The effects of the Otago Exercise Programme on actual and perceived balance in older adults: A meta-analysis

Huei-Ling Chiu¹, Ting-Ting Yeh², Yun-Ting Lo¹, Pei-Jung Liang³, Shu-Chun Lee¹*

¹ School of Gerontology Health Management, College of Nursing, Taipei Medical University, Taipei, Taiwan, ² Master Degree Program in Healthcare Industry, Chang Gung University, Taoyuan, Taiwan, ³ Department of Rehabilitation Medicine, Taipei Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, New Taipei City, Taiwan

* sclee@tmu.edu.tw

Abstract

Objective
Falls are serious issues in older populations. Balance problems are a major cause of falls and may lead to fear of falling and decreased balance confidence. The Otago Exercise Programme (OEP) is an effective fall prevention program that benefits balance function and fear of falling. The primary aim of the meta-analysis was to investigate the effectiveness of the OEP intervention on actual balance performance (i.e., static, dynamic, proactive or reactive balance) and perceived balance ability (i.e., balance confidence or fear of falling) for older adults; the secondary aim was to examine which OEP protocol most improves balance in older adults.

Methods
A systematic electronic review search was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analysis guidelines to identify randomized controlled trials (RCTs) investigating the effects of the OEP on actual balance performance and perceived balance ability in healthy older adults, and examining which OEP protocol and intervention format most improves balance.

Results
A total of 12 RCTs were included in the analyses. The OEP exerted significant effects on static balance (Hedges’s g = 0.388; 95% confidence interval [CI] = 0.131 to 0.645), dynamic balance (g = -0.228; 95% CI = -0.352 to -0.1.4), proactive balance (g = 0.239; 95% CI = 0.061 to 0.416) and perceived balance (g = -0.184; 95% CI = -0.320 to -0.048) in older adults. Subgroup analysis indicated that the group format for the OEP was more effective for improving static (p = 0.008), dynamic (p = 0.004) and perceived balance (p = 0.004) than was the individual format. Sessions of >30 minutes were more effective in improving static (p = 0.007) and perceived balance (p = 0.014) than were sessions of ≤30 minutes.
However, the effects of the OEP on balance were unrelated to the types of control group, training frequency and training period.

**Discussion**

The OEP is helpful for improving actual balance including static, dynamic, and proactive balance; enhancing confidence in balance control; and reducing fear of falling in older adults. In particular, administering the OEP in a group setting in >30-minute sessions may be the most appropriate and effective exercise protocol for improving balance.

**Introduction**

Falls are a major public health issue among older adults worldwide. More than a one-third of the community-dwelling older adults and half of older adults living in the institutions fall each year [1]. Furthermore, approximately half of those who fall do so repeatedly [2]. Although not all the falls are life threatening, it has been reported that 10%–20% of falls result in severe injuries, such as fractures, that can lead to increased morbidity and decreased quality of life [3].

Balance is defined as the ability to maintain the projection of the body’s center of mass within the limits of the base of support, as in the sitting or standing position, or in transit to establish a new base of support, as during walking [4]. Balance problems are a major cause of falls and have been shown to be associated with increased fear of falling and decreased balance confidence [5,6]. Both fear of falling and balance confidence are psychological factors that are related to balance impairment and falling and result in less social participation, greater dependence in activities of daily living, and further restriction of activity [7,8]. Older adults with postural instability and concomitant fear of falling have the greater risk of falls [9].

Recent evidence has suggested that a multi-component exercise regimen focusing on flexibility, strength, balance and endurance can effectively improve balance, mobility, and physical performance as well as reduce the incidence of falls and falls-related injuries in community-dwelling older adults [10–12]. The Otago exercise programme (OEP) encompasses all the aforementioned aspects and was developed for community-dwelling older adults aged >65 years old. The OEP consists of a set of exercises for leg muscles strengthening and balance retraining exercises and is designed to prevent falls, particularly for individuals aged >80 years who have fallen in the previous year [13]. Most studies have reported the OEP to be an effective fall prevention strategy that benefits balance function and lessens fear of falling [14–17].

In their systematic review, Martin and colleagues [18] investigated the effects of a modified OEP involving a new set of exercises to improving balance in older adults and reported improvements in balance performance and functional ability. Another meta-analysis conducted a decade ago examined the effects of the OEP on mortality and falls, and the findings indicated significant reductions in the rates of mortality and falls over a 12-month period [19]. Improving balance can reduce the likelihood of falls, but no meta-analysis has investigated the effectiveness of the OEP on actual balance performance including static, dynamic, proactive, and reactive balance. Balance is highly task-specific so specific balance categories should be evaluated separately. Moreover, the most appropriate and effective exercise training protocol (minutes per session, session frequency, and total intervention period) and intervention format (group or individual) remains unclear. Therefore, the primary purpose of this systematic review and meta-analysis was to investigate the effects of the OEP intervention on actual balance performance (e.g., static, dynamic, proactive, and reactive balance) and perceived balance.
ability (e.g., balance confidence and fear of falling) in older adults; the secondary purpose was to investigate which OEP protocol can most greatly improve balance improvement in older adults. Establishing an evidence-based intervention that can reduce fall, increase balance performance and perceived balance ability in older adults is of high importance.

**Methods**

**Reporting standards**

Systematic identification of the published literature was performed according to Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines [20].

**Search strategy**

A search for relevant studies was performed using the Physiotherapy Evidence Database (PEDro), PubMed, Embase, Web of Science, Oxford, Medline, and CINAHL databases from inception until 26 February 2021 by using the following keywords: “old” OR “aged” OR “elderly” AND “Otago exercise”. databases.

**Selection criteria**

Selection criteria were established on the basis of the Population Intervention Comparison Outcomes (PICO) framework [21] as follows: 1) Population: the population must be older adults aged >65 years without any neurological diseases; 2) Intervention: the intervention must comprise the original OEP with either an individual or group format; 3) Comparison: the comparison group must be alternative active treatment methods or no treatment; 4) Outcome: the reported outcomes must include actual and perceived balance-related parameters. In addition to the aforementioned PICO components, studies must be published in English articles, employ a randomized controlled trials (RCTs) design, and provide sufficient statistical data for effect size calculation. Study protocols and review articles, studies including older adults with neurological diseases, and studies with low quality based on a PEDro scale score <3 were excluded.

**Data extraction**

Two independent authors (SCL and YTL) extracted the following data from all selected RCTs: participants details (characteristics, sample size, age, and sex), intervention characteristics (format and frequency), outcomes of interest and results. If the two authors held different opinions, then the third author (HLC) resolved any disputes.

**Outcome measures**

Balance is highly task-specific; therefore, specific balance categories should be evaluated separately. The model proposed by Shumway-Cook and Woollacott divides balance performance into four components including static balance, dynamic balance, proactive balance, and reactive balance [22]. Several studies have indicated that there are only weak to moderate correlations among the four types of balance in older adults [23,24]. Therefore, this meta-analysis focused separately on these balance outcome categories.

Static balance is the ability to maintain postural stability and orientation with center of mass over the base of support and body at rest. It can be evaluated with tasks that require standing on one or both legs standing in a stationary posture. The time required to maintain balance and the postural sway measured using a force plate are considered proxies for static balance [25,26]. Dynamic balance is defined as the ability to maintain stability during weight
shifting, often while changing the base of support. The Timed Up and Go (TUG) test examines gait speed, stride length, and balance in locomotion. Thus, the TUG can be used to examine dynamic balance [27]. Proactive balance involves postural adjustment during a self-initiated movement, and the Functional Reach Test (FRT) is the preferred proxy [28]. Reactive balance is balance control in response to an unexpected perturbation [29], but the current meta-analysis could not include reactive balance because the output measures in the existing research are limited. A previous study reported a strong relationship between perceived balance and actual balance performance [30]. Perceived balance is often measured using self-reported questionnaires, such as the Falls Efficacy Scale (FES) [31], which assesses fear of falling in performing daily activities, and CONFbal scale, which measures an older adult’s confidence in maintaining balance [32]. If a study used other tests other than those mentioned, we included in our quantitative analyses those tests that were the most similar to the aforementioned tests in terms of their temporal and spatial structure.

Assessment of methodological quality

Two independent authors (SCL and YTL) independently applied the selection criteria and assessed the methodological quality of the studies by using the PEDro scale [33]. A total PEDro score is determined by counting the number of criteria that are satisfied, except that scale item 1 is not used to generate the total score; thus the score is calculated out of a total score of 10. According to the previous research and definition of PEDro scale [33,34], the score of 6–10, 4 or 5, and <3 indicates high, moderate, and low study quality. Low-quality studies were excluded from this analysis.

Data analysis

We performed the meta-analysis by using Comprehensive Meta-Analysis (VMA) Version 2.0 (Biosta, Inc. USA). The effect size was estimated using Hedges’s g coefficient and 95% confidence intervals (CIs). The magnitude of Hedges’ g was interpreted using Cohen’s convention of 0.2, 0.5, and 0.8 respectively indicating small, moderate, and large effects [35]. Heterogeneity was estimated using the $Q$ statistic and $I^2$ test. Each quartile was considered a heterogeneity interval, and values of 0%–25%, >25%–50%, >50%–75%, and >75% indicated no, minor, moderate, and high heterogeneity, respectively [36]. All overall effect size values in this study were examined using a fixed-effects model. Furthermore, subgroup analysis was further employed to determine whether the characteristics of the intervention or the types of control group affected the effect size among studies. In addition, Egger’s regression intercept was used to assess publication bias.

Results

Selection and characteristics of studies

A total of 616 unique titles and abstracts were retrieved from the literature research (Fig 1). Twelve RCTs published in peer-reviewed journals met the selection criteria [15–17,37–45]. Among these 12 RCTs, 4, 9, 4, and 5 analyzed the effects of the OEP on static [17,38,41,44], dynamic [15,17,37–40,42–44], proactive [40,43–45], and perceived balance [16,37,40–42], respectively.

The 12 RCTs comprised a total of 2807 participants, with sample sizes ranging from 10 to 125. The mean age of participants was 76.34±4.84 years old. Five studies applied the OEP for older adults who had experienced falls [17,39–40,43,45] and indicated that the OEP was safe and feasible for even those older individuals prone to falls. Eight studies (of 12) administrated
Fig 1. PRISMA flow diagram of the study selection process (RCT, randomized controlled trial).

https://doi.org/10.1371/journal.pone.0255780.g001
the OEP as an individual program [16–17,37,39–41,43,45]; however, four studies administered the OEP within a group [15,38,42,44]. Participants in active control groups participating in other exercise programs, such as Tai Chi [44] or Yoga [41]. Control group receiving no treatment maintained regular activities [15–17,37–40,42,43,45]. The training session length ranged from 20 to 60 minutes, the frequency was 2 or 3 sessions per week, and the intervention lasted 12–52 weeks, representing 1080–4320 minutes in total. The most common training protocol was 30 minutes per session for 3 sessions per week for 12 or 24 weeks, totaling 2160 minutes. The compliance rates were 77–93 (85±11) %, defined as the frequency of attendance to exercise sessions [15,38], and 24–67 (33±13) %, reported on the number of participants who adhered to the exercise protocol [17,37,40,43,45]. Compliance was not reported in 5 studies [16,39,41,42,44]. Table 1 lists the characteristics of the included studies.

Quality assessment
The average PEDro scale score of the 12 RCTs was 6.6 out of 10, suggesting the study designs were of high quality, with only one study [16] determined to have fair quality (Table 2). The included studies presented a reasonable control over eligibility criteria, random allocation, baseline comparability, between-group comparisons, and point estimates. However, a major design limitation was the lack of blinding procedures; no study performed blinding of both participants and therapists.

Effects on static balance, dynamic balance, proactive balance, and perceived balance
The effect of OEP on static balance in older adults demonstrated a significant but small effect (Hedges’s g = 0.388, 95% CI 0.131 to 0.645, p = 0.003) by four studies [17,38,41,44]. The results of heterogeneity testing revealed a high level of heterogeneity (Q = 14.17, p = 0.003, I² = 78.83%). The results of Egger’s regression intercept indicated that publication bias was not significant (p = 0.732).

The effect of OEP on dynamic balance in older adults demonstrated a significant but small effect (Hedges’s g = -0.228, the 95% CI -0.352 to -0.104, p < 0.001) by nine studies [15,17,37–40,42–44]. The results of heterogeneity testing showed a moderate level of heterogeneity (Q = 16.30, p = 0.0380, I² = 50.925%). The results of Egger’s regression intercept test indicated that publication bias was not significant (p = 0.100).

The effect of OEP on proactive balance in older adults demonstrated a significant but small effect (Hedges’s g = 0.239, 95% CI 0.061 to 0.416, p = 0.009) by four RCTs [40,43–45]. The results of heterogeneity testing revealed a high level of heterogeneity (Q = 20.49, p = 0.000, I² = 85.36%). The results of Egger’s regression intercept test indicated that publication bias was not significant (p = 0.264).

The effect of OEP on perceived balance demonstrated a significant but small effect (Hedges’ g = -0.184, 95% CI -0.320 to -0.048, p = 0.008) by five studies [16,37,40–42]. Heterogeneity testing revealed a moderate level of heterogeneity among the studies (Q = 9.796, p = 0.044, I² = 59.166%). The results of Egger’s regression intercept test indicated that publication bias was not significant (p = 0.062; Fig 2).

Therefore, the effect of OEP exerted significant effects on static balance, dynamic balance, proactive balance and perceived balance in older adults.

Subgroup analysis
Because the results revealed that the OEP exerted significant effects on static, dynamic, proactive, and perceived balance, we performed subgroup analysis to determine whether the
| Study | Participants | Intervention characterization | Outcome of interests/ Results |
|-------|--------------|------------------------------|-------------------------------|
| Arkkukan gas et al., 2019 [37] | **Characteristics:** Older adults  
Total N: EG1/EG2/CG: 61/58/56  
Complete N: EG1/EG2/CG: 54/52/55  
Age (yrs): EG1/EG2/CG: 83.0±5.0/84±4.1/82.0±4.7  
Gender (Female%): EG1/EG2/CG: 67/69/73 | EG1: Otago exercise  
EG2: Otago exercise plus motivational interviewing  
CG: Regular care  
**Format:** Individual  
**Frequency:** Minutes per session: 30  
Session per week: 3  
Total weeks: 12 | Dynamic balance  
Mini-BEST test (score)  
Perceived balance  
FES (score) |
| Benavent-Caballer et al., 2016 [38] | **Characteristics:** Older adults  
Total N: EG/CG: 28/23  
Complete N: EG/CG: 28/23  
Age (yrs): EG/CG: 69.1±4.0/69.0±3.3  
Gender (Female%): EG/CG: 82/69 | EG: Otago exercise  
CG: No intervention  
**Format:** Group  
**Frequency:** Minutes per session: 45  
Session per week: 3  
Total weeks: 16 | Static balance  
One leg stance test (s)  
Dynamic balance  
BBS (score)  
TUG (s) |
| Dadgari et al., 2016 [39] | **Characteristics:** Older fallers  
Total N: EG/CG: 160/157  
Complete N: EG/CG: 160/157  
Age (yrs): EG/CG: 70.60±5.80/70.06±5.20  
Gender (Female%): EG/CG: 68/70 | EG: Otago exercise  
CG: Regular care  
**Format:** Individual  
**Frequency:** Minutes per session: 60  
Session per week: 3  
Total weeks: 24 | Dynamic balance  
TUG (s)  
BBS (score) |
| Elley et al., 2008 [40] | **Characteristics:** Older fallers  
Total N: EG/CG: 155/157  
Complete N: EG/CG: 155/157  
Age (yrs): EG/CG: 80.4±4.8/81.1±5.3  
Gender (Female%): EG/CG: 68/70 | EG: Otago exercise  
CG: Regular care  
**Format:** Individual  
**Frequency:** Total weeks: 52 | Dynamic balance  
TUG (s)  
Proactive balance  
Step test (n)  
Perceived balance  
mFES (%) |
| Iliffe et al., 2015 [16] | **Characteristics:** Older adults  
Total N: EG1/CG1/CG2: 410/387/457  
Complete N: CONFbal: EG1/CG1/CG2: 179/183/218  
FES-I: EG1/CG1/CG2: 185/188/220  
Age (yrs): EG1/CG1/CG2: 72.8±5.8/72.9±6.1/73.1±6.2  
Gender (Female%): EG1/CG1/CG2: 63/62/62 | EG: Otago exercise  
CG1: Falls Management Exercise Programme  
CG2: Regular care  
**Format:** Individual  
**Frequency:** EG: Minutes per session: 30  
Session per week: 3  
Total weeks: 24  
CG1: Minutes per session: 60  
Session per week: 1  
Total weeks: 24  
**Outcome of interests/ Results:** Perceived balance  
CONFbal (score)  
FES-I (score)  
FES (score) |
| Kocic et al., 2018 [15] | **Characteristics:** Older adults  
Total N: EG/CG: 38/39  
Complete N: EG/CG: 27/33  
Age (yrs): EG/CG: 78.3±8.1/78.5±7.2  
Gender (Female%): EG/CG: 74/59 | EG: Otago exercise  
CG: Regular care  
**Format:** Group  
**Frequency:** Minutes per session: 40  
Session per week: 3  
Total weeks: 24 | Dynamic balance  
BBS (score)  
TUG (s) |
| Lee et al., 2017 [41] | **Characteristics:** Older females  
Total N: EG1/EG2/CG: 10/10/10  
Complete N: EG1/EG2/CG: 10/10/10  
Age (yrs): EG1/EG2/CG: 72.60±2.67/76.40±5.54/75.80±5.47  
Gender (Female%): EG1/EG2/CG: 100/100/100 | EG1: Augmented reality Otago exercise  
EG2: Self-Otago exercise  
CG: Yoga  
**Format:** Individual  
**Frequency:** Minutes per session: 60  
Session per week: 3  
Total weeks: 12 | Dynamic balance  
Postural sway (cm)-HoE  
Postural sway (cm)-SD-x  
Postural sway (cm)-EO  
CoP-x  
Postural sway (cm)-EC  
CoP-x  
Perceived balance  
Morse Fall Scale (score) |

(Continued)
characteristics of the intervention or the types of control group influenced the effect size. Group OEP interventions were discovered to exert a greater effect on static (p = 0.008), dynamic (p = 0.004) and perceived balance (p = 0.004) than did individual interventions. Sessions of > 30 minutes were more effective than those of ≤ 30 minutes on static (p = 0.007) and perceived balance (p = 0.014). However, the effects of the OEP on balance did not differ by control group type, training frequency, or training period (Table 3).

Discussion

Balance is a key component of many activities of older adults’ daily living, ranging from simple activities such as quiet standing to more complex activities such as walking while talking [46]. Balance improvement benefits older adults’ physical function, independence, and physical
The primary aim of this systematic review and meta-analysis was to examine the overall effects of the OEP on older adults’ actual and perceived balance and the secondary aim was to investigate which OEP protocol could maximize balance improvement. The 12 RCTs reported more favorable outcomes for the OEP groups than for the control group. A significant and small effect was observed on static, dynamic, proactive, and perceived balance. Furthermore, subgroup analysis further indicated that the group format was more effective than the individual format for improving balance performance with the OEP. A training session duration of >30 minutes was determined to be the most appropriate and effective for improving balance. However, the effects of the OEP on activity, leading to additional health benefits. The primary aim of this systematic review and meta-analysis was to examine the overall effects of the OEP on older adults’ actual and perceived balance and the secondary aim was to investigate which OEP protocol could maximize balance improvement. The 12 RCTs reported more favorable outcomes for the OEP groups than for the control group. A significant and small effect was observed on static, dynamic, proactive, and perceived balance. Furthermore, subgroup analysis further indicated that the group format was more effective than the individual format for improving balance performance with the OEP. A training session duration of >30 minutes was determined to be the most appropriate and effective for improving balance. However, the effects of the OEP on activity, leading to additional health benefits.
Effects of the OEP on actual balance performance

Balance control is complex and multifactorial. Age-related physiological changes include reductions in muscle strength, joint range of motion, and reaction time as well as the deterioration of sensory systems. These changes negatively influence older adults’ balance control and may lead to various levels of balance dysfunction [49]. Multimodal exercises, such as the OEP, that focus on muscle strengthening and balance training are recommended. Exercise

balance were not related to the control group type, training frequency, or overall intervention period.

Effects of the OEP on actual balance performance

Table 3. Subgroup analysis of study participants and intervention characteristics.

| Variables          | Static balance | Dynamic balance | Proactive balance | Perceived balance |
|--------------------|----------------|-----------------|-------------------|-------------------|
|                     | K Hedges's g (95%CI) | p<sup>a</sup> | K Hedges's g (95%CI) | p<sup>b</sup> | K Hedges's g (95%CI) | p<sup>b</sup> | K Hedges's g (95%CI) | p<sup>b</sup> |
| Intervention format|                |                |                   |                   |                   |                   |
| Group              | 2 0.83 (0.42, 1.25) | <0.001 | 4 -0.60 (-0.89, -0.32) | <0.001 | 1 0.59 (0.00, 1.18) | 0.049 | 1 -1.60 (-2.58, -0.63) | 0.001 |
| Individual         | 2 0.11 (-0.22, 0.44) | 0.502 | 5 -0.141 (-0.28, -0.00) | 0.044 | 3 0.20 (0.02, 0.39) | 0.033 | 4 -0.16 (-0.29, -0.02) | 0.026 |
| Control group      |                |                |                   |                   |                   |                   |
| Active control     | 2 0.36 (0.03, 0.69) | 0.034 | 1 -0.19 (-0.76, 0.39) | 0.527 | 1 0.59 (0.00, 1.18) | 0.049 | 1 -0.57 (-1.42, 0.29) | 0.195 |
| No treatment       | 2 0.43 (0.02, 0.83) | 0.038 | 8 -0.23 (-0.36, -0.10) | <0.001 | 3 0.20 (0.02, 0.39) | 0.033 | 4 -0.17 (-0.31, -0.04) | 0.013 |
| Minutes per session|                |                |                   |                   |                   |                   |
| >30min             | 3 0.58 (0.29, 0.87) | <0.001 | 5 -0.39 (-0.57, -0.22) | <0.001 | 1 0.59 (0.00, 1.18) | 0.049 | 2 -1.02 (-1.66, -0.37) | 0.002 |
| ≤30min             | 1 -0.29 (-0.84, 0.27) | 0.310 | 3 -0.08 (-0.35, 0.19) | 0.546 | 2 0.74 (0.43, 1.05) | 0.000 | 2 -0.18 (-0.35, -0.01) | 0.043 |
| undisclosed         | 1 1 1                  | 1 1 1                |                   |                   |
| Session per week   |                |                |                   |                   |                   |                   |
| >2 times/week      | 3 0.38 (0.09, 0.67) | 0.010 | 7 -0.31 (-0.46, -0.16) | <0.001 | 3 0.74 (0.43, 1.05) | 0.000 | 4 -0.24 (-0.40, -0.07) | 0.006 |
| ≤2 times/week      | 1 0.42 (-0.16, 1.01) | 0.154 | 1 -0.19 (-0.76, 0.39) | 0.527 | 0 0.59 (0.00, 1.18) | 0.049 | 0 – –                   | –               |
| undisclosed         | 1 1 1                  | 1 1 1                |                   |                   |
| Total weeks        |                |                |                   |                   |                   |                   |
| >12weeks           | 2 0.43 (0.02, 0.83) | 0.038 | 5 -0.24 (-0.38, -0.10) | 0.001 | 2 0.16 (-0.04, 0.36) | 0.108 | 2 -0.13 (-0.28, 0.02) | 0.097 |
| ≤12weeks           | 2 0.36 (0.03, 0.69) | 0.034 | 4 -0.19 (-0.45, 0.08) | 0.167 | 2 0.57 (0.16, 0.97) | 0.007 | 3 -0.45 (-0.77, -0.12) | 0.007 |
| Total minutes      |                |                |                   |                   |                   |                   |
| >2000minutes       | 3 0.38 (0.09, 0.67) | 0.010 | 4 -0.35 (-0.53, -0.18) | <0.001 | 2 0.83 (0.46, 1.20) | 0.000 | 2 -0.18 (-0.37, 0.01) | 0.067 |
| ≤2000minutes       | 1 0.42 (-0.16, 1.01) | 0.154 | 4 -0.19 (-0.45, 0.08) | 0.167 | 1 0.57 (0.16, 0.97) | 0.007 | 2 -0.43 (-0.78, -0.08) | 0.016 |
| undisclosed         | 1 1 1                  | 1 1 1                |                   |                   |

<sup>a</sup>, within studies; <sup>b</sup>, between studies; CI, confidence interval
<sup>*p < 0.05.</sup>
guidelines for older adults suggest multimodal regimens [50,51]. Studies have indicated that multimodal exercise is a comprehensive approach to fall prevention [52,53] and particularly effective for improving dynamic standing balance [54]. Dynamic balance is more crucial than other types of balance because it is a fundamental component of mobility in everyday life that allows a person to move safely and easily without difficulty and avoid falls [27].

The beneficial effects of the OEP on balance can be attributed to its resistance and balance training elements. Resistance training exercises included in the OEP improve strength in the large muscle groups of the lower limbs, including the quadriceps (e.g., front knee strengthening), hamstrings (e.g., back knee strengthening), hip abductors (e.g., side hip strengthening), calf muscles (e.g., calf raises), and tibialis anterior muscles (e.g., toe raises). These muscles are strongly correlated with balance, and their strength can be enhanced through resistance training to improve balance [55–57]. Improvement in overall balance resulting from the OEP can be attributed to its inclusion of tasks training multiple domains of balance, including static (e.g., heel-toe and one leg standing), dynamic (e.g., toe walking and sideways walking), and proactive balancing tasks (e.g., knee bends and sit to stand exercises). This reflects the principles of specificity in balance exercise; the more an exercise targets a specific motor task, the greater is the carryover from that exercise to performing real related tasks [58].

The improvement in balance through OEP intervention may be related to improvements in cognition. A study reported an association between cognitive function and balance ability in older adults [59]. This association might be due to cognitive and balance networks sharing common neuronal pathways [60]. A lower gray matter volume was reported to be associated with not only poorer cognitive function but also postural instability [61]. Aerobic exercise can improve cognition [62]; however, some studies have indicated that resistance [63] and balance training [64] may prevent or delay the age-related decline in cognitive functions. Therefore, the OEP may bolster cognitive function through exercise and balance training, further improving balance.

Effects of the OEP on perceived balance ability

Fear of falling is defined as a lasting concern about falling that can lead individuals to avoid activities that they remain capable of performing [65]. Balance confidence is defined as individuals’ belief in their abilities to maintain balance and further exacerbate activity avoidance due to a lack of confidence in the ability to maintain balance and not fall during feared activities [66]. Both fear of falling and balance confidence are psychological problems, that reduce activity levels and impair physical functions. Impaired physical function, in turn, affects neuromuscular ability and increases the risks of falling and its associated fear, thus perpetuating a vicious cycle [31]. Fear of falling and low balance confidence are reported in both fallers and non-fallers, and can potentially be more debilitating than a fall itself [67]. Thus, fear of falling and lack of balance confidence have been identified as key components in fall prevention programs. Resistance [68] or balance training [69] or a combination of both [70] have been shown to improve balance confidence and fall self-efficacy. In line with the findings of previous studies, the results of our meta-analysis indicated that the OEP, with its resistance and balance training, can reduce the fear of falling and enhance balance confidence. Interventions to overcome the fear of falling and build balance confidence are crucial because fall-related psychological factors can lead to various adverse health outcomes [71].

Intervention characteristics

Exercise programs, including home-based (individual-based) and group-based programs, have yielded promising results, reducing the risk of falls in older adults [72,73]. Previous
studies have reported conflicting results regarding whether group or home exercise is more effective [74–76] However, each approach has its own strengths and weaknesses. The decision to prescribe either approach may be driven by factors such as access, individual preference, available resources, the need for individually tailored exercises, and levels of supervision and socialization [73]. Group-based programs allow interactions and communication between participants and therapists as well as among participants, providing psychosocial support and a sufficient dose of overall exercise [77,78]. By contrast, home-based programs provide opportunities for participants to exercise without commuting, can be followed for an unlimited time by participants, and may be easier to sustain than group-based programs [79,80]. Although the OEP was originally designed as an individually tailored home exercise program, our subgroup analysis indicated that a group-based OEP was more effective than a home-based OEP for improving static, dynamic, and perceived balance. A recent meta-analysis suggested that a combination of a supervised group exercises and self-directed home-based exercises may be optimal for improving functional performance and preventing injurious falls in community-dwelling older adults with a risk of falling [81].

Our subgroup analysis revealed that >30-minute OEP training sessions were the most effective for improving balance, but the effects of the OEP on balance were not found to be related to the training period (total training week or total training minutes) or frequency (session per week). In fact, the American College of Sports Medicine (ACSM) guidelines for older adults recommend that all healthy older adults perform regular exercise for a minimum of 30 minutes and five days per week [82]. The OEP manual also suggests a training session duration of 30 minutes, with three training sessions each week and go for a walk at least twice every week for 6 months; although a broad range of intervention periods (12–52 weeks), training frequencies (2 or 3 sessions per week), session durations (20–60 minutes), and total OEP intervention times (1080–4320 minutes in total) was employed in the included studies [15–17,37–45].

Strengths and limitations

Our systematic review and meta-analysis has several strengths. First, the literature search was performed in accordance with the PRISMA guidelines. An electronic search of major databases was conducted using keywords based on the clinical recommendations of the PICO model. Second, the risk of bias was assessed using the PEDro scale, enabling a comprehensive and detailed analysis of the methodological quality and the effect of bias on the treatment outcomes [83]. In this literature review, 12 high-quality RCTs were included that provided stronger evidence than provided by studies with other designs.

This study has some limitations that should be addressed. The heterogeneity between studies was considerable and may be due to the different intervention characteristics or training formats. Therefore, subgroup analysis was performed. Although the overall quality of included studies was high, all of them failed to impose complete blinding procedures, and this might limit the credibility of our results. Future RCTs should be blind as many parties as possible in the trial to minimize bias and maximize the validity of the results. Moreover, independent therapists and outcome assessors should be used, and participants should be blinded to their group allocation by including them in a waitlist control group that receives intervention at some later point or an active control group that receives an alternative intervention. Additional high-quality RCTs should examine the benefits of the OEP and particularly focus on implementing blinding procedures are needed.

The model proposed by Shumway-Cook and Woollacott divided balance capacity into four components: static, dynamic, proactive and reactive balance [22]. However, the current meta-analysis could not include reactive balance because of limited output measures. The lack of
output measures may be related to the OEP not including reactive balance training, such as perturbation training. Reactive balance is crucial for restoring balance in response to an unexpected perturbation. An inadequate reaction to an unexpected disturbance can result in falls because the assessments performed in the included studies were mostly concerned with balance control under self-initiated conditions, future studies should examine the effects of the OEP on reactive balance in older adults [84]. The OEP supplemented with reactive balance training could possibly improve comprehensive balance capacity including static, dynamic, proactive and reactive balance.

Another limitation may be that the intervention period was not as recommended by the OEP manual (i.e., 24 weeks). Therefore, we performed subgroup analysis by investigating the effects of heterogeneous training frequencies. An optimal training duration of >30 minutes per session was identified, consistent with the original suggestions of the OEP manual. Another concern is the fact that the outcome measures of the included articles were mostly based on clinical tests. Clinical tests are commonly used because they are cost effective, time efficient, and easy to administer. Improvements in clinical test results may suggest clinically meaningful changes. However, a sophisticated laboratory instrument could not only provide an objective assessments of balance control under various conditions but also detects subtle changes in performing that clinical tests could not. Therefore, laboratory assessments such as the use of force plates and the GAITRite system to collect information regarding the center of pressure data and gait kinematics, respectively, should be included in future studies.

Perspective
The OEP is a multimodal exercise regimen focusing on flexibility, strength, balance, and endurance exercises designed to prevent falls. This meta-analysis of 12 high-quality RCTs provides evidence that the OEP significantly improves actual balance performance, including static, dynamic, and proactive balance, as well as perceived balance ability. In particular, administrating the OEP in a group setting in 30-minute sessions may be the most appropriate and effective protocol for improving balance. Therefore, the OEP is highly recommended for community-dwelling older adults to improve their actual balance performance and enhance their confidence in balance control.

Conclusions
The primary purpose of this systematic review and meta-analysis was to investigate the effects of OEP interventions on actual balance performance (i.e., static, dynamic, proactive or reactive balance) and perceived balance (i.e., balance confidence or fear of falling) in older adults; the secondary purpose was to investigate which OEP protocol leads to the greatest balance improvements. This meta-analysis provides evidence that the OEP is helpful for improving actual static, dynamic, and proactive balance; enhancing confidence in balance control; and reducing the fear of falling. In particular, administrating the OEP in a group setting in 30-minute sessions may be the most appropriate and effective protocol for improving balance. Future studies should examine the effects of the OEP on reactive balance performance, adopt a high-quality study design with blinding procedures, and finally utilize laboratory outcome measurements for precise assessment.

Supporting information
S1 Appendix. PRISMA 2009 checklist.
(DOC)
Author Contributions
Conceptualization: Shu-Chun Lee.
Formal analysis: Ting-Ting Yeh.
Funding acquisition: Shu-Chun Lee.
Investigation: Yun-Ting Lo.
Methodology: Huei-Ling Chiu, Yun-Ting Lo.
Software: Huei-Ling Chiu.
Supervision: Shu-Chun Lee.
Visualization: Pei-Jung Liang, Shu-Chun Lee.
Writing – original draft: Huei-Ling Chiu, Ting-Ting Yeh, Shu-Chun Lee.
Writing – review & editing: Huei-Ling Chiu, Ting-Ting Yeh, Yun-Ting Lo, Pei-Jung Liang, Shu-Chun Lee.

References
1. Gill T, Taylor AW, Pengelly A. A population-based survey of factors relating to the prevalence of falls in older people. Gerontology. 2005; 51(5):340–5. https://doi.org/10.1159/000086337 PMID: 16110237
2. Rubenstein LZ, Josephson KR, Robbins AS. Falls in the nursing home. Ann Intern Med. 1994 Sep; 121(6):442–51. https://doi.org/10.7326/0003-4819-121-6-199409150-00009 PMID: 8053619
3. Kannus P, Parkkari J, Koskinen S, Niemi S, Palvanen M, Jarvinen M, et al. Fall-induced injuries and deaths among older adults. JAMA. 1999 May; 281(20):1895–9. https://doi.org/10.1001/jama.281.20.1895 PMID: 10349892
4. Winter DA. Human balance and posture control during standing and walking. Gait Posture. 1995; 3(4):193–214.
5. Cuevas-Trisan R. Balance Problems and Fall Risks in the Elderly. Phys Med Rehabil Clin N Am. 2017 Nov; 28(4):727–37. https://doi.org/10.1016/j.pmr.2017.06.006 PMID: 29031339
6. Makino K, Makizako H, Doi T, Tsutsumimoto K, Hotta R, Nakakubo S, et al. Fear of falling and gait parameters in older adults with and without fall history. Geriatriol Gerontol Int. 2017 Dec; 17(12):2455–9. https://doi.org/10.1111/ggi.13102 PMID: 28656737
7. Scheffer AC, Schuurmans MJ, van Dijk N, van der Hooft T, de Rooij SE. Fear of falling: measurement strategy, prevalence, risk factors and consequences among older persons. Age Ageing. 2008 Jan; 37(1):19–24. https://doi.org/10.1093/ageing/afm169 PMID: 18194967
8. Curl A, Fitt H, Tomintz M. Experiences of the Built Environment, Falls and Fear of Falling Outdoors among Older Adults: An Exploratory Study and Future Directions. Int J Environ Res Public Health. 2020 Feb; 17(4):1224.
9. Pua Y-H, Ong P-H, Clark RA, Matcher DB, Lim EC-W. Falls efficacy, postural balance, and risk for falls in older adults with falls-related emergency department visits: prospective cohort study. BMC Geriatr. 2017 Dec; 17(1):1–7. https://doi.org/10.1186/s12877-016-0400-5 PMID: 28049446
10. Bird M, Hill KD, Ball M, Hetherington S, Williams AD. The long-term benefits of a multi-component exercise intervention to balance and mobility in healthy older adults. Arch Gerontol Geriatr. 2011; 52(2):211–6. https://doi.org/10.1016/j.archger.2010.03.021 PMID: 20416959
11. Freiberger E, Haberle L, Spirudo WW, Zijlstra GAR. Long-term effects of three multicomponent exercise interventions on physical performance and fall-related psychological outcomes in community-dwelling older adults: a randomized controlled trial. J Am Geriatr Soc. 2012 Mar; 60(3):437–46. https://doi.org/10.1111/j.1532-5415.2011.03859.x PMID: 22324753
12. Gillespie LD, Robertson MC, Gillespie WJ, Sherrington C, Gates S, Clemson LM, et al. Interventions for preventing falls in older people living in the community. Cochrane database Syst Rev. 2012 Sep;(9):CD0007146. https://doi.org/10.1002/14651858.CD0007146.pub3 PMID: 22972103
13. Karinkanta S, Nupponen R, Heinonen A, Pasanen M, Sievonen H, Uusi-Rasi K, et al. Effects of exercise on health-related quality of life and fear of falling in home-dwelling older women. J Aging Phys Act. 2012 Apr; 20(2):198–214. https://doi.org/10.1123/japa.20.2.198 PMID: 22472580
14. Bjerk M, Brovold T, Skelton DA, Liu-Am brose T, Bergland A. Effects of a falls prevention exercise pro-
gramme on health-related quality of life in older home care recipients: a randomised controlled trial. Age
Ageing. 2019 Mar; 48(2):213–9. https://doi.org/10.1093/ageing/afy192 PMID: 30615055

15. Kocic M, Stojanovic Z, Nikolic D, Lazovic M, Grbic R, Dimitrijevic L, et al. The effectiveness of group
Otago exercise program on physical function in nursing home residents older than 65 years: A random-
ized controlled trial. Arch Gerontol Geriatr. 2018 Mar; 75:112–8. https://doi.org/10.1016/j.archger.2017.12.001 PMID: 29241091

16. Iliffe S, Kendrick D, Morris R, Griffin M, Haworth D, Carpenter H, et al. Promoting physical activity in
older people in general practice: ProAct65+ cluster randomised controlled trial. Br J Gen Pract. 2015
Nov; 65(640):e731–8. https://doi.org/10.3399/bjgp15X687361 PMID: 26500320

17. Liu-Ambrose T, Donaldson MG, Ahamed Y, Graf P, Cook WL, Close J, et al. Otago home-based
strength and balance retraining improves executive functioning in older fallers: a randomized controlled
trial. J Am Geriatr Soc. 2008 Oct; 56(10):1821–30. https://doi.org/10.1111/j.1532-5415.2008.01931.x
PMID: 1879587

18. Martins AC, Santos C, Silva C, Baltazar D, Moreira J, Tavares N. Does modified Otago Exercise Pro-
gram improves balance in older people? A systematic review. Prev Med reports. 2018; 11:231–9.
https://doi.org/10.1016/j.pmedr.2018.06.015 PMID: 30210995

19. Thomas S, Mackintosh S, Halbert J. Does the “Otago exercise programme” reduce mortality and falls in
older adults?: a systematic review and meta-analysis. Age Ageing. 2010 Nov; 39(6):681–7. https://doi.
go/10.1093/ageing/afq102 PMID: 20817938

20. Moher D, Liberati A, Tetzlaff J, Altman DG, Prisma Group. Preferred reporting items for systematic
reviews and meta-analyses: the PRISMA statement (Reprinted from Annals of Internal Medicine) . Phys
Ther. 2009; 89:873–80. PMID: 19723669

21. Eriksen MB, Frandsen TF. The impact of patient, intervention, comparison, outcome (PICO) as a
search strategy tool on literature search quality: a systematic review. J Med Libr Assoc JMLA. 2018;
106(4):420. https://doi.org/10.5195/jmla.2018.345 PMID: 30271283

22. Shumway-Cook A, Woollacott MH. Motor control: translating research into clinical practice. Lippincott
Williams & Wilkins; 2007.

23. Muehlbauer T, Besemer C, Wehrle A, Gollihoffer A, Granacher U. Relationship between strength, power
and balance performance in seniors. Gerontology. 2012; 58(6):504–12. https://doi.org/10.1159/
000341614 PMID: 22922168

24. Granacher U, Bridenbaugh SA, Muehlbauer T, Wehrle A, Kressig RW. Age-related effects on postural
control under multi-task conditions. Gerontology. 2011; 57(3):247–55. https://doi.org/10.1159/
000322196 PMID: 20980734

25. Jonsson E, Seiger Å, Hirschfeld H. One-leg stance in healthy young and elderly adults: a measure of
postural steadiness? Clin Biomech. 2004; 19(7):688–94. https://doi.org/10.1016/j.clinbiomech.2004.04.
002 PMID: 15288454

26. Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambu-
latory and independent elderly population. J Gerontol. 1994; 49(2):M72–84. https://doi.org/10.1093/
geronj/49.2.m72 PMID: 8126355

27. Podsiaido D, Richardson S. The timed “Up & Go”: a test of basic functional mobility for frail elderly per-
sons. J Am Geriatr Soc. 1991 Feb; 39(2):142–8. https://doi.org/10.1111/j.1532-5415.1991.tb01616.x
PMID: 1991946

28. Duncan PW, Weiner DK, Chandler J, Studenski S. Functional reach: a new clinical measure of balance.
J Gerontol. 1990; 45(6):M192–7. https://doi.org/10.1093/geronj/45.6.m192 PMID: 2229941

29. Sibley KM, Inness EL, Straus SE, Salbach NM, Jaglal SB. Clinical assessment of reactive postural con-
trol among physiotherapists in Ontario, Canada. Gait Posture. 2013; 38(4):1026–31. https://doi.org/10.
1016/j.gaitpost.2013.05.016 PMID: 23810087

30. Myers AM, Powell LE, Maki BE, Holliday PJ, Brawley LR, Sherk W. Psychological indicators of balance
confidence: relationship to actual and perceived abilities. Journals Gerontol Ser A Biol Sci Med Sci.
1996; 51(1):M37–43. https://doi.org/10.1093/gerona/51a.1.m37 PMID: 8548512

31. Tinetti ME, Richman D, Powell L. Falls efficacy as a measure of fear of falling. J Gerontol. 1990; 45(6):
P239–43. https://doi.org/10.1093/geronj/45.6.p239 PMID: 2229948

32. Simpson JM, Worsfold C, Fisher KD, Valentine JD. The CONFbal scale: a measure of balance confi-
dence—a key outcome of rehabilitation. Physiotherapy. 2009; 95(2):103–9. https://doi.org/10.1016/j.
physio.2008.12.004 PMID: 19627691

33. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating
quality of randomized controlled trials. Phys Ther. 2003; 83(8):713–21. PMID: 12882612
34. Ajimsha MS, Al-Mudahka NR, Al-Madzhar JA. Effectiveness of myofascial release: systematic review of randomized controlled trials. J Bodyw Mov Ther. 2015; 19(1):102–12. https://doi.org/10.1016/j.jbmt.2014.06.001 PMID: 25603749
35. Cohen J. A power primer. Psychol Bull. 1992; 112(1):155. https://doi.org/10.1037/0033-2909.112.1.155 PMID: 19565683
36. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. Brmj. 2003; 327(7414):557–60. https://doi.org/10.1136/bmj.327.7414.557 PMID: 12958120
37. Arkkukangas M, Soderlund A, Eriksson S, Johansson A-C. Fall Preventive Exercise With or Without Behavior Change Support for Community-Dwelling Older Adults: A Randomized Controlled Trial With Short-Term Follow-up. J Geriatr Phys Ther. 2019; 42(1):9–17. https://doi.org/10.1519/JPT.000000000000129 PMID: 28244890
38. Benavenit-Caballer V, Rosado-Calatayud P, Segura-Orti E, Amer-Cuenca JJ, Lison JF. The effectiveness of a video-supported group-based Otago exercise programme on physical performance in community-dwelling older adults: a preliminary study. Physiotherapy. 2016 Sep; 102(3):280–6. https://doi.org/10.1016/j.physio.2015.08.002 PMID: 26395209
39. Dadgari A, Hamid TA, Chaman R, Mousavi SA, Hin LP, 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). https://doi.org/10.5812/ircmj.26340 PMID: 27478629
40. Elley CR, Robertson MC, Garrett S, Kerse NM, McKinlay E, Lawton B, et al. Effectiveness of a falls-and-fracture nurse coordinator to reduce falls: a randomized, controlled trial of at-risk older adults. J Am Geriatr Soc. 2008 Aug; 56(8):1383–9. https://doi.org/10.1111/j.1532-5415.2008.01802.x PMID: 18808597
41. Lee J, Yoo H-N, Lee B-H. 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 Sep; 29(9):1586–9. https://doi.org/10.1589/jpts.29.1586 PMID: 28931993
42. Leem S-H, Kim J-H, Lee B-H. Effects of Otago exercise combined with action observation training on balance and gait in the old people. J Exerc Rehabil. 2019; 15(6):848. https://doi.org/10.12965/jer.1938720.360 PMID: 31938708
43. Liew LK, Tan MP, Tan PJ, Mat S, Majid LA, Hill KD, et al. The Modified Otago Exercises Prevent Grip Strength Deterioration Among Older Fallers in the Malaysian Falls Assessment and Intervention Trial (MyFAIT). J Geriatr Phys Ther. 2019; 42(3):123–9. https://doi.org/10.1519/JPT.000000000000155 PMID: 29381526
44. Son N-K, Ryu YU, Jeong H-W, Jang Y-H, Kim H-D. Comparison of 2 Different Exercise Approaches: Tai Chi Versus Otago, in Community-Dwelling Older Women. J Geriatr Phys Ther. 2016; 39(2):51–7. https://doi.org/10.1519/JPT.0000000000000042 PMID: 25760277
45. Yang XJ, Hill K, Moore K, Mosley S, Donaldson L, Borschman K, et al. Effectiveness of a targeted exercise intervention in reversing older people’s mild balance dysfunction: a randomized controlled trial. Phys Ther. 2012 Jan; 92(1):24–37. https://doi.org/10.2522/ptj.20100289 PMID: 21979272
46. Karimi MT, Solomonidis S. The relationship between parameters of static and dynamic stability tests. J Res Med Sci Off J Isfahan Univ Med Sci. 2011 Apr; 16(4):530–5. PMID: 22091270
47. Wolfson L, Whipple R, Judge J, Amerman P, Derby C, King M. Training balance and strength in the elderly to improve function. J Am Geriatr Soc. 1993; 41(3):341–3. https://doi.org/10.1111/j.1532-5415.1993.tb06716.x PMID: 8440862
48. Peterson MJ, Giuliani C, Morey MC, Pieper CF, Evenson KR, Mercer V, et al. Physical activity as a preventative factor for frailty: the health, aging, and body composition study. Journals Gerontol Ser A. 2009; 64(1):61–8.
49. Peterka RJ. Sensorimotor integration in human postural control. J Neurophysiol. 2002 Sep; 88 (3):1097–118. https://doi.org/10.1152/jn.2002.88.3.1097 PMID: 12205132
50. Oja P, Titze S. Physical activity recommendations for public health: development and policy context. EPMA J. 2011 Sep; 2(3):253–9. https://doi.org/10.1007/s13167-011-0090-1 PMID: 23199160
51. Tremblay MS, Warburton DER, Janssen I, Paterson DH, Latimer AE, Rhodes RE, et al. New Canadian physical activity guidelines. Appl Physiol Nutr Metab. 2011 Feb; 36(1):36–58. https://doi.org/10.1139/H11-009 PMID: 21326376
52. Baker MK, Atlantis E, Fiatarone Singh MA. Multi-modal exercise programs for older adults. Age Ageing. 2007 Jul; 36(4):375–81. https://doi.org/10.1093/ageing/afm054 PMID: 17537741
53. Rose DJ, Hernandez D. The role of exercise in fall prevention for older adults. Clin Geriatr Med. 2010 Nov; 26(4):607–31. https://doi.org/10.1016/j.cger.2010.07.003 PMID: 20934613
54. Liu C, Chang W-P, Araujo de Carvalho I, Savage KEL, Radford LW, Amuthavalli Thiagarajan J. Effects of physical exercise in older adults with reduced physical capacity: meta-analysis of resistance exercise
55. Alonso AC, Ribeiro SM, Luna NMS, Peterson MD, Bocalini DS, Serra MM, et al. Association between handgrip strength, balance, and knee flexion/extension strength in older adults. PLoS One. 2018; 13(6): e0198185. https://doi.org/10.1371/journal.pone.0198185 PMID: 29856802

56. Porto JM, Freire Júnior RC, Bocarle L, Fernandes JA, Marques NR, Rodrigues NC, et al. Contribution of hip abductor-adductor muscles on static and dynamic balance of community-dwelling older adults. Aging Clin Exp Res. 2019 May; 31(5):621–7. https://doi.org/10.1007/s40520-018-1025-7 PMID: 30182152

57. Daubney ME, Culham EG. Lower-Extremity Muscle Force and Balance Performance in Adults Aged 65 Years and Older. Phys Ther. 1999 Dec 1; 79(12):1177–85. PMID: 10630286

58. Gamble P. Implications and applications of training specificity for coaches and athletes. Strength Cond J. 2006; 28(3):54.

59. Leandri M, Campbell J, Molfetta L, Barbera C, Tabaton M. Relationship between balance and cognitive performance in older people. J Alzheimer’s Dis. 2015; 45(3):705–7. https://doi.org/10.3233/JAD-142883 PMID: 25624415

60. Beaufect O, Barden J, Liu-Ambrose T, Chester VL, Szturm T, Allali G. The relationship between hippocampal volume and static postural sway: results from the GAIT study. Age (Omaha). 2016; 38(1):19. https://doi.org/10.1007/s11357-016-9883-4 PMID: 26833034

61. Kid O, Tabara Y, Igase M, Ochi N, Uetani E, Nagai T, et al. Postural instability is associated with brain atrophy and cognitive impairment in the elderly: the J-SHIPP study. Dement Geriatr Cogn Disord. 2010; 29(5):379–87. https://doi.org/10.1159/000255106 PMID: 20484907

62. Young J, Angevaren M, Rusted J, Tabet N. Aerobic exercise to improve cognitive function in older people without known cognitive impairment. Cochrane Database Syst Rev. 2015;(4). https://doi.org/10.1002/14651858.CD005381.pub4 PMID: 25900537

63. Herold F, Törpel A, Schega L, Müller NG. Functional and/or structural brain changes in response to resistance exercises and resistance training lead to cognitive improvements—a systematic review. Eur Rev Aging Phys Act. 2019; 16(1):10.

64. Rogge A-K, Röder B, Zech A, Nagel V, Hollander K, Braumann K-M, et al. Balance training improves memory and spatial cognition in healthy adults. Sci Rep. 2017; 7(1):1–10. https://doi.org/10.1038/s41598-016-0028-x PMID: 28127051

65. Tinetti ME, Powell L. Fear of falling and low self-efficacy: a cause of dependence in elderly persons. J Gerontol. 1993; 48(Spec Issue):35–38. https://doi.org/10.1093/geronj/48.special_issue.35 PMID: 8409238

66. Powell LE, Myers AM. The Activities-specific Balance Confidence (ABC) Scale. J Gerontol A Biol Sci Med Sci. 1995 Jan; 50A(1):M28–34. https://doi.org/10.1093/gerona/50a.1.m28 PMID: 7814786

67. Moore DS, Ellis R. Measurement of fall-related psychological constructs among independent-living older adults: a review of the research literature. Aging Ment Heal. 2008; 12(6):684–99. https://doi.org/10.1080/1360786802148855 PMID: 19023720

68. Yamada M, Arai H, Uemura K, Mori S, Nagai K, Tanaka B, et al. Effect of resistance training on physical performance and fear of falling in elderly with different levels of physical well-being. Age Ageing. 2011; 40(5):637–41. https://doi.org/10.1093/ageing/afr068 PMID: 21729292

69. Sartor-Grillenberg C, Bordenave E, Bay C, Bordenave L, Alexander JL. Effect of a Matter of Balance programme on avoidance behaviour due to fear of falling in older adults. Psychogeriatrics. 2018; 18 (3):224–30. https://doi.org/10.1111/psyg.12310 PMID: 29424113

70. Stanghellini B, Bentzen H, Giangregorio L, Pripp AH, Skelton D, Bergland A. Effects of a resistance and balance exercise programme on physical fitness, health-related quality of life and fear of falling in older women with osteoporosis and vertebral fracture: a randomized controlled trial. Osteoporos Int. 2020; 1–10.

71. Reventlow SD. Perceived risk of osteoporosis: Restricted physical activities?: Qualitative interview study with women in their sixties. Scand J Prim Health Care. 2007; 25(3):160. https://doi.org/10.1080/02813430701305668 PMID: 17846934

72. Sherrington C, Michaleff ZA, Fairhall N, Paul SS, Tiedemann A, Whitney J, et al. Exercise to prevent falls in older adults: an updated systematic review and meta-analysis. Br J Sports Med. 2017 Dec; 51 (24):1750–8. https://doi.org/10.1136/bjsports-2016-096547 PMID: 27707740

73. Shier V, Trieu E, Ganz DA. Implementing exercise programs to prevent falls: systematic descriptive review. Inj Epidemiol. 2016; 3(1):16. https://doi.org/10.1186/s40621-016-0081-B PMID: 27747553
74. Helbostad JL, Sletvold O, Moe-Nilssen R. Effects of home exercises and group training on functional abilities in home-dwelling older persons with mobility and balance problems. A randomized study. Aging Clin Exp Res. 2004; 16(2):113–21. https://doi.org/10.1007/BF03324539 PMID: 15195985

75. Helbostad JL, Sletvold O, Moe-Nilssen R. Home training with and without additional group training in physically frail old people living at home: effect on health-related quality of life and ambulation. Clin Rehabil. 2004; 18(5):498–508. https://doi.org/10.1191/0269215504cr761oa PMID: 15293484

76. Cyarto EV, Brown WJ, Marshall AL, Trost SG. Comparative effects of home- and group-based exercise on balance confidence and balance ability in older adults: cluster randomized trial. Gerontology. 2008; 54(5):272–80. https://doi.org/10.1159/000155653 PMID: 18787321

77. Carter ND, Khan KM, McKay HA, Pett MA, Waterman C, Heinonen A, et al. Community-based exercise program reduces risk factors for falls in 65-to 75-year-old women with osteoporosis: randomized controlled trial. Cmaj. 2002; 167(9):997–1004. PMID: 12403738

78. Hauer K, Rost B, Rütsche K, Opitz H, Specht N, Bärtsch P, et al. Exercise training for rehabilitation and secondary prevention of falls in geriatric patients with a history of injurious falls. J Am Geriatr Soc. 2001; 49(1):10–20. https://doi.org/10.1046/j.1532-5415.2001.49004.x PMID: 11207837

79. Campbell AJ, Robertson MC, Gardner MM, Norton RN, Tilyard MW, Buchner DM. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. Bmj. 1997; 315(7115):1065–9. https://doi.org/10.1136/bmj.315.7115.1065 PMID: 936737

80. Robertson MC, Campbell AJ, Gardner MM, Devlin N. Preventing injuries in older people by preventing falls: A meta-analysis of individual-level data. J Am Geriatr Soc. 2002; 50(5):905–11. https://doi.org/10.1046/j.1532-5415.2002.50218.x PMID: 12028179

81. Teng B, Gomersall SR, Hatton A, Brauer SG. Combined group and home exercise programmes in community-dwelling falls-risk older adults: Systematic review and meta-analysis. Physiotherapy research international. 2020; 25(3): e1839. https://doi.org/10.1002/pri.1839 PMID: 32394595

82. Chodzko-Zajko WJ, Proctor DN, Singh MAF, Minson CT, Nigg CR, Salem GJ, et al. Exercise and physical activity for older adults. Med Sci Sport Exerc. 2009; 41(7):1510–30. https://doi.org/10.1249/MSS.0b013e3181a0c95c PMID: 19516148

83. Fuentes-Contreras J, Armijo-Olivo S, Da Costa B, Cummings GG, Ha C, Saltaji H, et al. PEDro or Cochrane to assess the quality of clinical trials? A meta-epidemiological study. PloS one. 2015; 10(7): e0132634. https://doi.org/10.1371/journal.pone.0132634 PMID: 2616153

84. Carty CP, Cronin NJ, Nicholson D, Lichtwark GA, Mills PM, Kerr G, et al. Reactive stepping behaviour in response to forward loss of balance predicts future falls in community-dwelling older adults. Age Ageing. 2015; 44(1):109–15. https://doi.org/10.1093/ageing/afu054 PMID: 24918170