (Raichlen et al., 2020) as well as the combination of computer sessions and multicomponent training (Sipila et al., 2021).

Effect of Combined Training on Strength

Five studies assessed strength in older adults (Desjardins-Crepeau et al., 2016; Laatar et al., 2018; Adcock et al., 2020; Jardim et al., 2021; Párraga-Montilla et al., 2021). Meanwhile, handgrip strength was used as a measure of upper limb strength (Párraga-Montilla et al., 2021). The measurement of lower limb strength was assessed using the 30-second chair stand test (Desjardins-Crepeau et al., 2016; Laatar et al., 2018; Adcock et al., 2020; Jardim et al., 2021).

Scientific evidence supports the significant impact of cognitive-physical training on strength. Four studies showed significant improvements in lower body strength: exergaming interventions (Adcock et al., 2020; Jardim et al., 2021) demonstrated moderate evidence, computer training combined with aerobic and strength training (Desjardins-Crepeau et al., 2016) showed limited evidence, and cognitive combined with balance and resistance training (Laatar et al., 2018) also showed limited evidence. One study demonstrated significant changes in grip strength by combining cognitive, aerobic and strength training (Párraga-Montilla et al., 2021) with limited evidence. A chair stand test conducted during computer training combined with aerobic and strength training demonstrated a relationship between physical training and time interaction (Desjardins-Crepeau et al., 2016) with limited evidence.

Effect of Combined Training on Endurance

Five studies assessed endurance in older adults (Desjardins-Crepeau et al., 2016; Bacha et al., 2018; Adcock et al., 2020; Jardim et al., 2021; Hwang et al., 2021) using 6-MWT (Desjardins-Crepeau et al., 2016; Jardim et al., 2021), 6MST (Bacha et al., 2018), 10-MWT (Hwang et al., 2021), and Senior Fitness Test (Adcock et al., 2021).

The experiments revealed that combined cognitive-physical training, including exergaming (Bacha et al., 2018; Hwang et al., 2021; Jardim et al., 2021) demonstrated a significant impact on endurance with moderate evidence. Additionally, computer lessons combined with aerobic and resistance training (Desjardins-Crepeau et al., 2016) showed limited evidence of improving endurance levels. However, one study reported that the combination of Tai Chi and dance video games did not result in improved endurance levels with limited evidence (Adcock et al., 2020).

Effect of Combined Training on Mobility and Agility

Five studies assessed mobility in the elderly (Kitazawa et al., 2015; Desjardins-Crepeau et al., 2016; Laatar et al., 2018; Jardim et al., 2021; de Oliveira et al., 2021) via Timed Up and Go Test. One study assessed agility in the elderly (Jardim et al., 2021) using walking while talking test.

The experiments showed that cognitive-physical training, including net-step exercise (Kitazawa et al., 2015) (limited evidence), computer lessons combined with aerobic and strength training (Desjardins-Crepeau et al., 2016) (limited evidence), cognitive combined with balance and resistance training (Laatar et al., 2018) (limited evidence), exergaming (Jardim et al., 2021) (limited evidence), and cognition combined with unstable strength training (de Oliveira et al., 2021) (limited evidence), produced a significant impact on mobility. Exergaming (Jardim et al., 2021) (limited evidence) was found to improve agility in older adults. Furthermore, computerized training combined with aerobic and resistance exercise demonstrated a strong correlation between task-switching ability and functional mobility (Desjardins-Crepeau et al., 2016) (limited evidence).

Effect of Combined Training on Balance

Nine studies assessed balance in the elderly (Fraser et al., 2017; Wongcharoen et al., 2017; Htut et al., 2018; Bacha et al., 2018; Laatar et al., 2018; Kao et al., 2018; Norouzi et al., 2019; Adcock et al., 2020; Li et al., 2020). These studies applied the Matscan floor mat (Fraser et al., 2017), a nine-Camera Motion Capture System (Wongcharoen et al., 2017), Short Physical Performance Battery (Adcock et al., 2020), Functional Reach Test (Laatar et al., 2018), Borg Category Ratio Scale (Htut et al., 2018), Mini Balance Evaluation Systems Test (Bacha et al., 2018), Berg Balance Scale (Norouzi et al., 2019), Functional Gait Assessment (Kao et al., 2018), and One-Leg Standing Balance Test (Li et al., 2020) to assess functional balance ability.

The results revealed that integrated cognitive-physical training, including exergaming (Bacha et al., 2018; Htut et al., 2018; Li et al., 2020) (strong evidence), n-back task and aerobic training (Fraser et al., 2017) (limited evidence), cognitive and balance training (Wongcharoen et al., 2017) (limited evidence), cognitive combined with balance and strength training (Laatar et al., 2018) (limited evidence), cognitive combined with multicomponent training (Kao et al., 2018) (limited evidence), and cognitive combined with strength training (Norouzi et al., 2019) (limited evidence), had a positive impact on balance. However, no significant improvement in balance was achieved by combining Tai Chi and dance video games (Adcock et al., 2020) (limited evidence). Furthermore, combining multicomponent cognitive training with resistance training revealed a significant time-group interaction (Norouzi et al., 2019) (limited evidence).

Effect of Combined Training on Fall

Four studies assessed falls in older adults (Pichierri et al., 2012; Van et al., 2014; Eggenberer et al., 2015; Htut et al., 2018) using the Falls Efficacy Scale International. The experiments showed that the combination of cognitive-physical training, including exergaming (Eggenberer et al., 2015; Htut et al., 2018) (strong evidence) and the combination of computer-based lessons with strength and balance training (Van et al., 2014) (limited evidence), had a significant effect on reducing falls. However, no significant difference was reported in falls when using dance video games (Pichierri et al., 2012) (limited evidence).

Effect of Combined Training on the Activities of Daily Living

Two studies assessed ADLs in older adults (Desjardins-Crepeau et al., 2016; Laatar et al., 2018). The Physical Performance Test and daily tasks were used to measure functional ability. The experiments showed that the combination of cognitive-physical training, including computer lessons combined with strength and aerobic training (Desjardins- Crepeau et al., 2016) (limited evidence) and cognitive combined with strength and balance training (Laatar et al., 2018) (limited evidence), could have a significant impact on improving daily activities.

DISCUSSION

In line with the objectives of the current systematic review, the search strategy aimed to locate research studies that examined the effects of combined physical and cognitive training interventions. These interventions were compared either to interventions that were performed individually or to a control group. A total of 23 studies were identified, with 10 studies implementing simultaneous physical and cognitive interventions, and six studies using sequential interventions. Additionally, eight studies focused on exergaming interventions. All three types of motor-cognitive training demonstrated significant effects on physical function indicators in older adults. The research findings showed that combining multiple interventions has a positive effect on various walking parameters, including improving walking speed during single or dual-task, single/dual-task preferred speed, step length, stride length, single/dual-task balance, fall frequency, and other functional parameters such as 6-MWT, 10-MWT, TUG, cardiorespiratory fitness, physical function, QoL, and handgrip strength.

This review found that cognitive-motor training could effectively improve gait, which aligned with the findings of a previous review conducted by Levin et al. (2017). Improvements in gait have been associated with enhanced functional independence and quality of life. Furthermore, a study by Studenski et al. (2011) demonstrated a positive correlation between walking speed and survival rate in the elderly. Therefore, it is crucial to implement preventive interventions to mitigate the long-term consequences of cognitive and physical decline such as dementia, frequent falls, and decreased mobility.

Strong evidence supports the significant impact of exergaming on gait, balance, and fall prevention. However, there is limited evidence available for other assessment parameters, indicating the need for further experimental research. Conversely, three studies reported no significant differences in dual-task gait, gait speed, dual-task cost, balance, and endurance.

These benefits could be attributed to the increased release of Brain-Derived Neurotrophic Factor (BDNF) and Insulin-like Growth Factor (IGF) as well as the structural cortical/subcortical changes (Thiell et al., 2013). Meanwhile, motor-cognitive training could effectively preserve neuronal structural integrity and plasticity respectively. Thus, a combined intervention could be effective in slowing age-related cognitive and motor deterioration. Furthermore, a study argued that motor functions such as gait may not be solely attributed to motor function but also have a cognitive association (Alexander et al., 2008). Therefore, a dual-task training program is more likely to improve sensory-motor integrity, resulting in better balance, fall reduction and improved attention (Norouzi et al., 2019).

The American Heart Association recommends older people to incorporate either 20 minutes of vigorous-intensity aerobic exercise three times a week or 30 minutes of moderate-intensity aerobic exercise five times a week to maintain cardiorespiratory fitness and overall health (Haskell et al., 2007). It is important to gradually increase the training intensity, which can be measured by perceived effort on the Borg's Scale or as a percentage of maximum heart rate. Physical exercise not only affects brain function, but also influences the mental states and higher-order behaviour of the brain, particularly among the elderly (Stillman et al., 2020). Four studies (Bacha et al., 2018; Jardim et al., 2021; Hwang et al., 2021; Desjardins-Crepeau et al., 2016) provided conclusive evidence of the benefits of combined training interventions on cardiorespiratory fitness and general health compared to physical training alone. However, one study reported no significant difference between groups in the Senior Fitness Test (Adcock et al., 2021). The significant improvements in cardiovascular performance are likely to be reflective of the gains in gait, motor skills and cognitive, implying potential synergistic effects. Thus, combining motor-cognitive training can be an excellent strategy to improve the biologically deteriorating physical and cognitive performance associated with old age.

Higher levels of BDNF and IGF-1 in the bloodstream are characteristic of the alterations in hippocampus volume caused by exercise. Aerobic or combined training has been associated with higher levels of neurotrophic factors, and the levels are proportional to the intensity and interval of the training. Furthermore, the level of BDNF and IGF-1 has been used to evaluate the response to exercise (Heisz et al., 2017). BDNF and IGF-1 influence synaptogenesis, angiogenesis, and neurogenesis, contributing to synaptic plasticity. Physical exercises have also been shown to induce structural changes in specific brain regions such as the hippocampus, motor cortex, prefrontal cortex and cerebellum (Ruscheweyh et al., 2011), leading to improved functional outcomes, including gait and balance. The findings of this study supported the notion of these observed structural changes and their implications for functional improvements.

Recent reviews have examined the effects of combined motor-cognitive training on cognition and functional status in the elderly (Law et al., 2014; Joubert et al., 2018; Lauenroth et al., 2016). While cognitive outcomes have been extensively studied, the physical and functional aspects are equally important for clinicians and physical therapists. This current review investigated the impact of combined training on gait, balance, cardiorespiratory fitness, strength, mobility, and daily activities.

Studies have shown that individual training methods such as physical training can yield significant physical and functional improvements on their own, although to a lesser extent compared to a combined approach. The physical and functional improvements related to physical exercises suggest that these activities have specific effects that contribute to positive outcomes. Furthermore, a few studies (Kitazawa et al., 2015; Jardim et al., 20021) have demonstrated gait deterioration in control groups, which can be attributed to a lack of activity or inactivity.

The studies included in this review have employed various motor-cognitive training, either simultaneously or sequentially. Dual-task training requires the subject to exert sustained attention to multiple stimuli for an extended time, which engages the higher centers of the brain and promotes neuroplastic changes in the brain (Levin et al., 2017). The processing of information at the higher center level is faster, enabling the execution of a rapid series of tasks through simultaneous dual-task performance (Kitazawa et al., 2015). Despite the common belief that simultaneous training would result in greater physical or functional improvements, no clear advantages were found in the included studies. However, due to insufficient data, drawing definitive conclusions regarding the association between training patterns and physical and functional improvements is challenging.

Variations in results may be attributed to the different dosages of the combined intervention protocols, including exercise intensity, frequency and duration. These factors appear to influence the association between training and functional-physical performance. Studies with relatively short training durations (< 6 weeks) (Wangcharoen et al., 2017) or modest training durations (7-20 weeks) (Pichierri et al., 2012; Van et al., 2014; Falbo et al., 2016; Schattin et al., 2016; Fraser et al., 2017; Pothier et al., 2017; Adcock et al., 2020; Raichlen et al., 2020) have shown to be less effective in improving dual-task function and gait speed in single-task or dual-task regular and fast walks compared to extended interventions (>20 weeks) (Eggenberger et al., 2015; Sipila et al., 2021). Similar results were observed in balance and functional parameters following both modest and extended durations of activities (Eggenberger et al., 2015; Sipila et al., 2021), including 30-second CST, TUG and FES-I, while 6-MWT showed no significant changes (Desjardins et al., 2016; Fraser et al., 2017; Jardim et al., 2021). In contrast, a study reported conflicting findings, showing that an extended training duration was less effective in improving cognitive functions (Guo et al., 2020).

The included studies employed dual-task interventions consisting of 1-6 sessions per week, with an average frequency of three times per week. The findings indicated that training regimens of 1-6 sessions per week can improve physical function, and it appears that training frequency has little impact on physical and functional gains, particularly in gait and balance parameters. However, it is important to note that some studies reported conflicting results on the effects of intervention duration and frequency on dual-task cost, single-task average gait speed and quality of life. Thus, considering the potential methodological variability, the findings of this research should be interpreted and replicated with caution. Therefore, clinicians should also consider intervention components such as the type and complexity of physical activity and cognitive tasks.

In general, combined physical-cognitive training is unquestionably a superior and promising method for improving gait, balance and overall health in older individuals. It emphasises that the skills acquired in old age can modify fall reactions and increase functional independence. Thus, multi-modal exercise programs are strongly recommended for preventing and improving age-related motor and cognitive decline. However, determining the exact training intervention that yields better clinical and functional outcomes is challenging, given the wide variation of training and test protocols and the lack of consistency among the included studies. Therefore, the authors recommended that future experimental studies implement a prototype training regimen with a standardised protocol for exercise intensity, frequency and duration.

Limitations

This study utilised four databases namely Web of Science, Medline, Embase and PubMed, and identified 23 publications for inclusion. Five studies (Pichierri et al., 2012; Schattin et al., 2016; Laatar et al., 2018; Li et al., 2020; Hwang et al., 2021) had a sample size of less than 30 individuals. Only one of the selected studies focused exclusively on women (Párraga-Montilla et al., 2021), whereas no studies were conducted solely on men. Furthermore, most studies primarily focused on younger older people, with 16 studies including participants aged 65 to 74 and only seven studies including participants aged 75 to 89.Furthermore, the recruited population predominantly consisted of individuals from community-based settings, and only two studies utilized multiple recruitment channels to broaden the participant pool.

The intervention strategies employed in the selected studies varied significantly, making it challenging to conduct a homogeneous analysis. Only four studies (Eggenberer et al., 2015; Desjardins-Crepeau et al., 2016; Fraser et al., 2017; Pothier et al., 2017) compared different combined training modalities, while the remaining studies compared combined training with single training. Despite combined training showed significant improvements in physical performance and functional capacity, it remains challenging to determine which specific combination is the most effective. The included studies reported a wide range of intervention durations, spanning from 4 to 48 weeks. Ten studies (Kitazawa et al., 2015; Schattin et al., 2016; Wongcharoen et al., 2017; Htut et al., 2018; Bacha et al., 2018; Kao et al., 2018; Norouzi et al., 2019; Li et al., 2020; Hwang et al., 2021; Párraga-Montilla et al., 2021) conducted for ten weeks, while seven studies conducted two or fewer times per week, and 16 conducted three or more times per week. The duration of each intervention session ranged from 30 to 80 minutes. Additionally, most studies focused on assessing the impact of combined training on gait, balance and dual-task performance, with fewer studies examining other aspects of physical functions. Therefore, there is a need for further exploration of the comprehensive effects of combined training on various physical functions in older adults.

Based on findings of this this review, several recommendations have been made for future studies. Firstly, independent studies that focus exclusively on women or men can be conducted. Secondly, the sample size should be increased and the age range of participants should be limited to a narrower range such as within ten years. Thirdly, the experiment should involve older people. Besides that, the recruitment process should be expanded by including participants from diverse settings and locations. Furthermore, the investigation of various combinations of motor and cognitive training interventions should be expanded. Moreover, the frequency, duration and intensity of the training sessions should be increased. The study of other physical performance and functional capacity indicators should also be encouraged, and the effects of multiple exercise combinations should be explored.

Strength and Practical Implication of Study

The strength of this study is two-fold. Firstly, it provides evidence of the positive effects of combined cognitive-physical training on physical performance and functional capacity in older adults. Secondly, it has implications for the development of interventions that can improve physical performance and functional capacity in this population. Therefore, the study provides a basis for developing practical interventions that can have a real impact on the lives of older adults.

CONCLUSION

In summary, the combination of motor-cognitive training is an effective and practical strategy that can enhance gait, balance and overall health in the elderly compared to single training approaches. It has the potential to improve fall response and promote functional independence in the elderly population. However, determining the optimal training intervention for achieving better clinical and functional outcomes is challenging due to the wide variation in training and test protocols across the included studies as well as the lack of consistency. Therefore, the authors recommend that future experimental studies adopt a standardised training regimen with a common protocol for exercise intensity, frequency and duration to ensure more accurate comparisons and reliable results.

Author Contributions

XY and GQ performed the literature search, study selection, and quality assessment of the study. After an initial screening, XY and GQ independently reviewed potentially eligible studies based on specific selection criteria. LXB, RB and JZL resolved any disagreements or discrepancies in assessing the quality of the research. TF and RO served as arbitrators to resolve any disagreements regarding study inclusion. All authors read and approved the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

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