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SYSTEMATIC REVIEW

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The effectiveness of digital technology-based Otago Exercise Program on balance ability, muscle strength and fall efficacy in the elderly: a systematic review and meta-analysis

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Abstract

Objective To explore the impact of the digital implementation of the Otago Exercise Program (OEP) on balance ability (static and dynamic), muscle strength, and fall efficacy in elderly people; and analyze different potential influencing factors in subgroups to find the most suitable training plan.

Methods EBSCO, PubMed, Web of Science, and China Knowledge Network databases (core) were searched up to August 1, 2023. Experimental studies of implementing OEP based on digital technology to improve outcomes related to falls in the elderly were included. Bias risks were assessed using the Cochrane collaboration tool. Meta-analysis was performed to assess the pooled effect of balance ability (static and dynamic), muscle strength, and fall efficacy using a random effects model. Subgroup analyses were conducted to examine the potential modifying effects of different factors (e.g., training period, frequency, duration, age).

Results Twelve articles were included from the literature, including 10 randomized controlled trials, one single-group quasi-experimental study, and one case report. Digital technologies used in the studies were categorized into three types: (1) online interventions (Zoom, WeChat), (2) recorded videos (via computers, TVs, DVDs), and (3) wearable technologies (motion sensors, augmented reality systems). The implementation of OEP based on digital technology showed significantly improved on static balance (SMD = 0.86, 95% CI 0.35–1.37), dynamic balance (SMD = 1.07, 95% CI 0.90–1.24), muscular strength (SMD = 0.43, 95% CI 0.17–0.69), and fall efficacy (SMD=-0.70, 95% CI -0.98, -0.41); Subgroup analysis by period '≥12 weeks', frequency '≥3 times/week', and duration '≤45 minutes per session', respectively, showed significant improvements on static balance (SMD = 0.73, 95% CI 0.21–1.25; SMD = 0.86, 95% CI 0.35–1.37; SMD = 1.10, 95% CI 0.31–1.89), dynamic balance (SMD = 1.08, 95% CI 0.88–1.28; SMD = 1.01, 95% CI 0.93–1.27; SMD = 1.07, 95% CI 0.89–1.25), muscle strength (SMD = 0.43, 95% CI 0.10–0.75; SMD = 0.54, 95% CI 0.30–0.77;

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SMD = 0.53, 95% CI 0.19–0.87), and fall efficacy (SMD=-0.75, 95% CI -1.39, -0.11; SMD=-0.70, 95% CI -0.98, -0.41; SMD=-0.74, 95% CI -1.10, -0.39).

Conclusions OEP implemented through digital technology effectively enhances static and dynamic balance, muscle strength, and self-efficacy in older adults. A training regimen of 12 weeks or more, with sessions occurring three or more times per week for 30 to 45 min, appears to be an effective approach for improving these outcomes based on the available evidence from the included studies. Future research should prioritize specific digital technologies and target populations, employing high-quality research designs to further explore these interventions, and consider new technologies such as wearables, to assess changes in fall prevalence.

Keywords Digital technology, Otago Exercise Program, Seniors, Balance, Muscle strength, Fall efficacy

Introduction

Population aging presents an urgent and growing public health challenge worldwide, particularly about the increasing prevalence of falls among older adults. According to the 2022 United Nations World Population Prospects, the percentage of people aged 65 and older is projected to increase from 10% in 2022 to 16% by 2050. This demographic shift not only increases the population of older adults but also significantly heightens the total number of falls, which are now recognized as a major health concern globally [1, 2]. The World Health Organization (WHO) estimates that falls occur annually in 28-35% of people aged 65 and older, and in 32-42% of those aged 75 and older [3]. Falls impact both the physical health and quality of life of older adults, while also placing a considerable financial strain on families and healthcare systems [4–6]. In China, between 1990 and 2019, the rate of elderly deaths, disability-adjusted life years, disability-lost life years, and life years lost due to falls increased sharply (294.9%, 220.7%, 213.8%, and 230.3%, respectively) [6]. Consequently, fall prevention in older adults has become a critical public health priority.

Falls result from multiple interacting factors, with physiological aspects such as balance ability and muscle strength identified as primary risk factors, as outlined by *China's Technical Guidelines for Fall Intervention in the Elderly* [7]. Additionally, fall efficacy, which refers to an individual's confidence in avoiding falls, is a crucial psychological factor that influences the likelihood of falls. Higher fall efficacy has been associated with increased physical activity and reduced fear of falling, which can reduce the risk of falls [8]. Numerous studies have demonstrated that exercises targeting these factors can significantly reduce the risk of falls [9, 10]. However, traditional exercises like tai chi and square dancing are limited by physical, technical, and environmental constraints, and were not specifically designed to prevent falls [10]. This highlights the need for developing multimodal exercise interventions that address both the physiological and psychological factors related to falls [11].

The Otago Exercise Program (OEP), developed and tested by the New Zealand Falls Prevention Research Group in New Zealand, is a multimodal, progressive, and evidence-based intervention aimed at reducing falls in older persons [12]. The Program consists of 17 strength and balance exercises paired with a walking plan, designed to improve physical fitness over 6 to 12 months. Physical therapists guide participants through these exercises that progressively increase in difficulty, with participants encouraged to complete 30-minutes sessions three times a week, along with walking at least twice a week. The program is validated for use across various settings, including home, outpatient clinics, community centers, and online platforms, and can be delivered in individual or in group formats for maximum flexibility and accessibility [13]. OEP has been widely adopted across several countries [14], including developed nations such as the United States [15], Canada [16], and Germany [17] as well as developing countries like China [18], Malaysia [19] and Iran [20]. Several meta-analyses have confirmed that OEP can effectively improve the balance ability, muscle strength, and fall efficacy of older adults [21–24].

Despite its effectiveness, traditional implementation of the OEP required in person coaching, which poses challenges in regions with a lack of trained personnel or suitable venues, particularly in remote areas [25]. The increasing use of digital technologies in healthcare offers a promising solution to these barriers [26, 27]. The WHO's *Global Strategy on Digital Health 2020–2025* promotes the widespread use of digital technologies to improve health outcomes across diverse populations and regions [27]. Digital technology refers to the use of modern computer systems to convert traditional information into digital formats that are recognizable by computers, such as video digitization of exercise instructions [28]. These digital tools, including wearable devices and mobile applications, provide opportunities to enhance healthcare delivery, especially in remote and underserved areas. Recent studies have explored digital adaptations of the OEP, such as wearable devices for progress monitoring [], augmented reality (AR) for virtual coaching [3031], online learning through mobile apps [18], and community-based training via pre-recorded Digital Video Discs (DVDs) [3233]. However, the effectiveness of these digital interventions in improving balance, muscle strength, and fall efficacy remains inconsistent, and a comprehensive review of the impact of digital technology-based OEP on fall prevention is lacking. This study aims to systematically review the effects of digital Technology-based OEP on these outcomes, analyzing factors such as duration, frequency, and participant age, to identify optimal intervention strategies.

Methods

This review was reported in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [34]. A completed checklist can be found in Additional file 1. The study protocol was registered in PROSPERO (registration number: CRD42022372728).

Search strategy

A literature search was conducted in EBSCO, PubMed, Web of Science, and China National Knowledge Infrastructure (core), and the core keywords identified included older*, "Otago Exercise Program", and fall. Near synonyms of the keywords were found through the PubMed MeSH database and other search engines. In addition to obtaining RCTs that provide OEP interventions based on digital technology, other experimental-type studies will be searched [see Additional file 2].

Search terms included (1) population: older*, elder*, ag*; and (2) intervention: "Otago Exercise Program", "modified otago", OEP; (3) outcomes: "falls efficacy", "fall rate", "modified fall efficacy scale", MFES, "morse fall scale", MFS, "activities-specific balance confidence (ABC) scale", "physiological profile assessment", "falls efficacy scale international", FES-I, balance, "berg balance scale", BBS, "one-leg stand test", "time up and go test", TUG, "gait speed", "short physical performance battery", SPPB, "6-minute walking test", 6MWT, "30-seconds sit-to-stand", strength, "4-stage balance test", 4SBT, "step test", etc.

These keywords were searched in the database in free combinations with close synonyms up to August 1, 2023. In addition, the relevant references listed in the retrieved literature were perused to prevent missing relevant literature.

Initially, two reviewers (ZH and GZ) conducted a database search and exported each study to the reference management program to weed out duplicates. Additionally, two independent reviewers (ZH and CL) screened the titles and abstracts found in the electronic database to find articles that were appropriate for full-text analyses. The reference lists of relevant original studies and review studies were also manually reviewed by two reviewers (ZH and CL). Group discussions with a third reviewer (WR) were used to resolve disagreements.

Inclusion and exclusion criteria

Inclusion and exclusion criteria, according to PICOS (population, intervention, comparison, outcomes, and study) [35], were as follows:

Inclusion criteria: (P) Population: elderly people (≥60 years old) with no significant cognitive impairment and no serious physical illness; (I) Intervention: OEP was implemented using digital technologies, which convert traditional information into computer-recognizable digital formats, such as video digitization of exercise instructions [28], such as sensors, AR, and mobile apps; (C) Comparison: studies with a comparison group, such as usual care, no intervention, or other standard fall prevention programs, were included. Both controlled trials and experimental studies without comparison groups were eligible if the effects of the OEP-based digital interventions could be clearly distinguished; (O) Outcomes: indicator includes balance, muscle strength, fall efficacy, etc.; (S) Study design: RCT, controlled trials or other experimental study.

Exclusion criteria: (1) interventions that were not implemented based on digital technology; (2) full text was not available; (3) incomplete data in the literature or unsuccessful contact with the author; (4) not written in English or Chinese.

Data extraction and management

In the included studies, two researchers (CL and ZH) separately extracted the following data: (1) study characteristics: year, country, authors, study design; (2) subject characteristics: mean age, gender, sample size; (3) intervention characteristics: intervention strategy, intervention period; and (4) outcomes: balance (static balance, dynamic balance), muscular strength, and fall efficacy. In cases of disagreement, a third researcher (RW) was consulted to settle the matter For missing data, the authors were contacted up to three times over four weeks to obtain the necessary information.

Risk of bias and quality assessment

The Cochrane Collaboration risk bias assessment tool was used to evaluate the study quality of RCTs, which was categorized into seven items: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other bias [36]. Each item was assessed into 3 levels of low, unclear, and high risk of bias. Each study was assessed as a whole based on the 7-item assessment, which was categorized into 3 levels of low risk of bias, unclear, and high risk of bias. Risk of bias figures will be generated by the software RevMan (Review Manager 5.3). Risk of bias will be assessed by two researchers (CL and ZH), and disagreements will be resolved by consensus or consultation with a third researcher (RW).

Statistical analysis

Meta-analysis of the included studies was performed using a random effects model. For studies presenting data via graphs (e.g., boxplot), the y-axis and graph length were used to estimate the mean and standard deviation (SD) [37, 38]; for studies reporting standard error of mean (SE), confidence interval (CI), or quartile, these data were converted to SD [39]. The formulas for the mean and SD pre- to post-change values were as follows: '$Mean_{change}$ = $Mean_{post}$ - $Mean_{pre}$' and 'SD_{change} = SQRT [$(SD_{pre}^2 + SD_{post}^2) - (2 \times Corr \times SD_{pre} \times SD_{post})$]', according to the Cochrane Collaboration Handbook guidelines, where the Correlation Coefficient was set to 0.5 [40]. The included studies used different methods for measurement, so standardized mean difference (SMD) and 95% CI were used to estimate effect values. We multiplied the raw data by (-1) before normalizing the data if smaller indicator outcome data indicates a better result [41]. Studies in which outcomes were reported in other formats (e.g., walking speed, physical function, etc.) or studies were reported in other study types (e.g., single-group before-and-after experiments, cases, etc.) were included in the systematic review only because the data could not be analyzed for meta-analysis [42, 43].

Statistical heterogeneity between studies was tested using the I^2 and Cochran Q-test. $I^2 \leq 25\%$, $25\% < I^2 \leq 50\%$, $50\% < I^2 \leq 75\%$, $I^2 > 75$ were defined as very low, low, moderate, and high heterogeneity, respectively [44]. The Egger method was used to test for publication bias [45]. If publication bias existed the effect on the results was assessed using trim-and-fill method by Duval and Tweedie [46]. Sensitivity analysis was used to test the reliability of the findings, i.e., removing one article at a time and testing whether there was a significant effect of each article on the combined effect. In addition, subgroup analyses were further used to determine whether the characteristics of the intervention influenced the effect size between studies. All statistics were performed using the software STATA (produced by StataCorp, College Station, TX, USA. https://www.stata.com/); $P < 0.05$ was defined as a significant difference.

Result

Study selection

A total of 476 potentially relevant studies were obtained from various databases and 173 duplicates were removed. Following the screening of titles and abstracts, 247 articles were excluded. After excluding 44 articles by reading the full text of the remaining 56 articles, a total of 12 articles were finally included, of which 10 were RCTs [17, 18, 29–33, 37, 38, 47], one was a single-group quasi-experimental study [43], and one was a case study [42]. The literature screening process is shown in Fig. 1.

Study characteristics

The 12 included studies were published between 2013 and 2022, with regional distribution in South Korea ($n=2$), USA ($n=2$), China ($n=2$), Greece ($n=1$), Germany ($n=1$), Portugal ($n=1$), Russia ($n=1$), Spain ($n=1$), and Canada ($n=1$). The sample size was 427 in total, with a mean age ranging from 63 to 85 years.

Among the included studies, the digital technologies used for OEP implementation can be categorized into three main types: online interventions, recorded videos, and wearable technologies. Online interventions included platforms such as Zoom for real-time training [42] and the WeChat group for online OEP videos and synchronized workouts [18, 47]. Recorded videos were delivered through various mediums, including computers or TVs [29], and DVDs [32, 33]. Wearable technologies were employed for motion sensor monitoring [17, 37], while some studies utilized augmented reality (AR) [30, 31, 38] and Kinect-based systems for tracking exercise performance [43].

Intervention period lasted 4–48 weeks, with a frequency of 1–7 times per week and durations of 20–60 min per session, totaling 480–6480 min. The most common training regimen was 30 min 3 times per week for 24 weeks for a total of 2160 min. Two publications implemented training in teams [33, 38] and the rest in individuals. In the control group, one article was on yoga training, one was on-site OEP, and the rest were routine.

The main outcome indicators included in the literature were categorized into three main groups: balance, muscle strength, and fall efficacy. **For balance**, static balance assessments included one-legged standing, 4-stage balance test (4SBT), and force plate (eye open values are mean (EO CoP-x), eye close center of pressure-x (EC CoP-x), eye open standard deviation-x (EO SD-x) and eye open height of ellipse (EO HoE). Dynamic balance included Time Up and Go Test (TUG), Berg Balance Scale (BBS), and step test (ST). **For muscle strength**, assessments included 30-second chair stand test, grip strength, and manual muscle test (MMT), measuring right and left dorsiflexion (Rt. dorsiflex; Lt. dorsiflex) and hamstring strength (Rt. ham; Lt. ham). **Fall efficacy**, reflecting an individual's fear of falling and their confidence in avoiding falls during various activities [48], was measured using scales such as short Falls Efficacy Scale International (FES-I), short FES-I, Confidence in falls efficacy and Balance-GREEK, Modified Fall Efficacy Scale, Morse Fall Scale, and Physiological Profile Assessment (Table 1).

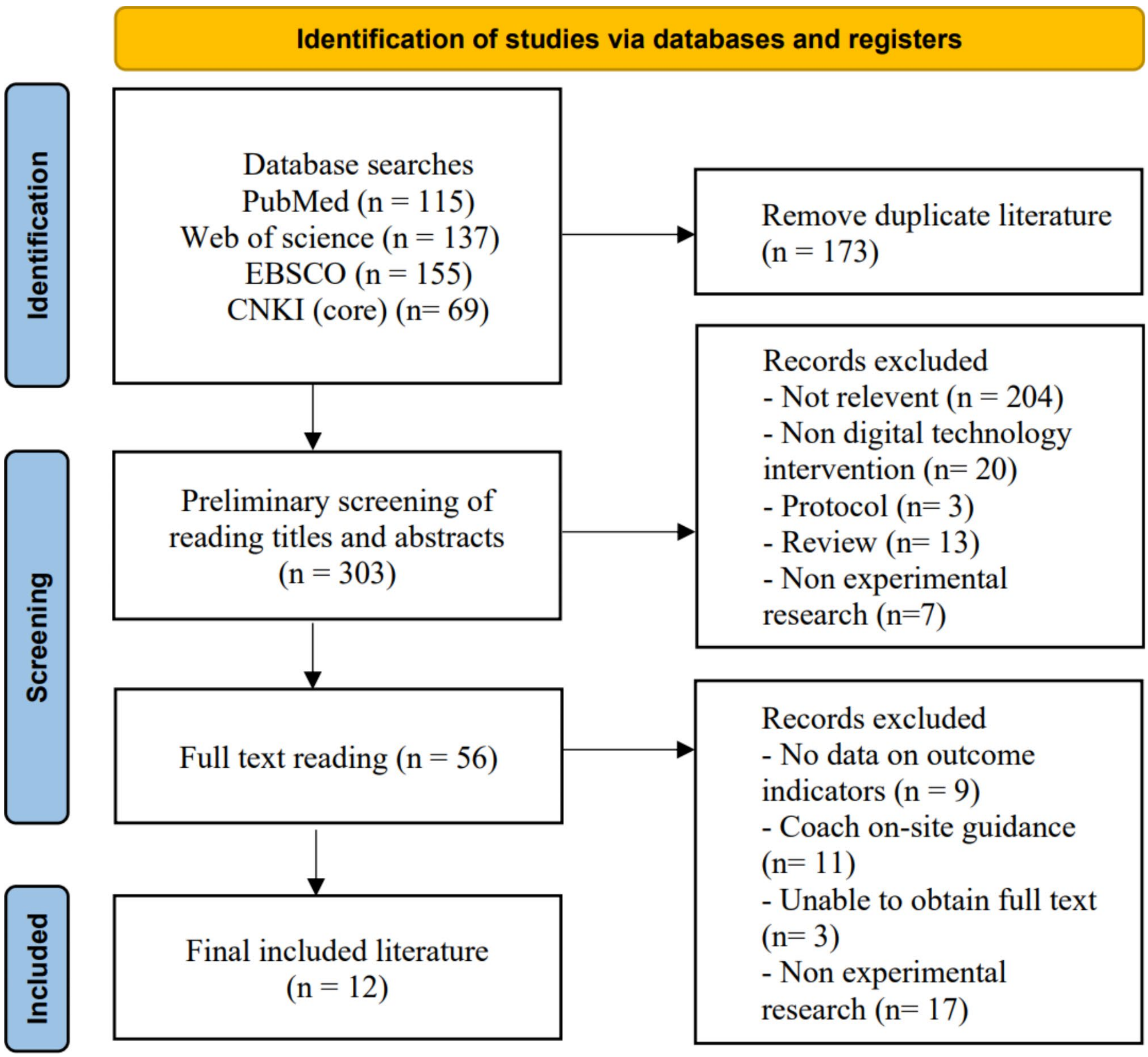

Fig. 1 Flow diagram of study selection

Risk of bias

Figures 2 and 3 show the risk of bias assessment of the 10 included studies; of these, 2 studies were classified as low risk of bias, 2 studies were classified as unclear risk of bias, and 6 as high risk of bias rating. Two studies employed a non-randomized approach for group allocation and concealment, while 5 studies did not specify whether allocation concealment was utilized.

Results of meta-analysis

Results of static balance ability

A random-effects meta-analysis, including 4 studies (7 effects) demonstrated that there was a significant improvement in the intervention group compared to the control group (SMD = 0.86, 95% CI 0.35–1.37, P = 0.001); the test for heterogeneity showed moderate heterogeneity (I^2 = 72%, P = 0.002) (Fig. 4). The Egger's test showed that there was no publication bias between studies (P = 0.43).

Results of dynamic balance ability

A random-effects meta-analysis, including 7 studies (11 effects) demonstrated that there was a significant improvement in the intervention group compared to the control group (SMD = 1.07, 95% CI 0.90–1.24, P < 0.001); the test for heterogeneity showed moderate heterogeneity (I^2 = 0.0%, P = 0.48) (Fig. 5). The Egger's test showed that there was no publication bias between studies (P = 0.27).

Table 1 Characteristics of included studies

Author(year)	Participants	Intervention	Outcomes
Lytras (2022) [29]	Sample:150 Mean age:70 ± 5.2	Type: RCT Intervention: computer/TV playback OEP Comparison group: routine Format: individuals Frequency: 12 months; 3 times per week; 45 min per session	Static balance: 4SBT Dynamic balance: TUG, BBS Muscle strength: 30-second chair stand test Fall efficacy: short FES-I, CONFbal-GREEK
Friedrich (2022) [30]	Sample: 15 Mean age: 84.8 ± 5.2	Type: RCT Intervention: motion sensor monitoring OEP implementation Comparison group: routine Format: individuals Frequency: 10 months; 1 time per week; 30 min per session	Dynamic balance: TUG
Hardy-Gostin (2022) [43]	Sample: 1 Mean age: 83	Type: case report Intervention: real-time OEP implementation and interaction through Zoom Format: individuals Frequency: 4 weeks; 3 times per week; 30 min per session	Static balance: one-leg stand Dynamic balance: TUG Muscle strength: 30-second chair stand test
Huang J (2021) [48]	Sample: 90 Mean age: 63.6 ± 13.7	Type: RCT Intervention: internet-based implementation of OEP Comparison group: Internet based implementation of routine rehabilitation Format: individuals Frequency: 12weeks; 7 time per weeks; 30–60 min per session	Dynamic balance: BBS
Martins (2020) [38]	Sample:34 Mean age: 83.2 ± 6.9	Type: RCT Intervention: wearable device monitoring Implementation OEP Comparison group: routine Format: individuals Frequency: 8 weeks; 3 times per week; 20 min per session	Static balance: 4SBT Dynamic balance: TUG, ST Muscle strength: 30-second chair stand test, grip strength
Gu Y (2020) [18]	Sample:60 Mean age: 74.9 ± 6.7	Type: RCT Intervention: WeChat mini program to watch OEP online Comparison group: routine Format: individuals Frequency: 24weeks; 3 times per week; 30 min per session	Dynamic balance: TUG, BBS Fall efficacy: MFES
Shubert (2020) [44]	Sample: 42 Mean age: 75.0 ± 9.1	Type: single-group quasi-experimental design Intervention: using a kinect camera, a computer, and a monitor to deliver OEP Format: individuals Frequency: 8 weeks; 3 times per week; 30 min per session	Static balance: 4ST Dynamic balance: TUG, BBS Muscle strength: 30-second chair stand test
Lee (2017) [31]	Sample: 20 Mean age: 72.6 ± 2.7	Type: RCT Intervention: implementation of OEP through AR technology Comparison group: yoga Format: individuals Frequency:12 weeks; 3 times per week;60 min per session	Static balance: force plate Muscle strength: MMT Fall efficacy: MFS
Baez (2017) [39]	Sample: 40 Mean age: 70.9 ± 8.2	Type: RCT Intervention: AR virtual team training Comparison group: routine Format: individuals Frequency: 10 weeks;2 times per week; 30–40 min per session	Muscle strength: 30-second chair stand test

Table 1 (continued)

Author(year)	Participants	Intervention	Outcomes
Davis (2016) [33]	Sample: 82 Mean age: 79.6 ± 4.5	Type: RCT Intervention: delivering OEP at home via DVD Comparison group: routine Format: individuals Frequency: 6 months; 3 times a week; 30 min per session	Dynamic balance: ST Muscle strength: 30-second chair stand test Fall efficacy: PPA
Benavent (2015) [34]	Sample: 51 Mean age: 69.1 ± 5.2	Type: RCT Intervention: provide team OEP through the DVD room Comparison group: routine Format: group Frequency: 4 months; 3 times per week; 45 min per session	Static balance: one-leg stand Dynamic balance: BBS, TUG
Yoo (2013) [32]	Sample: 21 Mean age: 74.3 ± 6.6	Type: RCT Intervention: implementation of OEP through AR technology Comparison group: OEP implemented face-to-face Format: individuals Frequency: 12 weeks; 3 times per week; 60 min per session	Dynamic balance: BBS Fall efficacy: FES-I

AR: augmented reality; BBS: Berg Balance Scale; CONFbal-GREEK: Confidence in falls self-efficacy and Balance- GREEK; DVD: Digital Video Disc; 4SBT: 4-stage balance test; FES-I: Falls Efficacy Scale International; MFES: Modified Fall Efficacy Scale; MFS: Morse Fall Scale; MMT: Manual Muscle Test; OEP: Otago Exercise Program; PPA: Physiological Profile Assessment; short FES-I: short Falls Efficacy Scale International; ST: Step Test; TUG: Time Up and Go Test

Results of muscle strength

A random-effects meta-analysis, including 4 studies (8 effects) demonstrated that there was a significant improvement in the intervention group compared to the control group (SMD = 0.43, 95% CI 0.17–0.69, P = 0.001); the test for heterogeneity showed moderate heterogeneity (I^2 = 18.3%, P = 0.29) (Fig. 6). The Egger's test showed that there was no publication bias between studies (P = 0.24).

Results of fall efficacy

A random-effects meta-analysis, including 5 studies (6 effects) demonstrated that there was a significant improvement in the intervention group compared to the control group (SMD=-0.70, 95% CI -0.98, -0.41, P < 0.001); the test for heterogeneity showed moderate heterogeneity (I^2 = 45.9%, P = 0.10) (Fig. 7). The Egger's test showed that there was no publication bias between studies (P = 0.71).

Robustness of the results

Sensitivity analyses were performed on the results to test the robustness of the findings. Removing one study each time in order to perform the meta-analysis again revealed no significant change in the results, indicating reliable findings.

Subgroup analysis

Subgroup analysis by period '≥12 weeks', frequency '≥3 times/week', and duration '≤45 minutes per session', respectively, showed significant improvements on static balance (SMD = 0.73, 95% CI 0.21–1.25; SMD = 0.86, 95% CI 0.35–1.37; SMD = 1.10, 95% CI 0.31–1.89), dynamic balance (SMD = 1.08, 95% CI 0.88–1.28; SMD = 1.01, 95% CI 0.93–1.27; SMD = 1.07, 95% CI 0.89–1.25), muscle strength (SMD = 0.43, 95% CI 0.10–0.75; SMD = 0.54, 95% CI 0.30–0.77; SMD = 0.53, 95% CI 0.19–0.87), and fall efficacy (SMD=-0.75, 95% CI -1.39, -0.11; SMD=-0.70, 95% CI -0.98, -0.41; SMD=-0.74, 95% CI -1.10, -0.39) in the intervention group. See Table 2.

Discussion

Summary of evidence

Balance, muscle strength, and fall efficacy are critical outcome markers for predicting fall risk in older adults [49–51]. This meta-analysis is the first comprehensive review of the effectiveness of the OEP delivered via digital technology. The findings demonstrate that digitally delivered OEP achieved outcomes comparable to traditional in-person delivery, with added benefits of convenience and scalability [21, 23]. Subgroup analyses highlight that a training duration of at least 12 weeks, with sessions conducted three or more times per week for up to 45 min, significantly enhances static and dynamic balance,

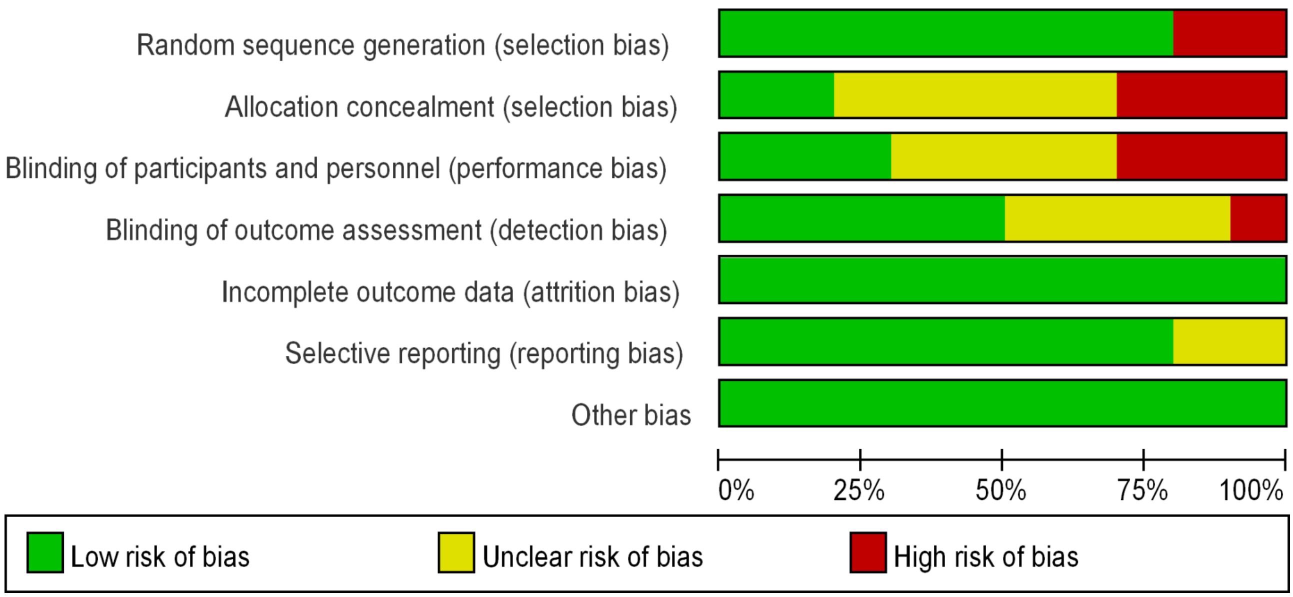

Fig. 2 Risk of bias graph: each risk of bias item presented as percentages

muscle strength, and fall efficacy. Importantly, the digital OEP intervention yielded notable improvements in muscle strength among individuals aged 80 years and above whereas no significant changes were observed in those under 80. These results emphasize the potential of digital technology-based OEP as an effective and scalable alternative to traditional delivery methods, addressing common barriers such as limited access to trained personnel and appropriate facilities.

Comparison with previous systematic review and meta-analysis

OEP significantly decreased mortality and falls in older adults, according to a meta-analysis by Thomas et al. [21]. However, this study only focused on adherence, suggesting that greater adherence to an exercise program might result in a more significant intervention effect. It did not explore the potential underlying mechanisms in detail. OEP consists of 17 balance and strength-building exercises, along with a walking program, designed to lower the risk of falls in older individuals through increased physical functioning. Consequently, improvements in physiological and psychological indicators may have contributed to the observed reductions in mortality and fall rates in this study. Our study adds further evidence to the body of knowledge in this field by demonstrating significant increases in balance, muscle strength, and fall efficacy. Two meta-analyses on balance and fall efficacy in non-healthy populations were also undertaken, and the results were also compatible with this study. Chiu et al.'s meta-analysis [23] likewise investigated the effects of OEP on static and dynamic balance in older persons. Together, these quantitative studies show that OEP, including OEP based on digital technology, is effective on reducing the risk of falls in older persons while also enhancing balance, muscle strength, and fall performance.

Notably, a systematic review by Martin et al. [52] concluded that older adults who are at risk for falling may benefit from technology-based interventions to enhance physical function, which may be a way to increase exercise adherence. The objective of this study was to ascertain the effects of a modified version of OEP, including digital technology-based implementation, on balance and physical function. It was discovered that the modified version of the intervention was helpful for the improvement of physical function, especially balance, demonstrated good acceptance, and met the expectations of the participants. Fall prevention programs should be customized to each individual because many different factors can cause falls. Examples of such characteristics include personal needs, preferences, and interests. Therefore, to adapt to various contexts, scientific and appropriate modifications of traditional OEP are required, such as technical support, other content assistance, etc. The decline in physical functioning among the elderly is accelerated by the current global trend of decreased physical activity, which implies a higher risk of falls. The digital implementation of the OEP represents offers a promising alternative to traditional in-person coaching. Our findings indicate that digital delivery can achieve equivalent, if not superior, outcomes compared to traditional methods. This makes it a highly effective and innovative approach for delivering evidence-based fall prevention interventions.

According to data, between 2013 and 2017, the number of Internet users in China over the age of 60 increased

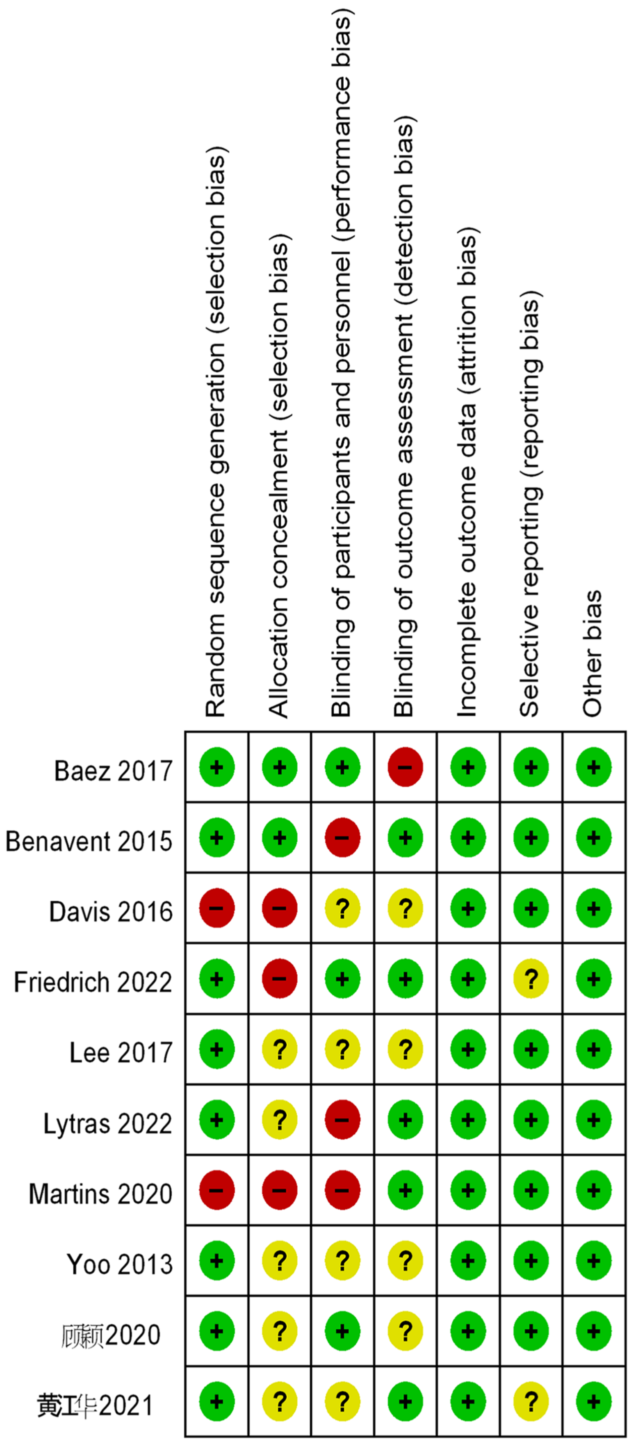

Fig. 3 Risk of bias of included studies

from 11.72 million to 40.14 million, and the percentage of older adults who use the internet increased from 5.8 to 16.6% [53]. Additionally, social media is being gradually used to manage senior citizens' health [54]. Furthermore, the two studies included in this review [30, 31] implemented OEP using augmented reality (AR) technology, allowing users to simulate a real-world environment by donning glasses and tracking the movements displayed. The computer then sent this information to the head-mounted display, which could significantly increase participation, and all endpoints demonstrated positive results. Therefore, using digital technologies to implement interventions that are not constrained by time or space may be a promising strategy.

Effects on balance ability and muscle strength

The digital adaptation of OEP enables older adults to effectively engage in both static and dynamic balance exercises remotely. These exercises, which are core components of the OEP, significantly improve balance, by incorporating both static exercises (e.g., standing on one leg) and dynamic exercises (e.g., walking and heel-to-toe movements). Digital delivery of OEP enhances accessibility by eliminating common barriers to in-person sessions, such as travel or scheduling conflicts. Additionally, digital platforms can offer personalized feedback and progress tracking, which may foster motivation and improve adherence to the program. While resistance exercises targeting lower body muscles such as the quadriceps, hamstrings, and calves are commonly recommended for older adults to help maintain balance and mitigate age-related muscle loss [55, 56], the specific impact of the digital delivery method on these outcomes was not directly assessed in the current study and awaits further investigation.

Effects on fall efficacy

In 1990, researcher Tinetti introduced the concept of fall efficacy, a variable reflecting the level of fear associated with falling and the degree of self-confidence in avoiding falls during various activities [48]. This concept underscores the importance of considering psychological factors related to falls, in addition to personal physiological variables, pharmacological considerations, and objective environmental factors. Physical inactivity in older adults can increase fall-related anxiety, which negatively impacts both their physical and mental well-being [57]. On the other hand, reduced physical activity further elevates the risk of falls [58]. This study found that utilizing digital technology in conducting OEP significantly enhanced older adults' ability to prevent falls. This improvement is attributable to the fact that OEP's instructional content encompasses functional movements commonly encountered in daily life, such as sit-to-stand, backward walking, walking and turning, and stair walking [14]. The OEP's emphasis on balance and resistance training helped older adults reduce their fear of falling and improve their confidence during activities requiring balance.

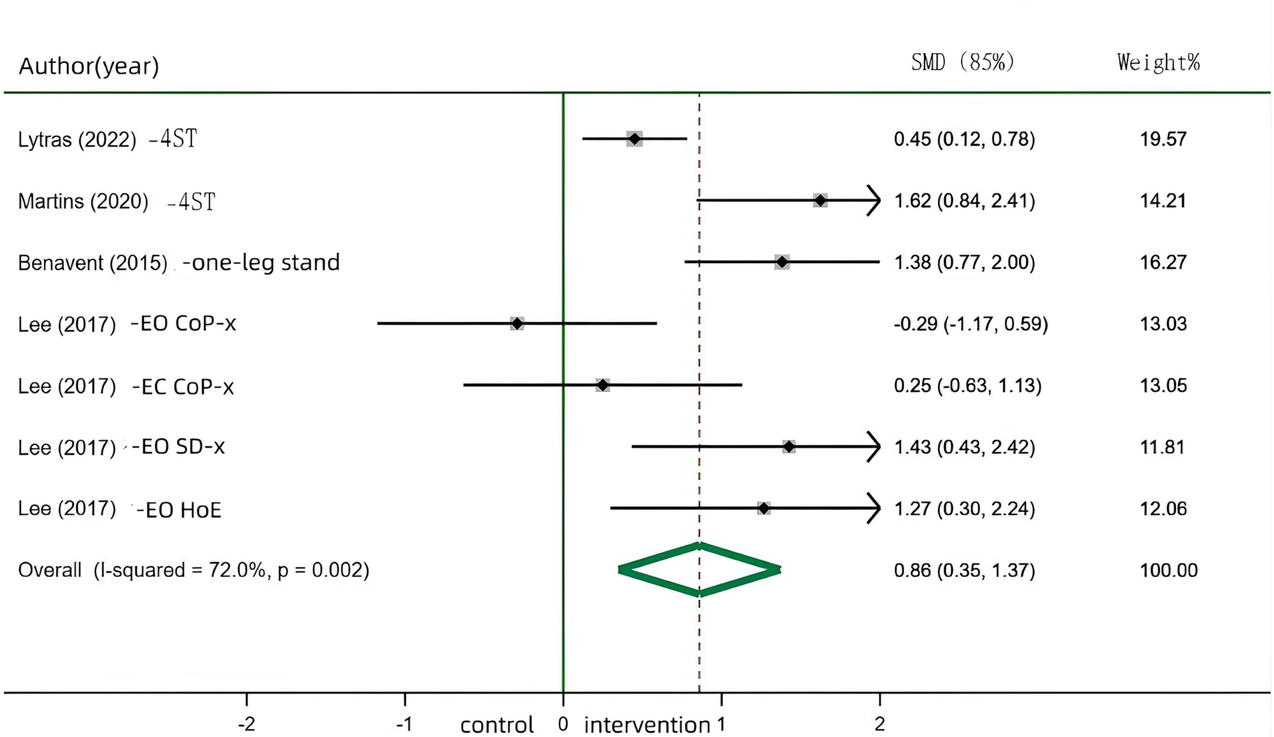

Fig. 4 Meta-analysis of effects of intervention versus control on static balance. CoP-x: center of pressure; EO: eye open; EC: eye close; HoE: height of ellipse

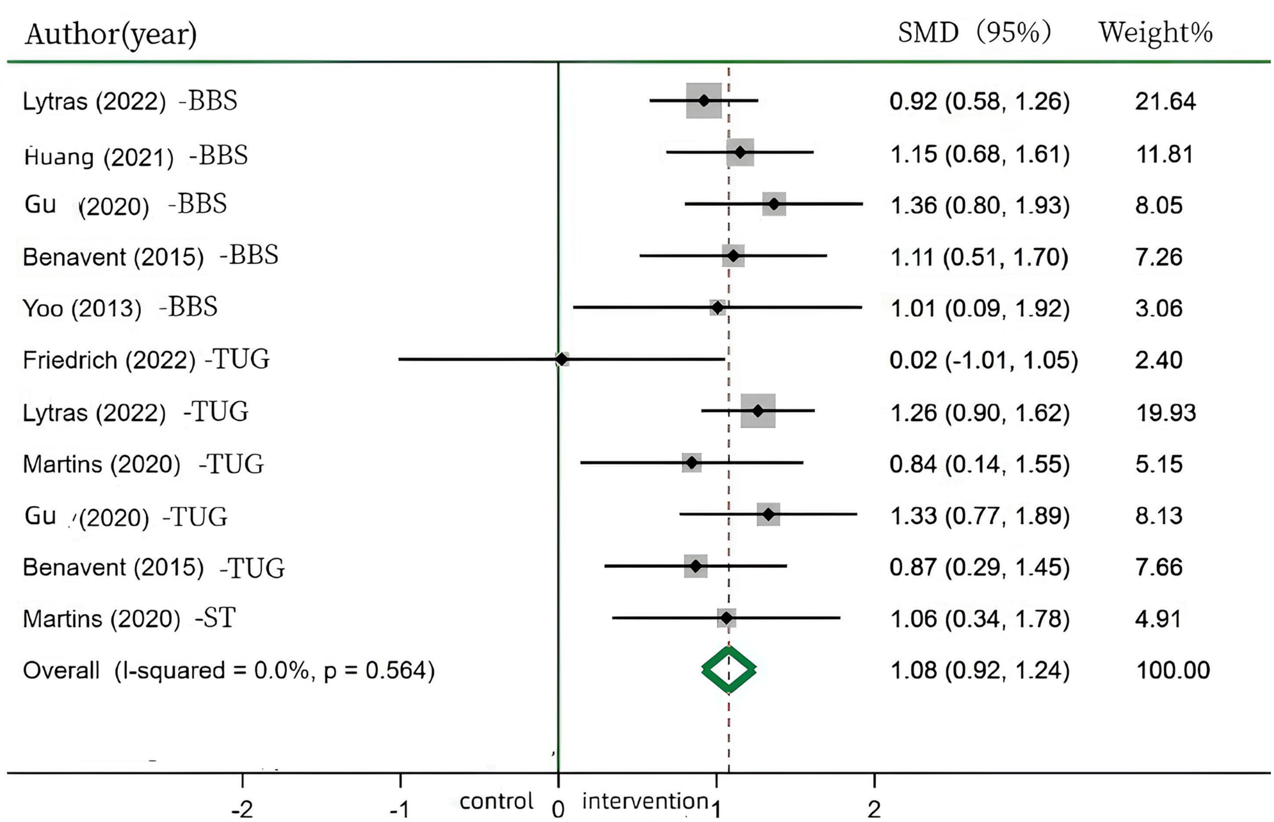

Fig. 5 Meta-analysis of effects of intervention versus control on dynamic balance

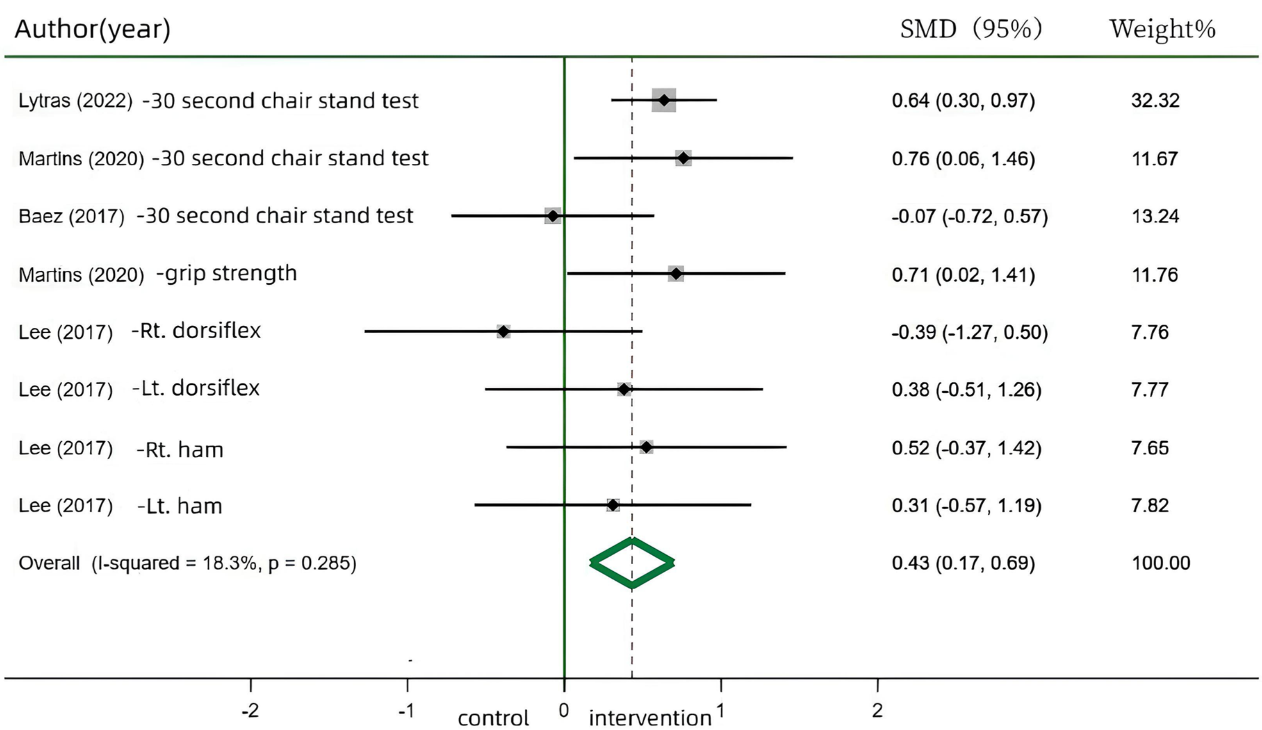

Fig. 6 Meta-analysis of effects of intervention versus control on muscle strength

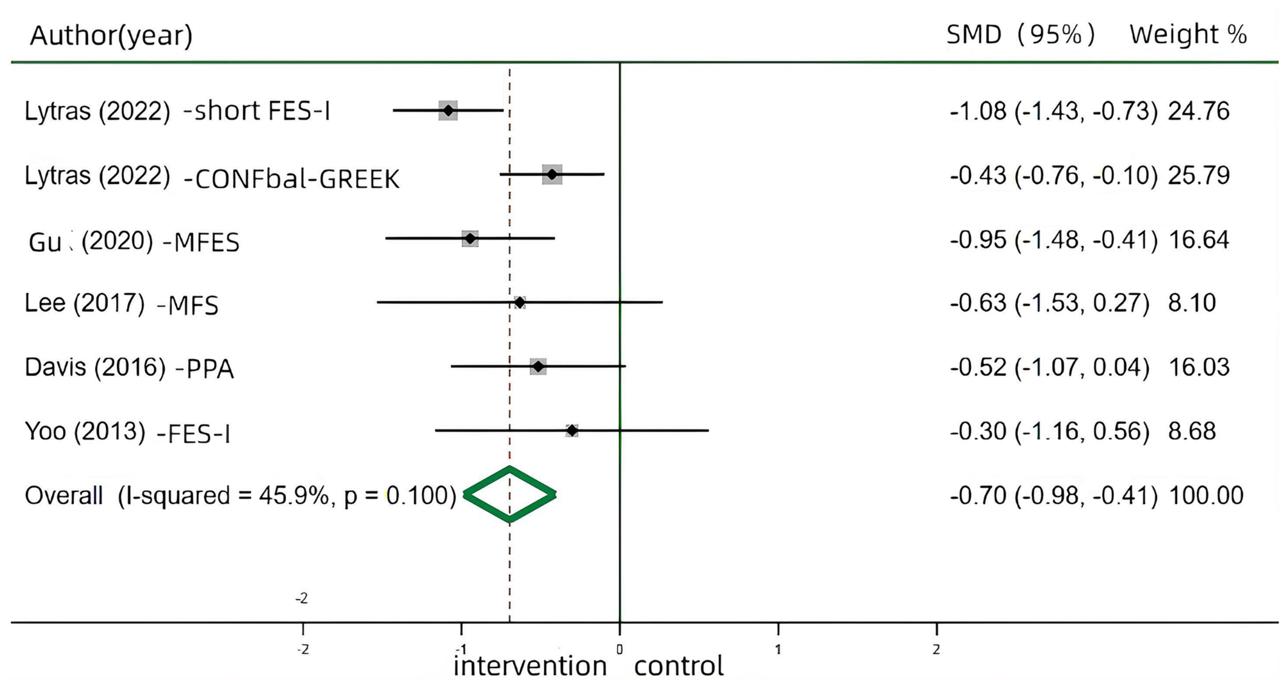

Fig. 7 Meta-analysis of effects of intervention versus control on fall efficacy

Characterization of intervention

Meta-analysis by Zhang et al. indicated that 12 weeks of OEP did not effectively improve fall efficacy in older adults, and suggested that the training period should be at least16 weeks or more [59]. In contrast, our study found that a training period of 12 weeks or longer yielded significant effects. The inconsistency in the results may be related to the different methods of implementing OEP; the use of digital technology is more convenient and innovative, potentially enhancing adherence

Table 2 Subgroup analyses on the effect of intervention versus control on balance ability, muscle strength and fall efficacy in older adults

Factors	Static balance		Dynamic balance		Muscle strength		Fall efficacy	
	N(7)	Effect size (95%)	N(11)	Effect size (95%)	N(8)	Effect size (95%)	N(6)	Effect size (95%)
Period								
≥ 12 weeks	6	0.73(0.21, 1.25)	9	1.08(0.88, 1.28)	5	0.43 (0.10, 0.75)	2	-0.75(-1.39, -0.11)
< 12 weeks	1	1.62(0.84, 2.41)	2	0.95(0.45, 1.45)	3	0.45 (-0.09, 0.99)	4	-0.66(-0.99, -0.33)
Frequency								
≥ 3 times	7	0.86(0.35, 1.37)	10	1.01(0.93, 1.27)	7	0.54(0.30, 0.77)	6	-0.70(-0.98, -0.41)
< 3 times	0	N/A	1	0.02(-1.01, 1.05)	1	-0.07(-0.72, 0.57)	0	N/A
Duration								
> 45 min	4	0.64(-0.17, 1.44)	1	1.01(0.09, 1.92)	4	0.20(-0.24, 0.65)	4	-0.46(-1.08, 0.16)
≤ 45 min	3	1.10(0.31, 1.89)	10	1.07(0.89, 1.25)	4	0.53(0.19, 0.87)	2	-0.74(-1.10, -0.39)
Total								
> 2160 min	1	0.45(0.12, 0.78)	2	1.09(0.75, 1.42)	1	0.64(0.30, 0.97)	2	-0.75(-1.39, -0.11)
≤ 2160 min	6	0.96(0.35, 1.57)	9	1.05(0.82, 1.29)	7	0.34(0.02, 0.65)	4	-0.66(-0.99, -0.33)
Age								
≥ 80	6	0.73(0.21, 1.25)	3	0.75(0.21, 1.28)	6	0.74(0.24, 1.23)	0	N/A
< 80	1	1.62(0.84, 2.41)	8	1.12(0.93, 1.30)	2	0.31(-0.02, 0.64)	6	-0.70(-0.98, -0.41)
Type								
Videos	2	0.88(-0.03,1.79)	5	1.07(0.88, 1.27)	1	0.64(0.30, 0.97)	3	-0.69(-1.14, -0.24)
Wearables	5	0.85(0.10,1.60)	4	0.82(0.41, 1.22)	7	0.34(0.02, 0.65)	2	-0.46(-1.08, 0.16)
Online	0	N/A	2	1.35(0.95, 1.74)		N/A	1	-0.95(-1.48, -0.41)

N/A: Not Applicable; Total: total duration = period × frequency × duration

and increasing the likelihood of demonstrating training effects [60, 61]. In addition, the results of Meta-analysis by Chiu et al. [14] differed from our study, as Chiu et al. found that a duration of more than 30 min per session and a frequency of three or more times per week had a significant interventional effect on static balance, dynamic balance, and fall efficacy. The optimal frequency for this study is consistent with the findings of our study and with the recommendation of the OEP manual to train three times per week. In terms of the duration of each intervention, this study found that subgroups with an intervention time of 45 min or more had significant effects. Excepting one article with an intervention time of 20 min, the other included articles had intervention times of 30 min and 45 min, which were not significantly different from the findings of Chiu et al. Therefore, 30 to 45 min per session may represent a more effective intervention duration.

Strengths and limitations

This study has the following strengths: (1) it strictly adheres to PRISMA guidelines, ensuring transparency and reliability in the reporting of the systematic review and meta-analysis; and (2) to our knowledge, it is the first systematic review exploring the effectiveness of the OEP implemented through digital technologies, filling a critical gap in the literature. However, this study also has several limitations: (1) although the overall statistical heterogeneity is low, there is a large variety of digital technologies, and future research should focus on the intervention effects of specific digital technologies; (2) the overall quality of the included literature is low, but the literature on the implementation of the OEP based on digital technologies has been obtained through a comprehensive search strategy, which is a useful exploration, necessitating the need for more high-quality RCTs in the future; (3) The subjects in the literature had a variety of illnesses and were not categorized into subgroups, such as diabetes [29] and arthritis [43], even though they did not exhibit significant cognitive impairments or serious physical conditions. Future intervention studies targeting specific populations are needed; and (4) the included studies did not assess fall rates, limiting the comprehensive understanding and application of the intervention effects.

Conclusions

OEP implemented based on digital technology is effective in improving static and dynamic balance, and muscle strength, as well as improving self-efficacy of falls and lowering fear of falling in older adults. The best program available to help older adults improve their balance, muscle strength, and fall efficacy may involve training for 12 weeks or longer, three or more times per week, for 30 to 45 min each time. Future research should be conducted using high-quality research designs, with a specific focus on particular digital technologies and populations, and consideration of new technologies such as wearables, to assess changes in fall prevalence.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions

ZH, RW, HW and GZ contributed to the conception and design of the review. ZH, GZ, RW and CL applied the search strategy. ZH, GZ, RW and CL applied the selection criteria. CL and ZH completed the assessment of the risk of bias. ZH, HW and GZ analyzed the data and interpreted data. ZH drafted this manuscript. HW, YZ, YX, AX and JY edited this manuscript. HW directed the experimental redesign and led the response to reviewer feedback.

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Data availability

All data generated or analyzed during this study are included in this published article and its supplementary information files.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Patient consent statement

Patient consent statement to confirm that the patient has consented to having their personal information or images included in the article.

Guarantor

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Competing interests

The authors declare no competing interests.

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References

1. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. The 2022 Revision of World Population Prospects. Available online: https://population.un.org/wpp/
2. Garbin A J, Fisher BE. The interplay between fear of falling, Balance Performance, and Future Falls: Data from the National Health and Aging trends Study. J Geriatr Phys Ther. 2023;46(2):110–5.
3. World Health Organization. Who Global Report On Falls Prevention in Older Age. 2008. Available online: https://www.who.int/publications/i/item/9789241563536
4. Peng K, Tian M, Andersen M, et al. Incidence, risk factors and economic burden of fall-related injuries in older Chinese people: a systematic review. Inj Prev. 2019;25(1):4–12.
5. Zhang K, Qi J, Zuo P, et al. The mortality trends of falls among the elderly adults in the mainland of China, 2013–2020: a population-based study through the National Disease Surveillance points system. Lancet Reg Health West Pac. 2022;19:100336.
6. Hu Y, Guo R, Min S et al. Disease burden on falls among older adults in China, 1990–2019 . Modern Preventive Medicine, 2021,48(09): 1542–1545. [In Chinese]. https://doi.org/10.1003-8507(2021)09-1542-05.
7. Ministry of Health of China. Notice of the Disease Prevention and Control Bureau of the Ministry of Health on Issuing a Series of Technical Guidelines for Injury Intervention. Available online: http://www.nhc.gov.cn/jkj/s5888/201109/d8f39b224bd144f4946b38491fa015dd.shtml
8. Chan J, Klainin-Yobas P, Chi Y, et al. The effectiveness of e-interventions on fall, neuromuscular functions and quality of life in community-dwelling older adults: a systematic review and meta-analysis. Int J Nurs Stud. 2021;113:103784.
9. Thomas E, Battaglia G, Patti A, et al. Physical activity programs for balance and fall prevention in elderly: a systematic review. Med (Baltim). 2019;98(27):e16218.
10. Sherrington C, Fairhall N J, Wallbank G K, et al. Exercise for preventing falls in older people living in the community. Cochrane Database Syst Rev. 2019;1:D12424.
11. Cress M E, Buchner D M, Prohaska T, et al. Best practices for physical activity programs and behavior counseling in older adult populations. J Aging Phys Act. 2005;13(1):61–74.
12. Campbell A J, Robertson M C, Gardner M M, et al. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. BMJ. 1997;315(7115):1065–9.
13. Campbell AJ, Robertson MC. Otago exercise programme to prevent falls in older adults. Wellington: ACC Thinksafe. 2003;3.
14. Health C F A. A. Carolina Geriatric Workforce Enhancement Program (CGWEP)-The Otago Exercise Program. Available online: https://www.med.unc.edu/aging/cgwep/courses/otago-exercise-program/
15. Shubert T E, Smith M L, Jiang L, et al. Disseminating the Otago Exercise Program in the United States: Perceived and actual physical performance improvements from Participants. J Appl Gerontol. 2018;37(1):79–98.
16. Davis JC, Khan K, Mansournia MA, et al. A 'case-mix' approach to understand adherence trajectories for a falls prevention exercise intervention: a longitudinal cohort study. Maturitas. 2021;147:1–6.
17. Friedrich B, Lubbe C, Steen E E et al. Using sensor graphs for monitoring the effect on the performance of the OTAGO exercise program in older adults. Sens (Basel). 2022;22(2):493.
18. Gu Y, Shen Y, Yu X et al. Application effect of Otago exercise programme in the elderly with the fear of falling . Chinese Nursing Research, 2020,34(07): 1253–1256. [In Chinese]. https://doi.org/10.12102/j.issn.1009–6493.2020.07.031.
19. Mat S, NG C T TANPJ, et al. Effect of Modified Otago exercises on postural balance, fear of falling, and fall risk in older fallers with knee osteoarthritis and impaired gait and balance: a secondary Analysis. PM R. 2018;10(3):254–62.
20. Dadgari A, Aizan H T, Hakim M N, et al. Randomized Control trials on Otago Exercise Program (OEP) to Reduce Falls among Elderly Community dwellers in Shahroud, Iran. Iran Red Crescent Med J. 2016;18(5):e26340.
21. Thomas S, Mackintosh S. Does the 'Otago exercise programme' reduce mortality and falls in older adults? A systematic review and meta-analysis. Age Ageing. 2010;39(6):681–7.
22. Yang Y, Wang K, Liu H, et al. The impact of Otago exercise programme on the prevention of falls in older adult: a systematic review. Front Public Health. 2022;10:953593.
23. Chiu H L, Yeh T T, Lo Y T, et al. The effects of the Otago Exercise Programme on actual and perceived balance in older adults: a meta-analysis. PLoS ONE. 2021;16(8):e255780.
24. Han J, Wang H, Ding Y, et al. Effect of Otago exercise on fear of falling in older adults: a systematic review and meta-analysis. BMC Sports Sci Med Rehabil. 2024;16(1):132.

25. Wadhwaniya S, Alonge O, UL B M et al. Epidemiology of fall Injury in Rural Bangladesh. Int J Environ Res Public Health, 2017,14(8).
26. Dettori M. Castiglia P. COVID-19 and Digital Health: evolution, perspectives and Opportunities. Int J Environ Res Public Health, 2022,19(14).
27. Global strategy on digital. health2020-2025. Geneva: World Health Organization; 2021.
28. National Library of Medicine Digital Technology (MeSH). Available online: https://www.ncbi.nlm.nih.gov/mesh/2051971
29. Lytras D, Sykaras E, Iakovidis P, et al. Effects of a modified Otago exercise program delivered through outpatient physical therapy to community-dwelling older adult fallers in Greece during the COVID-19 pandemic: a controlled, randomized, multicenter trial. Eur Geriatr Med. 2022;13(4):893–906.
30. Lee J, Yoo H N, Lee BH. Effects of augmented reality-based Otago exercise on balance, gait, and physical factors in elderly women to prevent falls: a randomized controlled trial. J Phys Ther Sci. 2017;29(9):1586–9.
31. Yoo H N Chunge, Lee B H. The effects of Augmented reality-based Otago Exercise on Balance, Gait, and Falls Efficacy of Elderly Women. J Phys Ther Sci. 2013;25(7):797–801.
32. Davis JC, HSU C L, Cheung W, et al. Can the Otago falls prevention program be delivered by video? A feasibility study. BMJ Open Sport Exerc Med. 2016;2(1):e59.
33. Benavent-Caballer V, Rosado-Calatayud P, Segura-Orti E, et al. The effectiveness of a video-supported group-based Otago exercise programme on physical performance in community-dwelling older adults: a preliminary study. Physiotherapy. 2016;102(3):280–6.
34. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009;339:b2535.
35. Liberati A, Altman D G, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. BMJ. 2009;339:b2700.
36. Higgins JPT G S. Cochrane Handbook for Systematic Reviews of Interventions. . Chichester, UK: Wiley; 2008.
37. Martins A C, Guia D, Saraiva M et al. Effects of a modified Otago Exercise Program on the functional abilities and social participation of older adults living in the community-the AGA@4life Model. Int J Environ Res Public Health, 2020,17(4).
38. Baez M, Khaghani F I, Ibarra F, et al. Effects of online group exercises for older adults on physical, psychological and social wellbeing: a randomized pilot trial. PeerJ. 2017;5:e3150.
39. Thiessen P H, Barrowman N, Garg A X. Imputing variance estimates do not alter the conclusions of a meta-analysis with continuous outcomes: a case study of changes in renal function after living kidney donation. J Clin Epidemiol. 2007;60(3):228–40.
40. Jonathan J Deeks J P H. D. Chapter 10: Analysing data and undertaking meta-analyses. Available online: https://training.cochrane.org/handbook/current/chapter-10
41. He Z, Wu H, Yu F, et al. Effects of Smartphone-based interventions on physical activity in children and adolescents: systematic review and Meta-analysis. JMIR Mhealth Uhealth. 2021;9(2):e22601.
42. Hardy-Gostin C J, Negley K J, Bender-Burnett JJ. Otago Exercise Program Delivery using Digital Practice: a prospective case Report. J Frailty Sarcopenia Falls. 2022;7(1):47–51.
43. Shubert T E, Chokshi A, Mendes V M, et al. Stand Tall-A virtual translation of the Otago Exercise Program. J Geriatr Phys Ther. 2020;43(3):120–7.
44. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med. 2002;21(11):1539–58.
45. Egger M, Davey S G, Schneider M, et al. Bias in meta-analysis detected by a simple, graphical test. BMJ. 1997;315(7109):629–34.
46. Weinhandl E D Duvals. Generalization of trim and fill for application in meta-regression. Res Synth Methods. 2012;3(1):51–67.
47. Huang J. Application of Otago exercise training based on internet + in home rehabilitation of stroke patients. University Of South China, 2021. [In Chinese].
48. Tinetti M E, Richman D. Falls efficacy as a measure of fear of falling. J Gerontol. 1990;45(6):P239–43.
49. Blodgett JM, Hardy R, Davis D, et al. One-Legged Balance performance and fall risk in Mid and later life: longitudinal evidence from a British birth Cohort. Am J Prev Med. 2022;63(6):997–1006.
50. Granacher U, Gollhofer A, Hortobagyi T, et al. The importance of trunk muscle strength for balance, functional performance, and fall prevention in seniors: a systematic review. Sports Med. 2013;43(7):627–41.
51. Yoshikawa A, Ramirez G, Smith ML, et al. Systematic review and meta-analysis of fear of falling and fall-related efficacy in a widely disseminated community-based fall prevention program. Arch Gerontol Geriatr. 2020;91:104235.
52. Martins A C, Santos C, Silva C, et al. Does modified Otago Exercise Program improves balance in older people? A systematic review. Prev Med Rep. 2018;11:231–9.
53. Zhou Y. The Rising of Digital Vulnerable Group. The influential factors of WeChat Adoption and Use among Senior citizens . Journalism Communication. 2018;25(07):66–86. [In Chinese].
54. Alanzi T. Role of Social Media in Diabetes Management in the Middle East Region: systematic Review. J Med Internet Res. 2018;20(2):e58.
55. Aartolahti E, Lonnroos E. Long-term strength and balance training in prevention of decline in muscle strength and mobility in older adults. Aging Clin Exp Res. 2020;32(1):59–66.
56. Muehlbauer T, Gollhofer A. Associations between measures of Balance and Lower-Extremity Muscle Strength/Power in Healthy Individuals across the Lifespan: a systematic review and Meta-Analysis. Sports Med. 2015;45(12):1671–92.
57. Friedman SM, Munoz B, West S K, et al. Falls and fear of falling: which comes first? A longitudinal prediction model suggests strategies for primary and secondary prevention. J Am Geriatr Soc. 2002;50(8):1329–35.
58. Low S T, Balaraman T. Physical activity level and fall risk among community-dwelling older adults. J Phys Ther Sci. 2017;29(7):1121–4.
59. Zhang Z. Effectiveness of Otago family exercise program in preventing daily fall injuries in the elderly. Chin J Rehabilitation Med. 2018;33(02):200–5. https://doi.org/10.3969/j.issn.1001-1242.2018.02.015. [In Chinese].
60. Heudel P E, Ait I M Favierb, et al. Can Digital Health improve therapeutic compliance in Oncology?. JCO Clin Cancer Inf. 2024;8:e2400205.
61. Perez-Jover V, Sala-Gonzalez M, Guilabert M, et al. Mobile apps for increasing treatment adherence: systematic Review. J Med Internet Res. 2019;21(6):e12505.